Biomass Potential for Heat, Electricity and Vehicle Fuel in Sweden

Volume II

Peter Hagström
Faculty of Natural Resources and Agricultural Sciences
Department of Bioenergy
Uppsala

Doctoral thesis
Swedish University of Agricultural Sciences
Uppsala 2006

Acta Universitatis Agriculturae Sueciae
2006: 11

ISSN 1652-6880
ISBN 91-576-7060-9

Tryck: Tierps Tryckeri AB, Tierp 2006

Abstract

Hagström, P. 2006. *Biomass Potential for Heat, Electricity and Vehicle Fuel in Sweden*. Doctoral dissertation.

The main objective of this thesis was to determine how far a biomass quantity, equal to the potential produced within the Swedish borders, could cover the present energy needs in Sweden with respect to economic and ecological circumstances. Three scenarios were studied where the available biomass was converted to heat, electricity and vehicle fuel. Three different amounts of biomass supply were studied for each scenario: 1) potential biomass amounts derived from forestry, non-forest land, forest industry and community; 2) the same amounts as in Case 1, plus the potential biomass amounts derived from agriculture; 3) the same amounts as in Case 1, plus 50% of the potential pulpwood quantity.

For evaluating the economic and ecological circumstances of using biomass in the Swedish energy system, the scenarios were complemented with energy, cost and emergy analysis.

The scenarios indicated that it may be possible to produce 170.2 PJ (47.3 TWh) per year of electricity from the biomass amounts in Case 2. From the same amount of biomass, the maximum annual production of hydrogen was 241.5 PJ (67.1 TWh) per year or 197.2 PJ (54.8 TWh) per year of methanol.

The energy analysis showed that the ratio of energy output to energy input for large-scale applications ranged from 1.9 at electric power generation by gasification of straw to 40 at district heating generation by combustion of recovered wood. The cost of electricity at gasification ranged from 7.95 to 22.58 €/GJ. The cost of vehicle work generated by using hydrogen produced from forestry biomass in novel fuel cells was economically competitive compared to today's propulsion systems. However, the cost of vehicle work generated by using methanol produced from forestry biomass in combustion engines was rather higher compared to use of petrol in petrol engines.

The emergy analysis indicated that the only biomass assortment studied with a larger emergy flow from the local environment, in relation to the emergy flow invested from society after conversion, was fuel wood from non-forest land. However, even use of this biomass assortment for production of heat, electricity or vehicle fuels had smaller yields of emergy output in relation to emergy invested from society compared to alternative conversion processes; thus, the net contribution of emergy generated to the economy was smaller compared to these alternative conversion processes.

Key words: bioenergy potential, biomass potential, cost analysis, emergy, energy analysis, energy scenarios, systems analysis, thermochemical conversion.

Author's adress: Peter Hagström, Department of Bioenergy, SLU, P.O. Box 7061,
SE-750 07 UPPSALA, Sweden. E-mail: peter.hagstrom@bioenergi.slu.se

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Appendix I: Tables A.I-1 through to A.I-17

Table A.I-1. *Emergy, energy and cost analysis of final felling*

Final felling		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	Solar emergy [10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
I Environmental inputs			**124.51**	**352.44**					
a Sunlight	2.57E+13 J/ha	1 sej/J		25.74	Not included. Nature's contribution considered free			Not included. Nature's contribution considered free	
b Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91					
c Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44					
Y0 Tree biomass production	5.03E+10 J/ha	7009 sej/J	124.51	352.44					
F1 Silvicultural inputs				**21.30**		**6.03**	**18.40**		**114.00**
d Seeds, plants	21.6 plants/ha	8.15E+09 sej/plant		1.76			15.69		
e Fertilizers	0.137 kg/ha	4.60E+12 sej/kg		0.63			2.33		
f Pesticides, herbicides	4.41E+04 J/ha	66,000 sej/J		0.003			0.02		
g Motor fuel	1.71E+07 J/ha	47,900 sej/J		0.82	1.14	6.03			
h Machines, equipment	0.031 kg/ha	2.97E+12 sej/kg		0.09			0.35		
i Expendables	5.83 SEK/ha	1.58E+11 sej/SEK		0.92					5.83
j Human services	85.14 SEK/ha	1.58E+11 sej/SEK		13.44					85.14
k Capital investment	23.04 SEK/ha	1.58E+11 sej/SEK		3.64					23.04
Y1 Tree biomass production	5.92E+10 J/ha	6317 sej/J	132.03	373.74	Sum of prim. en.	6.88	18.40	40.27	114.00
F2 Felling. delimbing and cutting						**53.73**	**2.95**	**59.60**	
l Motor fuel	5.37E+07 J/t_{dm}	47,900 sej/J	2.57		1.14	53.73			
m Machines, equipment	0.042 kg/t_{dm}	2.97E+12 sej/kg	0.12				2.95		
n Human services	45.00 SEK/t_{dm}	1.58E+11 sej/SEK	7.11					45.00	
o Capital investment	14.60 SEK/t_{dm}	1.58E+11 sej/SEK	2.31					14.60	
Y2 Tree biomass yield	2.09E+10 J/t_{dm}	6897 sej/J	144.14		Sum of prim. en.	68.13	21.35	99.87	

Table A.I-1 *continued*

F3	**Forwarding**			**10.16**		**52.76**	**2.98**	**47.64**
p	Motor fuel	5.28E+07 J/t_{dm}	47,900 sej/J	2.53	1.14	52.76		
q	Machines. equipment	0.037 kg/t_{dm}	2.97E+12 sej/kg	0.11			2.98	
r	Human services	38.15 SEK/t_{dm}	1.58E+11 sej/SEK	6.02				38.15
s	Capital investment	9.48 SEK/t_{dm}	1.58E+11 sej/SEK	1.50				9.48
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	7383 sej/J	154.30	Sum of prim. en.	128.28	24.32	147.51
F4	**Road transport**			**17.24**		**107.31**	**2.89**	**75.87**
t	Motor fuel	1.07E+08 J/t_{dm}	47,900 sej/J	5.14	1.14	107.31		
u	Machines. equipment	0.047 kg/t_{dm}	2.60E+12 sej/kg	0.12			2.89	
v	Human services	63.68 SEK/t_{dm}	1.58E+11 sej/SEK	10.06				63.68
w	Capital investment	12.19 SEK/t_{dm}	1.58E+11 sej/SEK	1.92				12.19
Y4	Tree biomass yield	2.09E+10 J/t_{dm}	8208 sej/J	171.54	Sum of prim. en.	250.61	27.21	223.38
					Direct + embodied prim. en.	277.82		

Table A.I-1 *continued: Summary of inputs, yields, solar transformities and investment indices*

Environmental inputs	
I Item c	124.51 x 10^{12} sej/t_{dm}
Inputs fed back from society (*i.e.* purchased)	
F1 Item d - k	7.53 x 10^{12} sej/t_{dm}
F2 Item l - o	12.11 x 10^{12} sej/t_{dm}
F3 Item p - s	10.16 x 10^{12} sej/t_{dm}
F4 Item t - w	17.24 x 10^{12} sej/t_{dm}
Solar emergy yields of products	
Y1 Standing biomass	132.03 x 10^{12} sej/t_{dm}
Y2 Harvested biomass in field	144.14 x 10^{12} sej/t_{dm}
Y3 Harvested biomass at truck road	154.30 x 10^{12} sej/t_{dm}
Y4 Harvested biomass in wood yard at industry	171.54 x 10^{12} sej/t_{dm}
Solar transformities	
(a) Standing biomass	6317 sej/J
(b) Harvested biomass in field	6897 sej/J
(c) Harvested biomass at truck road	7383 sej/J
(d) Harvested biomass in wood yard at industry	8208 sej/J
Net solar emergy yield ratio	
I. Standing biomass = Y1 / F1	17.54
II. Harvested biomass in field = Y2 / (F1+F2)	7.34
III. Harvested biomass at truck road = Y3 / (F1+F2+F3)	5.18
IV. Harvested biomass in wood yard at industry = Y4 / (F1+F2+F3+F4)	3.65
Solar emergy investment ratio	
I. Standing biomass = F1 / I	0.06
II. Harvested biomass in field = (F1+F2) / I	0.16
III. Harvested biomass at truck road = (F1+F2+F3) / I	0.24
IV. Harvested biomass in wood yard at industry = (F1+F2+F3+F4) / I	0.38

Footnotes to Table A.I-1

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).

Y_0 The tree biomass production was assumed as 85% of the tree biomass production after silvicultural inputs. The tree biomass production after silvicultural inputs = 5.92 x 10^{10} J/(ha x year) (see Y_1). The tree biomass production = 0.85 x 5.92 x 10^{10} J/(ha x year) = 5.03 x 10^{10} J/(ha x year)

Solar emergy = solar emergy of transpired rain = 352.44 x 10^{12} sej/(ha x year). Annual biomass growth per hectare = 2.831 t_{dm}/ha (see Table A.B-2). Thus, solar emergy = 352.44 x 10^{12} / 2.831 sej/t_{dm} = 124.51 sej/t_{dm}.

Solar transformity = 352.44 x 10^{12} / 5.03 x10^{10} sej/J = 7009 sej/J.

F_1 Silvicultural inputs:

d The average percentage of the annual final felling area being planted was 76% during 1998 to 2002 (National Board of Forestry, 2004). In this work, the percentage of the annual final felling area being planted was assumed as 80%. The number of plants ranged from 2000 to 2500 ha^{-1} between 1998 and 2002 (National Board of Forestry, 2004). In this work, the number of plants was assumed to be 2650 ha^{-1} (including 6% of the plants being supplemented). Number of plants per hectare of forest land and year = 2650 x 0.80 x 222.3 x 10^3 / 21.84 x 10^6 ha^{-1} x $year^{-1}$ = 21.58 ha^{-1} x $year^{-1}$.

Total solar emergy required per 1000 seedlings = 8.15 x 10^{13} sej (see Tabl A.J-1). Thus, total solar emergy required per plant (*i.e.* solar transformity) = 8.15 x 10^{10} sej.

The amount of embodied energy = 2059.25 MJ/1000 seedlings (see Table A.J-1). The amount of embodied energy per hectare of total forest land area = 2059.25 / 1000 x 21.58

MJ/ha = 44.44 MJ/ha. Annual biomass growth per hectare = 2.831 t_{dm}/ha (see Table A.B-2). Thus, the amount of embodied energy per ton of dry matter received = 44.44 / 2.831 MJ/t_{dm} = 15.70 MJ/t_{dm}.

e Normal amount of spread nitrogen = 150 kg/ha (National Board of Forestry, 2002). The average annual fertilized area within the Swedish large-scale forestry was 20,460 ha/year between 1998 and 2002 (National Board of Forestry, 2004). Thus, the fertilized area was assumed as 20,000 ha/year. Thus, the annual amount of spread nitrogen per total forest area = 150 x 20,000 / (21.84 x 10^6) kg/ha = 0.137 kg/ha. Solar transformity for nitrogen in nitrogen fertilizer = 4.60 x 10^{12} sej/kg (Odum, 1996).

The amount of embodied energy in nitrogen fertilizer = 48 MJ/kg (Börjesson, 1996). Thus, the amount of embodied energy in nitrogen fertilizer used per ton of dry matter of biomass received = 0.137 x 48 / 2.831 MJ/t_{dm} = 2.33 MJ/t_{dm}.

f Total active substance of pesticides in 2002 = 22,200 kg (National Board of Forestry, 2004). The energy content was assumed as equal to the LHV of refined fuels from crude oil. LHV of automotive petrol = 32.6 GJ/m^3 (Swedish Energy Agency, 2003a). Density of automotive petrol = 750 kg/m^3 (The Swedish Petroleum Institute, 9-Oct-2005 (URL)). LHV of automotive petrol per weight = 32.6 x 10^9 / 0.750 J/t = 4.35 x 10^{10} J/t. LHV of automotive gas oil (environmental class 1 and 2) = 9.80 MWh/m^3 = 9.80 x 3.60 GJ/m^3 = 35.3 GJ/m^3. Density of automotive gas oil (environmental classes 1 and 2) = 815 kg/m^3 (The Swedish Petroleum Institute, 9-Oct-2005 (URL)). Lower heating value of automotive gas oil (environmental classes 1 and 2) per weight = 35.3 x 10^9 / 0.815 J/t = 4.33 x 10^{10} J/t. The LHV of imported refined fuels was assumed to be equal to the mean value of the LHVs of automotive petrol and automotive gas oil (environmental classes 1 and 2), *i.e.* 4.34 x 10^{10} J/t. Thus, the energy amount of pesticides per total forest area = 22,200 x 4.34 x 10^7 / (21.84 x 10^6) kg/ha = 4.41 x 10^4 J/ha. Solar transformity for pesticides = 66,000 sej/J (Doherty, Nilsson & Odum, 2002).

The amount of embodied energy in pesticides used per ton of dry matter of biomass received = 4.41 x 10^4 / 2.831 J/t_{dm} = 1.56 x 10^4 J/t_{dm} = 0.02 MJ/t_{dm}.

g Total amount of annual fuel use per hectare at cleaning, scarification, planting, sawing, precommercial thinning, fertilization and ash recirculation = (53.46 x 55,000 + 886.94 x 195,624 + 283.13 x 177,840 + 53.46 x 222,300 + 363.49 x 20,000 + 583.38 x 217,600) x 10^6 / 21.84 x 10^6 J/ha = 17.1 MJ/ha (see Table A.J-2).

h The sum of mass depreciation of machinery used at scarification, fertilization, ash recirculation, forest drainage and construction and maintenance of forest roads = (0.436 x 195,624 + 0.193 x 20,000 + 0.193 x 217,600 + 7.76 x 10^3 + 5.36 x 10^5) / 21.84 x 10^6 kg/(ha x year) = 0.031 kg/(ha x year) (see Table A.J-2). Solar transformity for machine equipment was assumed as equal to the solar transformity of forwarders, *i.e.* 2.97 x 10^{12} sej/kg (see Table A.H-7).

The sum of embodied energy per hectare of total forest land area in machinery used at scarification, fertilization, ash recirculation, forest drainage and construction and maintenance of forest roads = ((26.72 x 195,624 + 29.26 x 20,000 + 58.52 x 217,600) / 21.84 x 10^6+ 2.20 x 10^{-3} + 0.152) MJ/(ha x year) = 1.003 MJ/(ha x year) (see Table A.J-2). The amount of embodied energy per ton of dry matter received = 1.003 / 2.831 MJ/t_{dm} = 0.354 MJ/t_{dm}.

i The cost of expendables included costs at plant production, fertilization and costs for pesticides. The cost for expendables at plant production was assumed to be 0.20 SEK/plant. Total expendables for plants = 0.20 x 21.6 SEK/(ha x year) = 4.32 SEK/(ha x year).

Expendables at fertilization = 1511 SEK/ha (see Table A.J-4). The fertilized area was assumed to be 20,000 ha/year (see footnote e). The total expendables for fertilization = 1511 x 20,000 / (21.84 x 10^6) SEK/ha = 1.38 SEK/ha.

The use of pesticides in forestry in 2002 was dominated by the use of plant-growth regulators in nurseries, as the consumption of plant-growth regulators was 15,000 kg, compared to the total use of pesticides being 22,200 kg (National Board of Forestry,

2004). The additional cost for plants treated with plant-growth regulators = 0.06 SEK per plant (Andersson, 2004), of which the cost for pesticide was assumed as 0.03 SEK/plant. Approximately 62 millon plants are treated annually (Andersson, 2004). Thus, the cost of plant-growth regulators = 0.03 / (15,000 / 62 x 10^6) SEK/kg = 124 SEK/kg. The costs of other pesticides used were assumed as equal to the cost of plant-growth regulators. Thus, total cost for pesticides = 124 x 22,200 / (21.84 x 10^6) SEK/ha = 0.13 SEK/ha.
Total costs for expendables = (4.32 + 1.38 + 0.13) SEK/ha = 5.83 SEK/ha.

j Human services = Total costs – capital costs – costs for expendables. Total cost in Swedish forestry in 2002 = 103 SEK/ha (National board of Forestry, 2004). It was assumed that the total cost of forestry was somewhat higher, 114 SEK/ha, due to more intense forestry. Capital costs = 23.04 SEK/ha (see note k) and costs for expendables = 5.83 SEK/ha (see note i). Thus, costs for human services = (114 – 23.04 – 5.83) SEK/ha = 85.14 SEK/ha.

k Total capital costs included capital costs at plant production, scarification, forest fertilization, ash recirculation, forest drainage, and construction and maintenance of forest roads. The capital cost at plant production was assumed to be 0.60 SEK/plant. Thus, the capital cost for plants = 0.60 x 21.6 SEK/(ha x year) = 12.95 SEK/(ha x year).
The capital cost at scarification = 137.27 SEK/ha (see Table A.J-3). 88% of the total final felled area was prepared with scarification during 2001-2003 (National Board of Forestry, 2004). Thus, the total capital cost for scarification = 137.27 x 0.88 x 222.3 x 10^3 / (21.84 x 10^6) SEK/ha = 1.23 SEK/ha.
The capital cost of fertilization = 61.12 SEK/ha (see Table A-J-4). The fertilized area was assumed to be 20,000 ha/year. Thus, the total capital cost for fertilization = 61.12 x 20,000 / (21.84 x 10^6) SEK/ha = 0.06 SEK/ha.
The capital cost of ash recirculation = 122.23 SEK/ha (see Table A.J-5). The annual area treated with ash recirculation = 217.6 kha (see Table 5-13). Thus, the total capital cost for fertilization = 122.23 x 217.6 x 10^3 / (21.84 x 10^6) SEK/ha = 1.22 SEK/ha.
The capital cost of construction and maintenance of forest drainage per hectare of forest land = 0.11 SEK/ha (see Table A.J-6).
The capital cost at construction and maintenance of forest roads per hectare of forest land = 7.48 SEK/ha (see Table A.J-7).
Total capital costs = (12.95 + 1.23 + 0.06 + 1.22 + 0.11 + 7.48) SEK/ha = 23.04 SEK/ha.

Y_1 Tree biomass production: annual biomass growth per hectare = 2.831 t_{dm}/ha, and the HHV = 20.9 MJ/kg_{dm} (see Table A.B-2). Thus, the tree biomass production = 20.9 x 10^9 x 2.831 J/(ha x year) = 5.92 x 10^{10} J/(ha x year).
Solar emergy = solar emergy of transpired rain + solar emergy of silvicultural inputs = (352.44 x 10^{12} + 21.30 x 10^{12}) sej/(ha x year) = 373.74 x 10^{12} sej/(ha x year) = 373.74 x 10^{12} / 2.831 sej/t_{dm} = 132.03 sej/t_{dm}.
Solar transformity = 373.74 x 10^{12} / 5.92 x 10^{10} sej/J = 6317 sej/J.

F_2 Felling, delimbing and cutting:

l Direct energy required = 53.73 MJ/t_{dm} (see Table A.J-8).

m Mass depreciation of machinery = 0.042 kg/t_{dm} (see Table A.J-8). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (see Table A.H-7). The amount of embodied energy in machinery = 2.95 MJ/t_{dm} (see Table A.J-8).

n Costs for human services = operating and maintenance (O & M) costs = 45.00 SEK/t_{dm} (see Table A.J-8).

o Capital costs = 14.60 SEK/t_{dm} (see Table A.J-8).

Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-2). Solar emergy = solar emergy of ($Y_1 + F_2$) = (132.03 + 2.57 + 0.12 + 7.11 + 2.31) x10^{12} sej/t_{dm} = 144.14 x10^{12} sej/t_{dm}. Solar transformity = 144.14 x 10^{12} / 2.09 x 10^{10} sej/J = 6897 sej/J.

F_3 Forwarding:

p Direct energy required = 52.76 MJ/t_{dm} (see Table A.J-11).

q Mass depreciation of machinery = 0.037 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.98 MJ/t_{dm} (see Table A.J-11).

r Costs for human services = O & M costs = 38.15 SEK/t_{dm} (see Table A.J-11).

s Capital costs = 9.48 SEK/t_{dm} (see Table A.J-11).

Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-2). Solar emergy = solar emergy of ($Y_2 + F_3$) = (144.14 + 2.53 + 0.11 + 6.02 + 1.50) x 10^{12} sej/t_{dm} = 154.30 x 10^{12} sej/t_{dm}. Solar transformity = 154.30 x 10^{12} / 2.09 x 10^{10} sej/J = 7383 sej/J.

F_4 Road transport:

t Direct energy required = 107.31 MJ/t_{dm} (see Table A.J-38b).

u Mass depreciation of machinery = 0.047 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.89 MJ/t_{dm} (see Table A.J-38b).

v Costs for human services = O & M costs = 63.68 SEK/t_{dm} (see Table A.J-38b).

w Capital costs = 12.19 SEK/t_{dm} (see Table A.J-38b).

Y_4 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of ($Y_3 + F_4$) = (154.30 + 5.14 + 0.12 + 10.06 + 1.92) x 10^{12} sej/t_{dm} = 171.54 x 10^{12} sej/t_{dm}. Solar transformity = 171.54 x 10^{12} / 2.09 x 10^{10} sej/J = 8208 sej/J.

Table A.I-2. *Emergy, energy and cost analysis of thinning*

	Final felling	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	Solar emergy [10^{12} sej/ha/yr]	Energy analysis: Prim. energy conv. factor	Energy analysis: Direct energy MJ/t_{dm}	Energy analysis: Embodied energy MJ/t_{dm}	Cost analysis: [SEK/t_{dm}]	Cost analysis: [SEK/ha/yr]
I	**Environmental inputs**			**124.51**	**352.44**					
a	Sunlight	2.52E+13 J/ha	1 sej/J		25.20		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
Y0	Tree biomass production	5.03E+10 J/ha	7009 sej/J	124.51	352.44					
F1	**Silvicultural inputs**				**21.31**		**6.03**	**18.40**		**114.00**
d	Seeds, plants	21.6 plants/ha	8.15E+09 sej/plant		1.76			15.70		
e	Fertilizers	0.137 kg/ha	4.60E+12 sej/kg		0.63			2.33		
f	Pesticides, herbicides	4.41E+04 J/ha	66,000 sej/J		0.003			0.02		
g	Motor fuel	1.71E+07 J/ha	47,900 sej/J		0.82	1.14	6.03			
h	Machines, equipment	0.031 kg/ha	2.97E+12 sej/kg		0.09			0.35		
i	Expendables	5.83 SEK/ha	1.58E+11 sej/SEK		0.92					5.83
j	Human services	85.14 SEK/ha	1.58E+11 sej/SEK		13.44					85.14
k	Capital investment	23.04 SEK/ha	1.58E+11 sej/SEK		3.64					23.04
Y1	Tree biomass production	5.92E+10 J/ha	6317 sej/J	132.03	373.74	Sum of prim. en.	6.88	18.40	40.27	114.00
F2	**Felling. delimbing and cutting**			**15.18**			**63.18**	**3.00**	**76.18**	
l	Motor fuel	6.32E+07 J/t_{dm}	47,900 sej/J	3.03		1.14	63.18			
m	Machines, equipment	0.042 kg/t_{dm}	2.97E+12 sej/kg	0.13				3.00		
n	Human services	58.92 SEK/t_{dm}	1.58E+11 sej/SEK	9.30					58.92	
o	Capital investment	17.26 SEK/t_{dm}	1.58E+11 sej/SEK	2.73					17.26	
Y2	Tree biomass yield	2.09E+10 J/t_{dm}	7044 sej/J	147.21		Sum of prim. en.	78.90	21.40	116.45	

Table A.I-2 *continued*

F3	**Forwarding**			**24.49**		**96.26**	**4.31**	**99.99**
p	Motor fuel	9.63E+07 J/t_{dm}	47,900 sej/J	4.61	1.14	96.26		
q	Machines, equipment	0.089 kg/t_{dm}	2.97E+12 sej/kg	0.26			4.31	
r	Human services	82.64 SEK/t_{dm}	1.58E+11 sej/SEK	13.05				82.64
s	Capital investment	17.35 SEK/t_{dm}	1.58E+11 sej/SEK	2.74				17.35
t	Handling and storage losses	5.43E+08 J/t_{dm}	7044 sej/J	3.83				
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	8216 sej/J	171.70	Sum of prim. en.	188.63	25.71	216.44
F4	**Road transport**			**17.24**		**107.31**	**2.89**	**75.87**
u	Motor fuel	1.07E+08 J/t_{dm}	47,900 sej/J	5.14	1.14	107.31		
v	Machines, equipment	0.047 kg/t_{dm}	2.60E+12 sej/kg	0.12			2.89	
w	Human services	63.68 SEK/t_{dm}	1.58E+11 sej/SEK	10.05				63.68
x	Capital investment	12.19 SEK/t_{dm}	1.58E+11 sej/SEK	1.92				12.19
Y4	Tree biomass yield	2.09E+10 J/t_{dm}	9040 sej/J	188.95	Sum of prim. en.	310.96	28.61	292.31
F5	**Comminution**			**7.02**		**54.78**		**27.65**
y	Motor fuel	5.48E+07 J/t_{dm}	47,900 sej/J	2.62	1.14	54.78		
z	Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/kg	0.03				
aa	Human services	23.79 SEK/t_{dm}	1.58E+11 sej/SEK	3.76				23.79
bb	Capital investment	3.85 SEK/t_{dm}	1.58E+11 sej/SEK	0.61				3.85
Y5	Tree biomass yield	2.09E+10 J/t_{dm}	9377 sej/J	195.97	Sum of prim. en.	373.41	28.61	319.96
					Direct + embodied prim. en	402.02		
					E(output, primary)/E(input, primary)	52.0		

Table A.I-2 *continued: Summary of inputs, yields, solar transformities and investment indices*

	Hydrogen	Methanol
Environmental inputs		
I Item c [x 10^{12} sej/t_{dm}]	124.5	124.5
Inputs fed back from society (*i.e.* purchased)		
F1 [x 10^{12} sej/t_{dm}]	7.5	7.5
F2 [x 10^{12} sej/t_{dm}]	15.2	15.2
F3 [x 10^{12} sej/t_{dm}]	24.5	24.5
F4 [x 10^{12} sej/t_{dm}]	17.2	17.2
F5 [x 10^{12} sej/t_{dm}]	7.0	7.0
F6 (Conversion) [x 10^{12} sej/t_{dm}]	201.6	191.1
Solar emergy yields of products		
Y1 [x 10^{12} sej/t_{dm}]	132.0	132.0
Y2 [x 10^{12} sej/t_{dm}]	147.2	147.2
Y3 [x 10^{12} sej/t_{dm}]	171.7	171.7
Y4 [x 10^{12} sej/t_{dm}]	188.9	188.9
Y5 [x 10^{12} sej/t_{dm}]	196.0	196.0
Y6 (Final product) [x 10^{12} sej/t_{dm}]	397.6	387.0
Solar transformities		
(a) Standing biomass [sej/J]	6317	6317
(b) After harvesting [sej/J]	7044	7044
(c) After forwarding [sej/J]	8216	8216
(d) After road transport [sej/J]	9040	9040
(e) After comminution [sej/J]	9377	9377
(f) After conversion [sej/J]	26,894	31,427
Net solar emergy yield ratio		
I. Standing biomass	17.54	17.54
II. After harvesting	6.48	6.48
III. After forwarding	3.64	3.64
IV. After road transport	2.93	2.93
V. After comminution	2.74	2.74
VI. After conversion	1.46	1.47
Solar emergy investment ratio		
I. Standing biomass	0.06	0.06
II. After harvesting	0.18	0.18
III. After forwarding	0.38	0.38
IV. After road transport	0.52	0.52
V. After comminution	0.57	0.57
VI. After conversion	2.19	2.11
Primary energy required at conversion [MJ/t_{dm}]	1602.72	1237.82
Amount of final product produced [GJ/t_{dm}]	14.78	12.32
Amount of final product produced [GJ/(ha x year)]	4.26	3.35
E(output)/E(primary energy input including biomass)	64.5%	54.6%
E(output)/E(primary energy input excluding biomass)	7.4	7.5
Cost of energy carrier		
SEK/GJ	73.19	91.91
SEK/MWh	263.49	330.88
€/GJ	8.03	10.08

Footnotes to Table A.I-2

I Environmental inputs:
a–c Data from Doherty, Nilsson & Odum (2002).
Y_0 See footnote to Table A.I-1.
F_1 Silvicultural inputs:
d– k See footnotes to Table A.I-1.
Y_1 See footnote to Table A.I-1.
F_2 Felling, delimbing and cutting:
l Direct energy required = 63.18 MJ/t_{dm} (see Table A.J-8).
m Mass depreciation of machinery = 0.042 kg/t_{dm} (see Table A.J-8). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (see Table A.H-7). The amount of embodied energy in machinery = 3.00 MJ/t_{dm} (see Table A.J-8).
n Costs for human services = O & M costs = 58.92 SEK/t_{dm} (see Table A.J-8).
o Capital costs = 17.26 SEK/t_{dm} (see Table A.J-8).
Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_1 + F_2) = (132.03 + 3.03 + 0.13 + 9.30 + 2.73) x 10^{12} sej/t_{dm} = 147.21 x 10^{12} sej/t_{dm}.
Solar transformity = 147.21 x10^{12} / 2.09 x10^{10} sej/J = 7044 sej/J.
F_3 Forwarding:
p Direct energy required = 96.26 MJ/t_{dm} (see Table A.J-11).
q Mass depreciation of machinery = 0.089 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.31 MJ/t_{dm} (see Table A.J-11).
r Costs for human services = O & M costs = 82.64 SEK/t_{dm} (see Table A.J-11).
s Capital costs = 17.35 SEK/t_{dm} (see Table A.J-11).
t Dry matter losses at storage = 2.6% of forwarded biomass (see Table A.G-1, footnote c). 0.026 x 2.09 x 10^{10} J/t_{dm} = 5.43 x 10^{8} J/t_{dm}.
Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_2 + F_3) = (147.21 + 4.61 + 0.26 + 13.05 + 2.74 + 3.83) x 10^{12} sej/t_{dm} = 171.70 x 10^{12} sej/t_{dm}.
Solar transformity = 171.70 x 10^{12} / 2.09 x 10^{10} sej/J = 8216 sej/J.
F_4 Road transport:
u Direct energy required = 107.31 MJ/t_{dm} (see Table A.J-38b).
v Mass depreciation of machinery = 0.047 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.89 MJ/t_{dm} (see Table A.J-38b).
w Costs for human services = O & M costs = 63.68 SEK/t_{dm} (see Table A.J-38b).
x Capital costs = 12.19 SEK/t_{dm} (see Table A.J-38b).
Y_4 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_3 + F_4) = (171.70 + 5.14 + 0.12 + 10.05 + 1.92) x 10^{12} sej/t_{dm} = 188.95 x 10^{12} sej/t_{dm}.
Solar transformity = 188.95 x 10^{12} / 2.09 x 10^{10} sej/J = 9040 sej/J.
F_5 Comminution:
y Direct energy required = 54.78 MJ/t_{dm} (see Table A.J-39).
z Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (See Table A.J-39).
aa Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).
bb Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).
Y_5 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_4 + F_5) = (188.95 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 195.97 x 10^{12} sej/t_{dm}.
Solar transformity = 195.97 x 10^{12} / 2.09 x 10^{10} sej/J = 9377 sej/J.

Table A.I-3. *Emergy, energy and cost analysis of logging residues from final felling*

Logging residues from final felling		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
Biomass input	**2.08E+10 J/t_{dm}**	**6897 sej/J**	**143.45**		**Primary energy**	**68.13**	**21.35**	**99.87**	
F3 Baling			**25.04**			**71.42**	**3.71**	**125.41**	
a Motor fuel	7.14E+07 J/t_{dm}	47,900 sej/J	3.42		1.14	71.42			
b Machines, equipment	0.154 kg/t_{dm}	2.48E+12 sej/kg	0.38				3.71		
c Human services	84.77 SEK/t_{dm}	1.58E+11 sej/SEK	13.39					84.77	
d Capital investment	40.65 SEK/t_{dm}	1.58E+11 sej/SEK	6.42					40.65	
e Handling and storage losses	2.08E+08 J/t_{dm}	6897 sej/J	1.43						
Y3 Tree biomass yield	2.08E+10 J/t_{dm}	8101 sej/J	168.49		Sum of prim. en.	149.55	25.06	225.29	
F4 Forwarding			**18.71**			**68.30**	**3.85**	**61.66**	
f Motor fuel	6.83E+07 J/t_{dm}	47,900 sej/J	3.27		1.14	68.30			
g Machines, equipment	0.048 kg/t_{dm}	2.97E+12 sej/kg	0.14				3.85		
h Human services	49.39 kr SEK/t_{dm}	1.58E+11 sej/SEK	7.80					49.39	
i Capital investment	12.27 kr SEK/t_{dm}	1.58E+11 sej/SEK	1.94					12.27	
j Handling and storage losses	6.86E+08 J/t_{dm}	8101 sej/J	5.56						
Y4 Tree biomass yield	2.08E+10 J/t_{dm}	9000 sej/J	187.20		Sum of prim. en.	227.41	28.91	286.95	
F5 Road transport			**27.60**			**174.37**	**4.57**	**120.71**	
k Motor fuel	1.74E+08 J/t_{dm}	47,900 sej/J	8.35		1.14	174.37			
l Machines, equipment	0.074 kg/t_{dm}	2.60E+12 sej/kg	0.19				4.57		
m Human services	101.47 SEK/t_{dm}	1.58E+11 sej/SEK	16.02					101.47	
n Capital investment	19.24 SEK/t_{dm}	1.58E+11 sej/SEK	3.04					19.24	
Y5 Tree biomass yield	2.08E+10 J/t_{dm}	10,327 sej/J	214.81		Sum of prim. en.	426.19	33.48	407.66	

Table A.I-3 *continued*

F6	**Comminution**					**7.02**		**54.78**		**27.65**
o	Motor fuel	5.48E+07	J/t_{dm}	47,900	sej/J	2.62	1.14	54.78		
p	Machines, equipment	0.015	kg/t_{dm}	2.24E+12	sej/kg	0.03				
q	Human services	23.79	SEK/t_{dm}	1.58E+11	sej/SEK	3.76				23.79
r	Capital investment	3.85	SEK/t_{dm}	1.58E+11	sej/SEK	0.61				3.85
Y6	Tree biomass yield	2.08E+10	J/t_{dm}	10,665	sej/J	221.83	Sum of prim. en	488.65	33.48	435.31
							Direct + embodied prim. en.	522.12		
							E(output, primary)/E(input, primary)	39.8		

Table A.I-3 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1+F2 from FinalFell [x 10^{12} sej/t_{dm}]	19.6	19.6	19.6	19.6	19.6
F3 [x 10^{12} sej/t_{dm}]	25.0	25.0	25.0	25.0	25.0
F4 [x 10^{12} sej/t_{dm}]	18.7	18.7	18.7	18.7	18.7
F5 [x 10^{12} sej/t_{dm}]	27.6	27.6	27.6	27.6	27.6
F6 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F7 (Conversion) [x 10^{12} sej/t_{dm}]	150.0	105.7	154.2	201.0	190.5
Solar emergy yields of products					
Y3 [x 10^{12} sej/t_{dm}]	168.5	168.5	168.5	168.5	168.5
Y4 [x 10^{12} sej/t_{dm}]	187.2	187.2	187.2	187.2	187.2
Y5 [x 10^{12} sej/t_{dm}]	214.8	214.8	214.8	214.8	214.8
Y6 [x 10^{12} sej/t_{dm}]	221.8	221.8	221.8	221.8	221.8
Y7 (Final product) [x 10^{12} sej/t_{dm}]	371.9	327.5	376.0	422.8	412.3
Solar transformities					
(c) After baling [sej/J]	8101	8101	8101	8101	8101
(d) After forwarding of bales [sej/J]	9000	9000	9000	9000	9000
(e) After road transport [sej/J]	10,327	10,327	10,327	10,327	10,327
(f) After comminution [sej/J]	10,665	10,665	10,665	10,665	10,665
(g) After conversion [sej/J]	21,650	53,088	38,716	28,742	33,638
(g) Heat generated at CHP [sej/J]		23,589			
Net solar emergy yield ratio					
III. After baling	3.77	3.77	3.77	3.77	3.77
IV. After forwarding of bales	2.95	2.95	2.95	2.95	2.95
V. After road transport	2.36	2.36	2.36	2.36	2.36
VI. After comminution	2.26	2.26	2.26	2.26	2.26
VII. After conversion	1.50	1.61	1.49	1.41	1.43
Solar emergy investment ratio					
III. After baling	0.36	0.36	0.36	0.36	0.36
IV. After forwarding of bales	0.51	0.51	0.51	0.51	0.51
V. After road transport	0.73	0.73	0.73	0.73	0.73
VI. After comminution	0.79	0.79	0.79	0.79	0.79
VII. After conversion	1.99	1.64	2.03	2.40	2.32
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1158.57	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	17.18	6.17	9.71	14.71	12.26
Amount of heat produced at CHP [GJ/t_{dm}]		13.88			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	5.80	2.08	3.28	4.96	4.14
Amount of heat produced at CHP [GJ/(ha x year)]		4.68			
E(output)/E(primary energy input including biomass)	79.6%	90.6%	43.2%	64.2%	54.3%
E(output)/E(primary energy input excluding biomass)	22.2	15.0	5.8	6.9	7.0

Table A.I-3 *continued*

Cost of energy carriers					
SEK/GJ	75.72	59.68	106.97	81.14	101.45
SEK/MWh	272.60	214.85	385.08	292.10	365.21
€/GJ	8.30	6.54	11.73	8.90	11.12
Cost of heat at CHP					
SEK/GJ		34.02			
SEK/MWh		122.46			
€/GJ		3.73			

Footnotes to Table A.I-3

Biomass input:

$HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the biomass yield after felling, delimbing and cutting in forestry (Y_2 in Table A.I-1). Solar emergy = annual flow x solar transformity.

F_3 Baling:

a Direct energy required = 71.42 MJ/t_{dm} (see Table A.J-14).

b Mass depreciation of machinery = 0.154 kg/t_{dm}, the solar transformity for machine equipment = 2.48 x 10^{12} sej/kg, and the amount of embodied energy in machinery = 3.71 MJ/t_{dm} (see Table A.J-14).

c Costs for human services = O & M costs = 84.77 SEK/t_{dm} (see Table A.J-14).

d Capital costs = 40.65 SEK/t_{dm} (see Table A.J-14).

e Dry matter losses at baling = 1.0% of baled biomass (see Table A.G-1, footnote a). 0.01 x 2.08 x 10^{10} J/t_{dm} = 2.08 x 10^8 J/t_{dm}.

Y_3 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (143.45 + 3.42 + 0.38 + 13.39 + 6.42 + 1.43) x 10^{12} sej/t_{dm} = 168.49 x 10^{12} sej/t_{dm}. Solar transformity = 168.49 x 10^{12} / 2.08 x 10^{10} sej/J = 8101 sej/J.

F_4 Forwarding of bales:

f Direct energy required = 68.30 MJ/t_{dm} (see Table A.J-11).

g Mass depreciation of machinery = 0.048 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 3.85 MJ/t_{dm} (see Table A.J-11).

h Costs for human services = O & M costs = 49.39 SEK/t_{dm} (see Table A.J-11).

i Capital costs = 12.27 SEK/t_{dm} (see Table A.J-11).

j Dry matter losses at storage = 3.3% of baled biomass (see Table A.G-1, footnote b). 0.033 x 2.08 x 10^{10} J/t_{dm} = 6.86 x 10^8 J/t_{dm}.

Y_4 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (168.49 + 3.27 + 0.14 + 7.80 + 1.94 + 5.56) x 10^{12} sej/t_{dm} = 187.20 x 10^{12} sej/t_{dm}. Solar transformity = 187.20 x 10^{12} / 2.08 x 10^{10} sej/J = 9000 sej/J.

F_5 Road transport:

k Direct energy required = 174.37 MJ/t_{dm} (see Table A.J-38b).

l Mass depreciation of machinery = 0.074 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^9 sej/g (See Table A.H-7). The amount of embodied energy in machinery = 4.57 MJ/t_{dm} (see Table A.J-38b).

m Costs for human services = O & M costs = 101.47 SEK/t_{dm} (see Table A.J-38b).

n Capital costs = 19.24 SEK/t_{dm} (see Table A.J-38b).

Y_5 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_5 + F_6) = (187.20 + 8.35 + 0.19 + 16.02 + 3.04) x 10^{12} sej/t_{dm} = 214.81 x 10^{12} sej/t_{dm}. Solar transformity = 214.81 x 10^{12} / 2.08 x 10^{10} sej/J = 10,327 sej/J.

F_6 Comminution:

o Direct energy required = 54.78 MJ/t_{dm} (see Table A.J-39).

p Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (see Table A.J-39).

q Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

r Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_6 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_6 + F_7) = (214.81 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 221.83 x 10^{12} sej/t_{dm}. Solar transformity = 221.83 x 10^{12} / 2.08 x 10^{10} sej/J = 10,665 sej/J.

Table A.I-4. *Emergy, energy and cost analysis of logging residues from thinning*

Logging residues from thinning			Emergy analysis			Energy analysis			Cost analysis	
		Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
Biomass input		**2.08E+10 J/t_{dm}**	**7044 sej/J**	**146.51**		**Primary energy**	**78.90**	**21.40**	**116.45**	
F3	**Baling**			**38.08**			**111.42**	**5.79**	**195.65**	
a	Motor fuel	1.11E+08 J/t_{dm}	47,900 sej/J	5.34		1.14	111.42			
b	Machines, equipment	0.154 kg/t_{dm}	2.48E+12 sej/kg	0.38				5.79		
c	Human services	132.24 SEK/t_{dm}	1.58E+11 sej/SEK	20.88					132.24	
d	Capital investment	63.41 SEK/t_{dm}	1.58E+11 sej/SEK	10.01					63.41	
e	Handling and storage losses	2.08E+08 J/t_{dm}	7.04E+03 sej/J	1.47						
Y3	Tree biomass yield	2.08E+10 J/t_{dm}	8874 sej/J	184.59		Sum of prim. en.	205.92	27.19	312.10	
F4	**Forwarding**			**29.90**			**110.93**	**4.97**	**115.23**	
f	Motor fuel	1.11E+08 J/t_{dm}	47,900 sej/J	5.31		1.14	110.93			
g	Machines, equipment	0.102 kg/t_{dm}	2.97E+12 sej/kg	0.30				4.97		
h	Human services	95.24 SEK/t_{dm}	1.58E+11 sej/SEK	15.04					95.24	
i	Capital investment	19.99 SEK/t_{dm}	1.58E+11 sej/SEK	3.16					19.99	
j	Handling and storage losses	6.86E+08 J/t_{dm}	8.87E+03 sej/J	6.09						
Y4	Tree biomass yield	2.08E+10 J/t_{dm}	10,312 sej/J	214.49		Sum of prim. en	332.38	32.17	427.33	
F5	**Road transport**			**27.60**			**174.37**	**4.57**	**120.71**	
k	Motor fuel	1.74E+08 J/t_{dm}	47,900 sej/J	8.35		1.14	174.37			
l	Machines, equipment	0.074 kg/t_{dm}	2.60E+12 sej/kg	0.19				4.57		
m	Human services	101.47 SEK/t_{dm}	1.58E+11 sej/SEK	16.02					101.47	
n	Capital investment	19.24 SEK/t_{dm}	1.58E+11 sej/SEK	3.04					19.24	
Y5	Tree biomass yield	2.08E+10 J/t_{dm}	11,639 sej/J	242.10		Sum of prim. en	531.16	36.73	548.04	

Table A.I-4 *continued*

F6	**Comminution**					**7.02**		**54.78**			**27.65**
o	Motor fuel	5.48E+07	J/t_{dm}	47,900	sej/J	2.62	1.14	54.78			
p	Machines. equipment	0.015	kg/t_{dm}	2.30E+12	sej/kg	0.04					
q	Human services	23.79	SEK/t_{dm}	1.58E+11	sej/SEK	3.76					23.79
r	Capital investment	3.85	SEK/t_{dm}	1.58E+11	sej/SEK	0.61					3.85
Y6	Tree biomass yield	2.08E+10	J/t_{dm}	11,977	sej/J	249.12		Sum of prim. en	593.61	36.73	575.69
								Direct and embodied primary energy	630.35		
								E(output, primary)/E(input, primary)	33.0		

Table A.I-4 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from Thinning [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1+F2 from FinalFell [x 10^{12} sej/t_{dm}]	25.9	25.9	25.9	25.9	25.9
F3 [x 10^{12} sej/t_{dm}]	38.1	38.1	38.1	38.1	38.1
F4 [x 10^{12} sej/t_{dm}]	29.9	29.9	29.9	29.9	29.9
F5 [x 10^{12} sej/t_{dm}]	27.6	27.6	27.6	27.6	27.6
F6 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F7 (Conversion) [x 10^{12} sej/t_{dm}]	150.0	105.7	154.2	201.0	190.5
Solar emergy yields of products					
Y3 [x 10^{12} sej/t_{dm}]	184.6	184.6	184.6	184.6	184.6
Y4 [x 10^{12} sej/t_{dm}]	214.5	214.5	214.5	214.5	214.5
Y5 [x 10^{12} sej/t_{dm}]	242.1	242.1	242.1	242.1	242.1
Y6 [x 10^{12} sej/t_{dm}]	249.1	249.1	249.1	249.1	249.1
Y7 (Final product) [x 10^{12} sej/t_{dm}]	399.2	354.8	403.3	450.1	439.6
Solar transformities					
(c) After baling [sej/J]	8874	8874	8874	8874	8874
(d) After forwarding of bales [sej/J]	10,312	10,312	10,312	10,312	10,312
(e) After road transport [sej/J]	11,639	11,639	11,639	11,639	11,639
(f) After comminution [sej/J]	11,977	11,977	11,977	11,977	11,977
(g) After conversion [sej/J]	23,238	57,511	41,526	30,597	35,864
(g) Heat generated at CHP [sej/J]		25,555			
Net solar emergy yield ratio					
III. After baling	2.89	2.89	2.89	2.89	2.89
IV. After forwarding of bales	2.29	2.29	2.29	2.29	2.29
V. After road transport	1.99	1.99	1.99	1.99	1.99
VI. After comminution	1.94	1.94	1.94	1.94	1.94
VII. After conversion	1.43	1.52	1.43	1.37	1.38
Solar emergy investment ratio					
III. After baling	0.61	0.61	0.61	0.61	0.61
IV. After forwarding of bales	0.90	0.90	0.90	0.90	0.90
V. After road transport	1.16	1.16	1.16	1.16	1.16
VI. After comminution	1.23	1.23	1.23	1.23	1.23
VII. After conversion	2.67	2.25	2.71	3.16	3.06
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1158.57	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	17.18	6.17	9.71	14.71	12.26
Amount of heat produced at CHP [GJ/t_{dm}]		13.88			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	1.72	0.62	0.97	1.47	1.23
Amount of heat produced at CHP [GJ/(ha x year)]		1.39			
E(output)/E(primary energy input including biomass)	79.2%	90.1%	43.0%	63.9%	54.1%
E(output)/E(primary energy input excluding biomass)	19.5	13.8	5.4	6.6	6.6

Table A.I-4 *continued*

Cost of energy carrier					
SEK/GJ	83.90	66.68	121.42	90.68	112.90
SEK/MWh	302.02	240.05	437.12	326.45	406.44
€/GJ	9.20	7.31	13.32	9.94	12.38
Cost of heat at CHP					
SEK/GJ		41.02			
SEK/MWh		147.66			
€/GJ		4.50			

Footnotes to Table A.I-4

Biomass input:
$HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the biomass yield after felling, delimbing and cutting in forestry (Y_2 in Table A.I-1). Solar emergy = annual flow x solar transformity.

F_3 Baling:

a Direct energy required = 111.42 MJ/t_{dm} (see Table A.J-14).

b Mass depreciation of machinery = 0.154 kg/t_{dm} (see Table A.J-14). Solar transformity for machine equipment = 2.48 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 5.79 MJ/t_{dm} (see Table A.J-14).

c Costs for human services = O & M costs = 132.24 SEK/t_{dm} (see Table A.J-14).

d Capital costs = 63.41 SEK/t_{dm} (see Table A.J-14).

e Dry matter losses at baling = 1.0% of baled biomass (see Table A.G-1, footnote a). 0.01 x 2.08 x 10^{10} J/t_{dm} = 2.08 x 10^8 J/t_{dm}.

Y_3 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_2 + F_3) = (146.51 + 5.34 + 0.38 + 20.88 + 10.01 + 1.47) x 10^{12} sej/t_{dm} = 184.59 x 10^{12} sej/t_{dm}. Solar transformity = 184.59 x 10^{12} / 2.08 x 10^{10} sej/J = 8874 sej/J.

F_4 Forwarding of bales:

f Direct energy required = 110.93 MJ/t_{dm} (see Table A.J-11).

g Mass depreciation of machinery = 0.102 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.97 MJ/t_{dm} (see Table A.J-11).

h Costs for human services = O & M costs = 95.24 SEK/t_{dm} (see Table A.J-11).

i Capital costs = 19.99 SEK/t_{dm} (see Table A.J-11).

j Dry matter losses at storage = 3.3% of baled biomass (see Table A.G-1, footnote b). 0.033 x 2.08 x 10^{10} J/t_{dm} = 6.86 x 10^8 J/t_{dm}.

Y_4 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_3 + F_4) = (184.59 + 5.31 + 0.30 + 15.04 + 3.16 + 6.09) x 10^{12} sej/t_{dm} = 214.49 x 10^{12} sej/t_{dm}. Solar transformity = 214.49 x10^{12} / 2.08 x10^{10} sej/J = 10,312 sej/J.

F_5 Road transport:

k Direct energy required = 174.37 MJ/t_{dm} (see Table A.J-38b).

l Mass depreciation of machinery = 0.074 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^9 sej/g (See Table A.H-7). The amount of embodied energy in machinery = 4.57 MJ/t_{dm} (see Table A.J-38b).

m Costs for human services = O & M costs = 101.47 SEK/t_{dm} (see Table A.J-38b).

n Capital costs = 19.24 SEK/t_{dm} (see Table A.J-38b).

Y_5 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_5 + F_6) = (214.49 + 8.35 + 0.19 + 16.02 + 3.04) x 10^{12} sej/t_{dm} = 242.10 x 10^{12} sej/t_{dm}. Solar transformity = 242.10 x 10^{12} / 2.08 x 10^{10} sej/J = 11,639 sej/J.

F_6 Comminution:

o Direct energy required = 54.78 MJ/t_{dm} (see Table A.J-39).

p Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (see Table A.J-39).

q Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

r Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_6 $HHV_{Logging\ residues}$ = 20.8 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_6 + F_7) = (242.10 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 249.12 x 10^{12} sej/t_{dm}.
Solar transformity = 249.12 x 10^{12} / 2.08 x 10^{10} sej/J = 11,977 sej/J.

Table A.I-5. *Emergy. energy and cost analysis of early thinning*

Early thinning		Average annual flows	Emergy analysis: Solar transformity [sej/unit]	Emergy analysis: Solar emergy $[10^{12}$ sej/$t_{dm}]$	Solar emergy $[10^{12}$ sej/ha/yr]	Energy analysis: Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	Cost analysis: [SEK/t_{dm}]	[SEK/ha/yr]
I	**Environmental inputs**			**124.51**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
Y0	Tree biomass production	5.03E+10 J/ha	7009 sej/J	124.51	352.44					
F1	**Silvicultural inputs**			**7.53**	**21.30**		**6.03**	**18.40**		**114.00**
d	Seeds, plants	21.6 plants/ha	8.15E+09 sej/plant		1.76			15.70		
e	Fertilizers	0.137 kg/ha	4.60E+12 sej/kg		0.63			2.33		
f	Pesticides, herbicides	4.17E+04 J/ha	66,000 sej/J		0.003			0.02		
g	Motor fuel	1.71E+07 J/ha	47,900 sej/J		0.82	1.14	6.03			
h	Machines, equipment	0.031 kg/ha	2.97E+12 sej/kg		0.09			0.35		
i	Expendables	5.83 SEK/ha	1.58E+11 sej/SEK		0.92					5.83
j	Human services	85.14 SEK/ha	1.58E+11 sej/SEK		13.44					85.14
k	Capital investment	23.04 SEK/ha	1.58E+11 sej/SEK		3.64					23.04
Y1	Tree biomass production	5.92E+10 J/ha	6317 sej/J	132.03	373.74	Sum of prim. en.	6.88	18.40	40.27	114.00
F2	**Felling. delimbing and cutting**			**12.27**			**43.61**	**2.70**	**63.78**	
l	Motor fuel	4.36E+07 J/t_{dm}	47,900 sej/J	2.09		1.14	43.61			
m	Machines, equipment	0.042 kg/t_{dm}	2.71E+12 sej/kg	0.11				2.70		
n	Human services	49.72 SEK/t_{dm}	1.58E+11 sej/SEK	7.85					49.72	
o	Capital investment	14.05 SEK/t_{dm}	1.58E+11 sej/SEK	2.22					14.05	
Y2	Tree biomass yield	2.09E+10 J/t_{dm}	6905 sej/J	144.31		Sum of prim. en.	56.59	21.09	104.05	

Table A.I-5 *continued*

F3	**Forwarding**			**24.42**			**96.26**	**4.31**	**99.99**
p	Motor fuel	9.63E+07 J/t_{dm}	47,900 sej/J	4.61		1.14	96.26		
q	Machines, equipment	0.089 kg/t_{dm}	2.97E+12 sej/kg	0.26				4.31	
r	Human services	82.64 SEK/t_{dm}	1.58E+11 sej/SEK	13.05					82.64
s	Capital investment	17.35 SEK/t_{dm}	1.58E+11 sej/SEK	2.74					17.35
t	Handling and storage losses	5.43E+08 J/t_{dm}	6905 sej/J	3.75					
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	8073 sej/J	168.72	Sum of prim. en.		166.32	25.41	204.04
F4	**Road transport**			**17.24**			**107.31**	**2.89**	**75.87**
u	Motor fuel	1.07E+08 J/t_{dm}	47,900 sej/J	5.14		1.14	107.31		
v	Machines, equipment	0.05 kg/t_{dm}	2.60E+12 sej/kg	0.12				2.89	
w	Human services	63.68 SEK/t_{dm}	1.58E+11 sej/SEK	10.05					63.68
x	Capital investment	12.19 SEK/t_{dm}	1.58E+11 sej/SEK	1.92					12.19
Y4	Tree biomass yield	2.09E+10 J/t_{dm}	8898 sej/J	185.96	Sum of prim. en.		288.65	28.30	279.90
F5	**Comminution**			**7.02**			**54.78**		**27.65**
y	Motor fuel	5.48E+07 J/t_{dm}	47,900 sej/J	2.62		1.14	54.78		
z	Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/kg	0.03					
aa	Human services	23.79 SEK/t_{dm}	1.58E+11 sej/SEK	3.76					23.79
bb	Capital investment	3.85 SEK/t_{dm}	1.58E+11 sej/SEK	0.61					3.85
Y5	Tree biomass yield	2.09E+10 J/t_{dm}	9234 sej/J	192.99	Sum of prim. en.		351.11	28.30	307.55
					Direct + embodied prim. en.		379.41		
					E(output, primary)/E(input, primary)		55.1		

Table A.I-5 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I Item c [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1 [x 10^{12} sej/t_{dm}]	7.5	7.5	7.5	7.5	7.5
F2 [x 10^{12} sej/t_{dm}]	12.3	12.3	12.3	12.3	12.3
F3 [x 10^{12} sej/t_{dm}]	24.4	24.4	24.4	24.4	24.4
F4 [x 10^{12} sej/t_{dm}]	17.2	17.2	17.2	17.2	17.2
F5 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F6 (Conversion) [x 10^{12} sej/t_{dm}]	150.7	106.0	154.9	201.6	191.1
Solar emergy yields of products					
Y1 [x 10^{12} sej/t_{dm}]	132.0	132.0	132.0	132.0	132.0
Y2 [x 10^{12} sej/t_{dm}]	144.3	144.3	144.3	144.3	144.3
Y3 [x 10^{12} sej/t_{dm}]	168.7	168.7	168.7	168.7	168.7
Y4 [x 10^{12} sej/t_{dm}]	186.0	186.0	186.0	186.0	186.0
Y5 [x 10^{12} sej/t_{dm}]	193.0	193.0	193.0	193.0	193.0
Y6 (Final product) [x 10^{12} sej/t_{dm}]	343.7	298.9	347.9	394.6	384.1
Solar transformities					
(a) Standing biomass [sej/J]	6317	6317	6317	6317	6317
(b) After harvesting [sej/J]	6905	6905	6905	6905	6905
(c) After forwarding [sej/J]	8073	8073	8073	8073	8073
(d) After road transport [sej/J]	8898	8898	8898	8898	8898
(e) After comminution [sej/J]	9234	9234	9234	9234	9234
(f) After conversion [sej/J]	19,913	48,225	35,651	26,692	31,184
(f) Heat generated at CHP [sej/J]		21,429			
Net solar emergy yield ratio					
I. Standing biomass	17.54	17.54	17.54	17.54	17.54
II. After harvesting	7.29	7.29	7.29	7.29	7.29
III. After forwarding	3.82	3.82	3.82	3.82	3.82
IV. After road transport	3.03	3.03	3.03	3.03	3.03
V. After comminution	2.82	2.82	2.82	2.82	2.82
VI. After conversion	1.57	1.71	1.56	1.46	1.48
Solar emergy investment ratio					
I. Standing biomass	0.06	0.06	0.06	0.06	0.06
II. After harvesting	0.16	0.16	0.16	0.16	0.16
III. After forwarding	0.36	0.36	0.36	0.36	0.36
IV. After road transport	0.49	0.49	0.49	0.49	0.49
V. After comminution	0.55	0.55	0.55	0.55	0.55
VI. After conversion	1.76	1.40	1.79	2.17	2.08
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1164.14	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	17.26	6.20	9.76	14.78	12.32
Amount of heat produced at CHP [GJ/t_{dm}]		13.95			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	1.65	0.59	0.93	1.41	1.18
Amount of heat produced at CHP [GJ/(ha x year)]		1.33			

Table A.I-5 *continued*

E(final product)/E(primary energy input including biomass)	80.2%	91.2%	43.5%	64.6%	54.7%
E(output)/E(primary energy input excluding biomass)	27.4	16.8	6.3	7.5	7.6
Cost of energy carrier					
SEK/GJ	68.20	53.23	93.66	72.35	90.90
SEK/MWh	245.52	191.61	337.18	260.47	327.26
€/GJ	7.48	5.84	10.27	7.93	9.97
Cost of heat at CHP					
SEK/GJ		27.56			
SEK/MWh		99.23			
€/GJ		3.02			

Footnotes to Table 6-A5

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).

Y_0 See footnote to Table A.I-1.

F_1 Silvicultural inputs:

d–k See footnotes to Table A.I-1.

Y_1 See footnote to Table A.I-1.

F_2 Felling, delimbing and cutting:

l Direct energy required = 43.61 MJ/t_{dm} (see Table A.J-8).

m Mass depreciation of machinery = 0.042 kg/t_{dm}, the solar transformity for machine equipment = 2.71 x 10^{12} sej/kg and the amount of embodied energy in machinery = 2.70 MJ/t_{dm} (see Table A.J-8).

n Costs for human services = O & M costs = 49.72 SEK/t_{dm} (see Table A.J-8).

o Capital costs = 14.05 SEK/t_{dm} (see Table A.J-8).

Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_1 + F_2) = (132.03 + 2.09 + 0.11 + 7.85 + 2.22) x 10^{12} sej/t_{dm} = 144.31 x 10^{12} sej/t_{dm}. Solar transformity = 144.31 x 10^{12} / 2.09 x 10^{10} sej/J = 6905 sej/J.

F_3 Forwarding:

p Direct energy required = 96.26 MJ/t_{dm} (see Table A.J-11).

q Mass depreciation of machinery = 0.089 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.31 MJ/t_{dm} (see Table A.J-11).

r Costs for human services = O & M costs = 82.64 SEK/t_{dm} (see Table A.J-11).

s Capital costs = 17.35 SEK/t_{dm} (see Table A.J-11).

t Dry matter losses at storage = 2.6% of forwarded biomass (see Table A.G-1, footnote c). 0.026 x 2.09 x 10^{10} J/t_{dm} = 5.43 x 10^{8} J/t_{dm}.

Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (144.31 + 4.61 + 0.26 + 13.05 + 2.74 + 3.75) x 10^{12} sej/t_{dm} = 168.72 x 10^{12} sej/t_{dm}.
Solar transformity = 168.72 x 10^{12} / 2.09 x 10^{10} sej/J = 8073 sej/J.

F_4 Road transport:

u Direct energy required = 107.31 MJ/t_{dm} (see Table A.J-38b).

v Mass depreciation of machinery = 0.047 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.89 MJ/t_{dm} (see Table A.J-38b).

w Costs for human services = O & M costs = 63.68 SEK/t_{dm} (see Table A.J-38b).

x Capital costs = 12.19 SEK/t_{dm} (see Table A.J-38b).

Y_4 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (168.72 + 5.14 + 0.12 + 10.05 + 1.92) x 10^{12} sej/t_{dm} = 185.96 x

10^{12} sej/t_{dm}. Solar transformity = 185.96 x 10^{12} / 2.09 x 10^{10} sej/J = 8898 sej/J.

F_5 Comminution:

y Direct energy required = 54.78 MJ/t_{dm} (see Table A.J-39).

z Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (See Table A.J-39).

aa Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

bb Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_5 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_4 + F_5) = (185.96 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 192.99 x 10^{12} sej/t_{dm}. Solar transformity = 192.99 x 10^{12} / 2.09 x 10^{10} sej/J = 9234 sej/J.

Table A.I-6. *Emergy. energy and cost analysis of industrial wood cuttings*

Industrial wood cuttings		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
I Environmental inputs			**124.51**	**352.44**					
a Sunlight	2.57E+13 J/ha	1 sej/J		25.74	Not included			Not included	
b Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91	Nature´s contribution			Nature's contribution	
c Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44	considered free			considered free	
Y0 Tree biomass production	5.03E+10 J/ha	7009 sej/J	124.51	352.44					
F1 Silvicultural inputs			**7.53**	**21.30**		**6.03**	**18.40**		**114.00**
d Seeds, plants	21.6 plants/ha	8.15E+09 sej/plant		1.76			15.70		
e Fertilizers	0.137 kg/ha	4.60E+12 sej/kg		0.63			2.33		
f Pesticides, herbicides	4.17E+04 J/ha	66,000 sej/J		0.003			0.02		
g Motor fuel	1.71E+07 J/ha	47,900 sej/J		0.82	1.14	6.03			
h Machines, equipment	0.031 kg/ha	2.97E+12 sej/kg		0.09			0.35		
i Expendables	5.83 SEK/ha	1.58E+11 sej/SEK		0.92					5.83
j Human services	85.14 SEK/ha	1.58E+11 sej/SEK		13.44					85.14
k Capital investment	23.04 SEK/ha	1.58E+11 sej/SEK		3.64					23.04
Y1 Tree biomass production	5.92E+10 J/ha	6317 sej/J	132.03	373.74	Sum of prim. en.	6.88	18.40	40.27	114.00
F2 Felling. delimbing and cutting			**15.18**			**63.18**	**3.00**	**76.18**	
l Motor fuel	6.32E+07 J/t_{dm}	47,900 sej/J	3.03		1.14	63.18			
m Machines, equipment	0.042 kg/t_{dm}	2.97E+12 sej/kg	0.13				3.00		
n Human services	58.92 SEK/t_{dm}	1.58E+11 sej/SEK	9.30					58.92	
o Capital investment	17.26 SEK/t_{dm}	1.58E+11 sej/SEK	2.73					17.26	
Y2 Tree biomass yield	2.09E+10 J/t_{dm}	7044 sej/J	147.21		Sum of prim. en.	78.90	21.40	116.45	

Table A.I-6 *continued*

F3	**Forwarding**			**24.49**		**96.26**	**4.31**	**99.99**
p	Motor fuel	9.63E+07 J/t_{dm}	47,900 sej/J	4.61	1.14	96.26		
q	Machines, equipment	0.089 kg/t_{dm}	2.97E+12 sej/kg	0.26			4.31	
r	Human services	82.64 SEK/t_{dm}	1.58E+11 sej/SEK	13.05				82.64
s	Capital investment	17.35 SEK/t_{dm}	1.58E+11 sej/SEK	2.74				17.35
t	Handling and storage losses	5.43E+08 J/t_{dm}	7016 sej/J	3.83				
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	8216 sej/J	171.70	Sum of prim. en.	188.63	25.71	216.44
F4	**Road transport**			**17.24**		**107.31**	**2.89**	**75.87**
u	Motor fuel	1.07E+08 J/t_{dm}	47,900 sej/J	5.14	1.14	107.31		
v	Machines, equipment	0.047 kg/t_{dm}	2.60E+12 sej/kg	0.12			2.89	
w	Human services	63.68 SEK/t_{dm}	1.58E+11 sej/SEK	10.05				63.68
x	Capital investment	12.19 SEK/t_{dm}	1.58E+11 sej/SEK	1.92				12.19
Y4	Tree biomass yield	2.09E+10 J/t_{dm}	9040 sej/J	188.95	Sum of prim. en.	310.96	28.61	292.31
F5	**Comminution**			**7.02**		**54.78**		**27.65**
y	Motor fuel	5.48E+07 J/t_{dm}	47,900 sej/J	2.62	1.14	54.78		
z	Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/kg	0.03				
aa	Human services	23.79 SEK/t_{dm}	1.58E+11 sej/SEK	3.76				23.79
bb	Capital investment	3.85 SEK/t_{dm}	1.58E+11 sej/SEK	0.61				3.85
Y5	Tree biomass yield	2.09E+10 J/t_{dm}	9377 sej/J	195.97	Sum of prim. en.	373.41	28.61	319.96
					Direct + embodied prim. en.	402.02		
					E(output, primary)/E(input, primary)	52.0		

Table A.I-6 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I Item c [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased):					
F1 [x 10^{12} sej/t_{dm}]	7.5	7.5	7.5	7.5	7.5
F2 [x 10^{12} sej/t_{dm}]	15.2	15.2	15.2	15.2	15.2
F3 [x 10^{12} sej/t_{dm}]	24.5	24.5	24.5	24.5	24.5
F4 [x 10^{12} sej/t_{dm}]	17.2	17.2	17.2	17.2	17.2
F5 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F6 (Conversion) [x 10^{12} sej/t_{dm}]	150.7	106.0	154.9	201.6	191.1
Solar emergy yields of products:					
Y1 [x 10^{12} sej/t_{dm}]	132.0	132.0	132.0	132.0	132.0
Y2 [x 10^{12} sej/t_{dm}]	147.2	147.2	147.2	147.2	147.2
Y3 [x 10^{12} sej/t_{dm}]	171.7	171.7	171.7	171.7	171.7
Y4 [x 10^{12} sej/t_{dm}]	188.9	188.9	188.9	188.9	188.9
Y5 [x 10^{12} sej/t_{dm}]	196.0	196.0	196.0	196.0	196.0
Y6 (Final product) [x 10^{12} sej/t_{dm}]	346.7	301.9	350.9	397.6	387.0
Solar transformities:					
(a) Standing biomass [sej/J]	6317	6317	6317	6317	6317
(b) After harvesting [sej/J]	7044	7044	7044	7044	7044
(c) After forwarding [sej/J]	8216	8216	8216	8216	8216
(d) After road transport [sej/J]	9040	9040	9040	9040	9040
(e) After comminution [sej/J]	9377	9377	9377	9377	9377
(f) After conversion [sej/J]	20,086	48,706	35,957	26,894	31,427
(f) Heat generated at CHP [sej/J]		21,642			
Net solar emergy yield ratio					
I. Standing biomass	17.54	17.54	17.54	17.54	17.54
II. After harvesting	6.48	6.48	6.48	6.48	6.48
III. After forwarding	3.64	3.64	3.64	3.64	3.64
IV. After road transport	2.93	2.93	2.93	2.93	2.93
V. After comminution	2.74	2.74	2.74	2.74	2.74
VI. After conversion	1.56	1.70	1.55	1.46	1.47
Solar emergy investment ratio					
I. Standing biomass	0.06	0.06	0.06	0.06	0.06
II. After harvesting	0.18	0.18	0.18	0.18	0.18
III. After forwarding	0.38	0.38	0.38	0.38	0.38
IV. After road transport	0.52	0.52	0.52	0.52	0.52
V. After comminution	0.57	0.57	0.57	0.57	0.57
VI. After conversion	1.78	1.42	1.82	2.19	2.11
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1164.14	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	17.26	6.20	9.76	14.78	12.32
Amount of heat produced at CHP [GJ/t_{dm}]		13.95			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	0.77	0.28	0.44	0.66	0.55
Amount of heat produced at CHP [GJ/(ha x year)]		0.62			

Table A.I-6 *continued*

E(final product)/E(primary energy input including biomass)	80.1%	91.1%	43.4%	64.5%	54.6%
E(output)/E(primary energy input excluding biomass)	26.4	16.5	6.2	7.4	7.5
Cost of energy carrier					
SEK/GJ	68.92	53.84	94.93	73.19	91.91
SEK/MWh	248.11	193.83	341.75	263.49	330.88
€/GJ	7.56	5.90	10.41	8.03	10.08
Cost of heat at CHP					
SEK/GJ		28.18			
SEK/MWh		101.44			
€/GJ		3.09			

Footnotes to Table 6-A6

I Environmental inputs:
a–c Data from Doherty, Nilsson & Odum (2002).
Y_0 See footnote to Table A.I-1.
F_1 Silvicultural inputs:
d–k See footnotes to Table A.I-1.
Y_1 See footnote to Table A.I-1.
F_2 Felling, delimbing and cutting:
l Direct energy required = 63.18 MJ/t_{dm} (see Table A.J-8).
m Mass depreciation of machinery = 0.042 kg/t_{dm} (see Table A.J-8). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (see Table A.H-7). The amount of embodied energy in machinery = 3.00 MJ/t_{dm} (see Table A.J-8).
n Costs for human services = O & M costs = 58.92 SEK/t_{dm} (see Table A.J-8).
o Capital costs = 17.26 SEK/t_{dm} (see Table A.J-8).
Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of ($Y_1 + F_2$) = (132.03 + 3.03 + 0.13 + 9.30 + 2.73) x 10^{12} sej/t_{dm} = 147.21 x 10^{12} sej/t_{dm}.
Solar transformity = 147.21 x 10^{12} / 2.09 x 10^{10} sej/J = 7044 sej/J.
F_3 Forwarding:
p Direct energy required = 96.26 MJ/t_{dm} (see Table A.J-11).
q Mass depreciation of machinery = 0.089 kg/t_{dm} (see Table A.J-11). Solar transformity for machine equipment = 2.97 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.31 MJ/t_{dm} (see Table A.J-11).
r Costs for human services = O & M costs = 82.64 SEK/t_{dm} (see Table A.J-11).
s Capital costs = 17.35 SEK/t_{dm} (see Table A.J-11).
t Dry matter losses at storage = 2.6% of forwarded biomass (see Table A.G-1, footnote c). 0.026 x 2.09 x 10^{10} J/t_{dm} = 5.43 x 10^8 J/t_{dm}.
Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of ($Y_2 + F_3$) = (147.21 + 4.61 + 0.26 + 13.05 + 2.74 + 3.83) x 10^{12} sej/t_{dm} = 171.70 x 10^{12} sej/t_{dm}.
Solar transformity = 171.70 x 10^{12} / 2.09 x 10^{10} sej/J = 8216 sej/J.
F_4 Road transport:
u Direct energy required = 107.31 MJ/t_{dm} (see Table A.J-38b).
v Mass depreciation of machinery = 0.047 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.89 MJ/t_{dm} (see Table A.J-38b).
w Costs for human services = O & M costs = 63.68 SEK/t_{dm} (see Table A.J-38b).
x Capital costs = 12.19 SEK/t_{dm} (see Table A.J-38b).

Y_4 Tree biomass yield: HHV = 20.9 MJ/kg$_{dm}$ (see Table A.B-1c). Solar emergy = solar emergy of ($Y_3 + F_4$) = (171.70 + 5.14 + 0.12 + 10.05 + 1.92) x 10^{12} sej/t$_{dm}$ = 188.95 x 10^{12} sej/t$_{dm}$. Solar transformity = 188.95 x 10^{12} / 2.09 x 10^{10} sej/J = 9040 sej/J.

F_5 Comminution:

y Direct energy required = 54.78 MJ/t$_{dm}$ (see Table A.J-39).

z Mass depreciation of machinery = 0.015 kg/t$_{dm}$, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (See Table A.J-39).

aa Costs for human services = O & M costs = 23.79 SEK/t$_{dm}$ (see Table A.J-39).

bb Capital costs = 3.85 SEK/t$_{dm}$ (see Table A.J-39).

Y_5 Tree biomass yield: HHV = 20.9 MJ/kg$_{dm}$ (see Table A.B-1c). Solar emergy = solar emergy of ($Y_4 + F_5$) = (188.95 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t$_{dm}$ = 195.97 x 10^{12} sej/t$_{dm}$. Solar transformity = 195.97 x 10^{12} / 2.09 x 10^{10} sej/J = 9377 sej/J.

Table A.I-7. *Emergy, energy and cost analysis of fuel wood from non-forest land*

Wood from non-forest land			Emergy analysis			Energy analysis			Cost analysis	
						Prim. energy conv. factor	Direct energy	Embodied energy		
		Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]		MJ/t_{dm}	MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
I	**Environmental inputs**			**749.23**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74	Not included			Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91	Nature´s contribution			Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44	considered free			considered free	
Y0	Tree biomass production	9.83E+09 J/ha	35,848 sej/J	749.23	352.44					
F1	**Felling, delimbing and cutting**			**49.04**			**23.46**	**0.24**	**303.38**	
d	Motor fuel	2.35E+07 J/t_{dm}	47,900 sej/J	1.12		1.21	23.46			
e	Machines, equipment	0.006 kg/t_{dm}	1.64E+12 sej/kg	0.01				0.24		
f	Human services	289.16 SEK/t_{dm}	1.58E+11 sej/SEK	45.66					289.16	
g	Capital investment	14.22 SEK/t_{dm}	1.58E+11 sej/SEK	2.25					14.22	
Y1	Tree biomass yield	2.09E+10 J/t_{dm}	38,195 sej/J	798.27		Sum of prim. en.	28.38	0.24	303.38	
F2	**Forwarding**			**43.60**			**49.31**	**6.11**	**116.04**	
h	Motor fuel	4.93E+07 J/t_{dm}	47,900 sej/J	2.36		1.14	49.31			
i	Machines, equipment	0.997 kg/t_{dm}	2.16E+12 sej/kg	2.16				6.11		
j	Human services	99.83 SEK/t_{dm}	1.58E+11 sej/SEK	15.76					99.83	
k	Capital investment	16.21 SEK/t_{dm}	1.58E+11 sej/SEK	2.56					16.21	
l	Handling and storage losses	5.43E+08 J/t_{dm}	38,195 sej/J	20.76						
Y2	Tree biomass yield	2.09E+10 J/t_{dm}	40,281 sej/J	841.87		Sum of prim. en.	84.60	6.35	419.43	
F3	**Road transport**			**17.24**			**107.31**	**2.89**	**75.87**	
m	Motor fuel	1.07E+08 J/t_{dm}	47,900 sej/J	5.14		1.14	107.31			
n	Machines, equipment	0.05 kg/t_{dm}	2.60E+12 sej/kg	0.12				2.89		
o	Human services	63.68 SEK/t_{dm}	1.58E+11 sej/SEK	10.05					63.68	
p	Capital investment	12.19 SEK/t_{dm}	1.58E+11 sej/SEK	1.92					12.19	
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	41,106 sej/J	859.11		Sum of prim. en.	206.93	9.24	495.29	

Table A.I-7 *continued*

F4	**Comminution**					**7.02**		**54.78**		**27.65**
q	Motor fuel	5.48E+07	J/t_{dm}	47,900	sej/J	2.62	1.14	54.78		
r	Machines, equipment	0.015	kg/t_{dm}	2.24E+12	sej/kg	0.03				
s	Human services	23.79	SEK/t_{dm}	1.58E+11	sej/SEK	3.76				23.79
t	Capital investment	3.85	SEK/t_{dm}	1.58E+11	sej/SEK	0.61				3.85
Y4	Tree biomass yield	2.09E+10	J/t_{dm}	41,442	sej/J	866.13	Sum of prim. en.	269.38	9.24	522.94
							Direct + embodied prim. en.	278.62		
							E(output, primary)/E(input, primary)	75.0		

Table A.I-7 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I Item c [x 10^{12} sej/t_{dm}]	749.2	749.2	749.2	749.2	749.2
Inputs fed back from society (*i.e.* purchased):					
F1 [x 10^{12} sej/t_{dm}]	49.0	49.0	49.0	49.0	49.0
F2 [x 10^{12} sej/t_{dm}]	43.6	43.6	43.6	43.6	43.6
F3 [x 10^{12} sej/t_{dm}]	17.2	17.2	17.2	17.2	17.2
F4 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F5 (Conversion) [x 10^{12} sej/t_{dm}]	150.7	106.0	154.9	201.6	191.1
Solar emergy yields of products:					
Y1 [x 10^{12} sej/t_{dm}]	798.3	798.3	798.3	798.3	798.3
Y2 [x 10^{12} sej/t_{dm}]	841.9	841.9	841.9	841.9	841.9
Y3 [x 10^{12} sej/t_{dm}]	859.1	859.1	859.1	859.1	859.1
Y4 [x 10^{12} sej/t_{dm}]	866.1	866.1	866.1	866.1	866.1
Y5 (Final product) [x 10^{12} sej/t_{dm}]	1016.8	972.1	1021.0	1067.7	1057.2
Solar transformities:					
(a) After harvesting [sej/J]	38,195	38,195	38,195	38,195	38,195
(b) After forwarding [sej/J]	40,281	40,281	40,281	40,281	40,281
(c) After road transport [sej/J]	41,106	41,106	41,106	41,106	41,106
(d) After comminution [sej/J]	41,442	41,442	41,442	41,442	41,442
(e) After conversion [sej/J]	58,915	155,975	104,635	72,230	85,842
(e) Heat generated at CHP [sej/J]		67,087			
Net solar emergy yield ratio					
I. After harvesting	16.28	16.28	16.28	16.28	16.28
II. After forwarding	9.09	9.09	9.09	9.09	9.09
III. After road transport	7.82	7.82	7.82	7.82	7.82
IV. After comminution	7.41	7.41	7.41	7.41	7.41
V. After conversion	3.80	4.36	3.76	3.35	3.43
Solar emergy investment ratio					
I. After harvesting	0.07	0.07	0.07	0.07	0.07
II. After forwarding	0.12	0.12	0.12	0.12	0.12
III. After road transport	0.15	0.15	0.15	0.15	0.15
IV. After comminution	0.16	0.16	0.16	0.16	0.16
V. After conversion	0.36	0.30	0.36	0.43	0.41
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1164.14	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	17.26	6.20	9.76	14.78	12.32
Amount of heat produced at CHP [GJ/t_{dm}]		13.95			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	0.37	0.13	0.21	0.32	0.26
Amount of heat produced at CHP [GJ/(ha x year)]		0.30			
E(output)/E(primary energy input including biomass)	80.5%	94.2%	43.7%	64.9%	54.9%
E(output)/E(primary energy input excluding biomass)	32.6	18.9	6.8	7.9	8.1

Table A.I-7 *continued*

Cost of energy carrier					
SEK/GJ	80.68	63.91	115.73	86.92	108.39
SEK/MWh	290.44	230.09	416.64	312.93	390.22
€/GJ	8.85	7.01	12.69	9.53	11.89
Cost of heat at CHP					
SEK/GJ		38.25			
SEK/MWh		137.71			
€/GJ		4.19			

Footnotes to Table A.I-7

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).

Y_0 The tree biomass production was assumed to be 0.80 m^3_{sk}/(ha x year). 40% was added considering branches and roots. The basic density of wood = 420 kg_{dm}/m^3_f (see Table A.B-2). HHV = 20.9 MJ/kg_{dm} (see Table A.B-1). Thus, the tree biomass production = 0.80 x 1.4 x 420 x 20.9 x 10^6 J/(ha x year) = 9.83 x 10^9 J/(ha x year).
Solar emergy = solar emergy of transpired rain = 352.44 x 10^{12} sej/(ha x year). Annual biomass growth per hectare = 0.80 x 1.4 x 420 t_{dm}/ha = 0.470 t_{dm}/ha. Thus, solar emergy = 352.44 x 10^{12} / 0.470 sej/t_{dm} = 749.23 sej/t_{dm}.
Solar transformity = 352.44 x 10^{12} / 9.83 x 10^9 sej/J = 35,848 sej/J.

F_1 Felling, delimbing and cutting:

d Direct energy required = 23.46 MJ/t_{dm} (see Table A.J-9).

e Mass depreciation of machinery = 0.006 kg/t_{dm} (see Table A.J-9). Solar transformity for machine equipment = 1.64 x 10^{12} sej/kg (see Table A.H-7). The amount of embodied energy in machinery = 0.24 MJ/t_{dm} (see Table A.J-9).

f Costs for human services = O & M costs = 289.16 SEK/t_{dm} (see Table A.J-9).

g Capital costs = 14.22 SEK/t_{dm} (see Table A.J-9).

Y_1 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_1 + F_2) = (749.23 + 1.12 + 0.01 + 45.66 + 2.25) x 10^{12} sej/t_{dm} = 798.27 x 10^{12} sej/t_{dm}. Solar transformity = 798.27 x 10^{12} / 2.09 x 10^{10} sej/J = 38,195 sej/J.

F_2 Forwarding:

h Direct energy required = 49.31 MJ/t_{dm} (see Table A.J-12).

i Mass depreciation of machinery = 0.997 kg/t_{dm}, the solar transformity for machine equipment = 2.16 x 10^{12} sej/kg and the amount of embodied energy in machinery = 6.11 MJ/t_{dm} (see Table A.J-12).

j Costs for human services = O & M costs = 99.83 SEK/t_{dm} (see Table A.J-12).

k Capital costs = 16.21 SEK/t_{dm} (see Table A.J-12).

l Dry matter losses at storage = 2.6% of forwarded biomass (see Table A.G-1, footnote c). 0.026 x 2.09 x 10^{10} J/t_{dm} = 5.43 x 10^8 J/t_{dm}.

Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (798.27 + 2.36 + 2.16 + 15.76 + 2.56 + 20.76) x 10^{12} sej/t_{dm} = 841.87 x 10^{12} sej/t_{dm}. Solar transformity = 841.87 x 10^{12} / 2.09 x 10^{10} sej/J = 40,281 sej/J.

F_3 Road transport:

m Direct energy required = 107.31 MJ/t_{dm} (see Table A.J-38a).

n Mass depreciation of machinery = 0.047 kg/t_{dm} (see Table A.J-38a). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 2.89 MJ/t_{dm} (see Table A.J-38a).

o Costs for human services = O & M costs = 63.68 SEK/t_{dm} (see Table A.J-38a).

p Capital costs = 12.19 SEK/t_{dm} (see Table A.J-38a).

Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (841.87 + 5.14 + 0.12 + 10.05 + 1.92) x 10^{12} sej/t_{dm} = 859.11 x 10^{12} sej/t_{dm}. Solar transformity = 859.11 x 10^{12} / 2.09 x 10^{10} sej/J = 41,106 sej/J.

F_4 Comminution:

q Direct energy required = 54.78 MJ/t_{dm} (see Table A.J-39).

r Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (See Table A.J-39).

s Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

t Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_4 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_4 + F_5) = (859.11 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 866.13 x 10^{12} sej/t_{dm}. Solar transformity = 866.13 x 10^{12} / 2.09 x 10^{10} sej/J = 41,442 sej/J.

Table A.I-8. *Emergy, energy and cost analysis of wood chips*

Wood chips	Average annual flows	Emergy analysis: Solar transformity [sej/unit]	Emergy analysis: Solar emergy [10^{12} sej/t_{dm}]	Emergy analysis: Solar emergy [10^{12} sej/ha/yr]	Energy analysis: Prim. energy conv. factor	Energy analysis: Direct energy MJ/t_{dm}	Energy analysis: Embodied energy MJ/t_{dm}	Cost analysis: [SEK/t_{dm}]	Cost analysis: [SEK/ha/yr]
Biomass input	**2.09E+10 J/t_{dm}**	**8208 sej/J**	**171.54**		**Primary energy**	**250.61**	**27.21**	**223.38**	
F5 Saw milling			**177.42**			**300.00**		**714.29**	
a Electricity	3.00E+08 J/t_{dm}	80,200 sej/J	24.06		1.59	300.00			
b Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/SEK	0.03						
c Expendables	238.10 SEK/t_{dm}	1.58E+11 sej/SEK	37.60					238.10	
d Human services	476.19 SEK/t_{dm}	1.58E+11 sej/SEK	75.19					476.19	
e Capital investment	238.10 SEK/t_{dm}	1.58E+11 sej/J	37.60					238.10	
f Handling and storage losses	3.58E+08	8208 sej/J	2.94						
Y5 Tree biomass yield	1.99E+10 J/t_{dm}	17,536 sej/J	348.96		Sum of prim. en.	727.61	27.21	937.67	
F6 Road transport			**25.40**			**148.89**	**4.43**	**114.49**	
g Motor fuel	1.49E+08 J/t_{dm}	47,900 sej/J	7.13		1.14	148.89			
h Machines, equipment	0.072 kg/t_{dm}	2.60E+12 sej/kg	0.19				4.43		
i Human services	94.83 SEK/t_{dm}	1.58E+11 sej/SEK	14.97					94.83	
j Capital investment	19.66 SEK/t_{dm}	1.58E+11 sej/SEK	3.10					19.66	
Y6 Tree biomass yield	1.99E+10 J/t_{dm}	18,812 sej/J	374.36		Sum of prim. en.	897.35	31.64	1052.15	
					Direct + embodied prim. en.	928.99			
					E(output, primary)/E(input, primary)	21.4			

Table A.I-8 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1+F2+F3+F4 from FinalFell [x 10^{12} sej/t_{dm}]	47.0	47.0	47.0	47.0	47.0
F5 [x 10^{12} sej/t_{dm}]	177.4	177.4	177.4	177.4	177.4
F6 [x 10^{12} sej/t_{dm}]	25.4	25.4	25.4	25.4	25.4
F7 (Conversion) [x 10^{12} sej/t_{dm}]	144.1	103.2	147.5	195.8	184.9
Solar emergy yields of products					
Y5 [x 10^{12} sej/t_{dm}]	349.0	349.0	349.0	349.0	349.0
Y6 [x 10^{12} sej/t_{dm}]	374.4	374.4	374.4	374.4	374.4
Y7 (Final product) [x 10^{12} sej/t_{dm}]	518.4	477.5	521.8	570.2	559.3
Solar transformities					
e) After saw milling [sej/J]	17,536	17,536	17,536	17,536	17,536
(f) After road transport [sej/J]	18,812	18,812	18,812	18,812	18,812
(g) After conversion [sej/J]	31,548	80,908	56,166	40,509	47,694
(g) Heat generated at CHP [sej/J]		35,951			
Net solar emergy yield ratio					
V. After saw milling	1.55	1.55	1.55	1.55	1.55
VI. After road transport	1.50	1.50	1.50	1.50	1.50
VII. After conversion	1.32	1.35	1.31	1.28	1.29
Solar emergy investment ratio					
V. After saw milling	1.80	1.80	1.80	1.80	1.80
VI. After road transport	2.01	2.01	2.01	2.01	2.01
VII. After conversion	3.16	2.84	3.19	3.58	3.49
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1108.44	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	16.43	5.90	9.29	14.07	11.73
Amount of heat produced at CHP [GJ/t_{dm}]		13.28			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	0.44	0.16	0.25	0.38	0.32
Amount of heat produced at CHP [GJ/(ha x year)]		0.36			
E(output)/E(primary energy input including biomass)	78.0%	88.6%	42.4%	62.7%	53.1%
E(output)/E(primary energy input excluding biomass)	13.9	11.0	4.6	5.6	5.4
Cost of energy carrier					
SEK/GJ	114.41	92.91	175.39	126.30	155.66
SEK/MWh	411.86	334.48	631.39	454.69	560.36
€/GJ	12.55	10.19	19.23	13.85	17.07
Cost of heat at CHP					
SEK/GJ		67.25			
SEK/MWh		242.09			
€/GJ		7.37			

Footnotes to Table A.I-8

Biomass input:

$HHV_{Roundwood}$ = 20.9 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the biomass after road transport of roundwood (Y_4 in Table A.I-1). Solar emergy = (annual flow) x (solar transformity)

F_5 Saw milling:

a From environmental accounts by Stora Enso Timber (saw mills in Gruvön, Ala, Kopparfors and Linghed, Sweden), an estimated 35 kWh/m^3_{fpb} of electricity was required. Density of timber was assumed as 420 kg/m^3_{fpb}, according to data in Table A.B-2. Thus, the amount of electricity required = 35 x 10^3 x 3600 / 0.420 J/t_{dm} = 3.00 x 10^8 J/t_{dm}. Solar transformity for Swedish hydroelectricity = 8.02 x 10^4 sej/J (Odum, 1996).

b The mass depreciation of machinery and the transformity for machine equipment at saw milling were assumed as equal to the mass depreciation of machinery and the transformity at comminution, *i.e.* 0.015 kg/t_{dm} and 2.24 x 10^{12} sej/kg respectively (see Table A.J-39).

c Expendables at saw milling were assumed as 100 SEK/m^3_{fpb}. The expendables per t_{dm} = 100 / 0.420 SEK/t_{dm} = 238.10 SEK/t_{dm}.

d Costs of human services at saw milling were assumed as 200 SEK/m^3_{fpb}. Costs of human services per t_{dm} = 200 / 0.420 SEK/t_{dm} = 467.19 SEK/t_{dm}.

e Capital investment at saw milling was assumed as 100 SEK/m^3_{fpb}. Capital investment per t_{dm} = 100 / 0.420 SEK/t_{dm} = 238.10 SEK/t_{dm}.

f Dry matter losses at storage = 1.8% (see Table A.G-1, footnote d). 0.018 x 1.99 x 10^{10} J/t_{dm} = 3.58 x 10^8 J/t_{dm}.

Y_5 $HHV_{Wood\ chips}$ = 19.9 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_4 + F_5) = (171.54 + 24.06 + 0.03 + 37.60 + 75.19 + 37.60 + 2.94) x10^{12} sej/t_{dm} = 348.96 x 10^{12} sej/t_{dm}. Solar transformity = 348.96 x 10^{12} / 1.99 x 10^{10} sej/J = 17,536 sej/J.

F_6 Road transport:

g Direct energy required = 148.89 MJ/t_{dm} (see Table A.J-38c).

h Mass depreciation of machinery = 0.072 kg/t_{dm} (see Table A.J-38c). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.43 MJ/t_{dm} (see Table A.J-38c).

i Costs for human services = O & M costs = 94.83 SEK/t_{dm} (see Table A.J-38c).

j Capital costs = 19.66 SEK/t_{dm} (see Table A.J-38c).

Y_6 Tree biomass yield: HHV = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (348.96 + 7.13 + 0.19 + 14.97 + 3.10) x 10^{12} sej/t_{dm} = 374.36 x 10^{12} sej/t_{dm}. Solar transformity = 374.36 x 10^{12} / 1.99 x 10^{10} sej/J = 18,812 sej/J.

Table A.I-9. *Emergy, energy and cost analysis of sawdust*

Sawdust		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
Biomass input	**2.09E+10 J/t_{dm}**	**8208 sej/J**	**171.54**		**Primary energy**	**250.61**	**27.21**	**223.38**	
F5 Saw milling			**176.28**			**300.00**		**714.29**	
a Electricity	3.00E+08 J/t_{dm}	80,200 sej/J	24.06		1.59	300.00			
b Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/SEK	0.03						
c Expendables	238 SEK/t_{dm}	1.58E+11 sej/SEK	37.60					238.10	
d Human services	476 SEK/t_{dm}	1.58E+11 sej/SEK	75.19					476.19	
e Capital investment	238 SEK/t_{dm}	1.58E+11 sej/J	37.60					238.10	
f Handling and storage losses	2.19E+08	8208 sej/J	1.80						
Y5 Tree biomass yield	1.99E+10 J/t_{dm}	17,478 sej/J	347.82		Sum of prim. en.	727.61	27.21	937.67	
F6 Road transport			**25.40**			**148.89**	**4.43**	**114.49**	
g Motor fuel	1.49E+08 J/t_{dm}	47,900 sej/J	7.13		1.14	148.89			
h Machines, equipment	0.0715 kg/t_{dm}	2.60E+12 sej/kg	0.19				4.43		
i Human services	94.83 SEK/t_{dm}	1.58E+11 sej/SEK	14.97					94.83	
j Capital investment	19.66 SEK/t_{dm}	1.58E+11 sej/SEK	3.10					19.66	
Y6 Tree biomass yield	1.99E+10 J/t_{dm}	18,755 sej/J	373.22		Sum of prim. en.	897.35	31.64	1052.15	
					Direct + embodied prim. en.	928.99			
					E(output, primary)/E(input, primary)	21.4			

Table A.I-9 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1+F2+F3+F4 from FinalFell [x 10^{12} sej/t_{dm}]	47.0	47.0	47.0	47.0	47.0
F5 [x 10^{12} sej/t_{dm}]	176.3	176.3	176.3	176.3	176.3
F6 [x 10^{12} sej/t_{dm}]	25.4	25.4	25.4	25.4	25.4
F7 (Conversion) [x 10^{12} sej/t_{dm}]	144.1	103.2	147.5	195.8	184.9
Solar emergy yields of products					
Y5 [x 10^{12} sej/t_{dm}]	347.8	347.8	347.8	347.8	347.8
Y6 [x 10^{12} sej/t_{dm}]	373.2	373.2	373.2	373.2	373.2
Y7 (Final product) [x 10^{12} sej/t_{dm}]	517.3	476.4	520.7	569.0	558.1
Solar transformities					
(e) After saw milling [sej/J]	17,478	17,478	17,478	17,478	17,478
(f) After road transport [sej/J]	18,755	18,755	18,755	18,755	18,755
(g) After conversion [sej/J]	31,479	80,715	56,043	40,428	47,596
(g) Heat generated at CHP [sej/J]		35,865			
Net solar emergy yield ratio					
V After saw milling	1.56	1.56	1.56	1.56	1.56
VI. After road transport	1.50	1.50	1.50	1.50	1.50
VII. After conversion	1.32	1.35	1.31	1.28	1.29
Solar emergy investment ratio					
V. After saw milling	1.79	1.79	1.79	1.79	1.79
VI. After road transport	2.00	2.00	2.00	2.00	2.00
VII. After conversion	3.15	2.83	3.18	3.57	3.48
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1108.44	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	16.43	5.90	9.29	14.07	11.73
Amount of heat produced at CHP [GJ/t_{dm}]		13.28			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	1.19	0.43	0.67	1.02	0.85
Amount of heat produced at CHP [GJ/(ha x year)]		0.96			
E(output)/E(primary energy input including biomass)	78.0%	88.6%	42.4%	62.7%	53.1%
E(output)/E(primary energy input excluding biomass)	13.9	11.0	4.6	5.6	5.4
Cost of energy carrier					
SEK/GJ	114.41	92.91	175.39	126.30	155.66
SEK/MWh	411.86	334.48	631.39	454.69	560.36
€/GJ	12.55	10.19	19.23	13.85	17.07
Cost of heat at CHP					
SEK/GJ		67.25			
SEK/MWh		242.09			
€/GJ		7.37			

Footnotes to Table A.I-9

Biomass input:

$HHV_{Roundwood}$ = 20.9 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the biomass after road transport of roundwood (Y_4 in Table A.I-1). Solar emergy = (annual flow) x (solar transformity)

F_5 Saw milling:

a–e See footnotes to Table A.I-8.

f Dry matter losses at storage = 1.1% (see Table A.G-1, footnote e). 0.011 x 1.99 x 10^{10} J/t_{dm} = 2.19 x 10^8 J/t_{dm}.

Y_5 $HHV_{Sawdust}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_4 + F_5) = (171.54 + 24.06 + 0.03 + 37.60 + 75.19 + 37.60 + 1.80) x 10^{12} sej/t_{dm} = 347.82 x 10^{12} sej/t_{dm}. Solar transformity = 347.82 x 10^{12} / 1.99 x 10^{10} sej/J = 17,478 sej/J.

F_6 Road transport:

g Direct energy required = 148.89 MJ/t_{dm} (see Table A.J-38c).

h Mass depreciation of machinery = 0.072 kg/t_{dm} (see Table A.J-38c). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.43 MJ/t_{dm} (see Table A.J-38c).

i Costs for human services = O & M costs = 94.83 SEK/t_{dm} (see Table A.J-38c).

j Capital costs = 19.66 SEK/t_{dm} (see Table A.J-38c).

Y_6) Tree biomass yield: HHV = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (347.82 + 7.13 + 0.19 + 14.97 + 3.10) x 10^{12} sej/t_{dm} = 373.22 x 10^{12} sej/t_{dm}. Solar transformity = 373.22 x 10^{12} / 1.99 x 10^{10} sej/J = 18,755 sej/J.

Table A.I-10. *Emergy, energy and cost analysis of bark*

Bark	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	Solar emergy [10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	Cost analysis [SEK/t_{dm}]	Cost analysis [SEK/ha/yr]
Biomass input	**2.09E+10 J/t_{dm}**	**8208 sej/J**	**171.54**		**Primary energy**	**250.61**	**27.21**	**223.38**	
F5 Saw milling			**181.04**			**300.00**		**714.29**	
a Electricity	3.00E+08 J/t_{dm}	80,200 sej/J	24.06		1.59	300.00			
b Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/SEK	0.03						
c Expendables	238 SEK/t_{dm}	1.58E+11 sej/SEK	37.60					238.10	
d Human services	476 SEK/t_{dm}	1.58E+11 sej/SEK	75.19					476.19	
e Capital investment	238 SEK/t_{dm}	1.58E+11 sej/J	37.60					238.10	
f Handling and storage losses	8.00E+08	8208 sej/J	6.56						
Y5 Tree biomass yield	2.05E+10 J/t_{dm}	17,199 sej/J	352.58		Sum of prim. en.	727.61	27.21	937.67	
F6 Road transport			**25.81**			**151.32**	**4.50**	**116.35**	
g Motor fuel	1.51E+08 J/t_{dm}	47,900 sej/J	7.25		1.14	151.32			
h Machines, equipment	0.073 kg/t_{dm}	2.60E+12 sej/kg	0.19				4.50		
i Human services	96.37 SEK/t_{dm}	1.58E+11 sej/SEK	15.22					96.37	
j Capital investment	19.98 SEK/t_{dm}	1.58E+11 sej/SEK	3.16					19.98	
Y6 Tree biomass yield	2.05E+10 J/t_{dm}	18,458 sej/J	378.39		Sum of prim. en.	900.11	31.72	1054.02	
					Direct + embodied prim. en.	931.83			
					E(output, primary)/E(input, primary)	22.0			

Table A.I-10 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1+F2+F3+F4 from FinalFell [x 10^{12} sej/t_{dm}]	47.0	47.0	47.0	47.0	47.0
F5 [x 10^{12} sej/t_{dm}]	181.0	181.0	181.0	181.0	181.0
F6 [x 10^{12} sej/t_{dm}]	25.8	25.8	25.8	25.8	25.8
F7 (Conversion) [x 10^{12} sej/t_{dm}]	148.1	104.9	125.3	199.3	188.6
Solar emergy yields of products					
Y5 [x 10^{12} sej/t_{dm}]	352.6	352.6	352.6	352.6	352.6
Y6 [x 10^{12} sej/t_{dm}]	378.4	378.4	378.4	378.4	378.4
Y7 (Final product) [x 10^{12} sej/t_{dm}]	526.4	483.2	503.7	577.7	567.0
Solar transformities					
(e) After saw milling [sej/J]	17,199	17,199	17,199	17,199	17,199
(f) After road transport [sej/J]	18,458	18,458	18,458	18,458	18,458
(g) After conversion [sej/J]	31,097	79,477	52,629	39,841	46,938
(g) Heat generated at CHP [sej/J]		35,315			
Net solar emergy yield ratio					
V. After saw milling	1.55	1.55	1.55	1.55	1.55
VI. After road transport	1.49	1.49	1.49	1.49	1.49
VII. After conversion	1.31	1.35	1.33	1.27	1.28
Solar emergy investment ratio					
V. After saw milling	1.83	1.83	1.83	1.83	1.83
VI. After road transport	2.04	2.04	2.04	2.04	2.04
VII. After conversion	3.23	2.88	3.05	3.64	3.55
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1141.86	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	16.93	6.08	9.57	14.50	12.08
Amount of heat produced at CHP [GJ/t_{dm}]		13.68			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	1.92	0.69	1.09	1.65	1.37
Amount of heat produced at CHP [GJ/(ha x year)]		1.55			
E(output)/E(primary energy input including biomass)	78.1%	88.8%	42.4%	62.9%	53.3%
E(output)/E(primary energy input excluding biomass)	14.3	11.3	4.6	5.7	5.6
Cost of energy carrier					
SEK/GJ	112.64	91.33	154.66	124.24	153.19
SEK/MWh	405.51	328.80	556.79	447.27	551.47
€/GJ	12.35	10.02	16.96	13.62	16.80
Cost of heat at CHP					
SEK/GJ		65.67			
SEK/MWh		236.41			
€/GJ		7.20			

Footnotes to Table A.I-10

Biomass input:

$HHV_{Roundwood}$ = 20.9 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the biomass after road transport of roundwood (Y_4 in Table A.I-1). Solar emergy = (annual flow) x (solar transformity)

F_5 Saw milling:

a–e See footnotes to Table A.I-8.

f Dry matter losses at storage = 3.9% (see Table A.G-1, footnote f). 0.039 x 2.05 x 10^{10} J/t_{dm} = 8.00 x 10^8 J/t_{dm}.

Y_5 HHV_{Bark} = 20.5 MJ/kg_{dm} (see Table A.B-1). Solar emergy = solar emergy of (Y_4 + F_5) = (171.54 + 24.06 + 0.03 + 37.60 + 75.19 + 37.60 + 6.56) x 10^{12} sej/t_{dm} = 352.58 x 10^{12} sej/t_{dm}. Solar transformity = 352.58 x 10^{12} / 2.05 x 10^{10} sej/J = 17,199 sej/J.

F_6 Road transport:

g Direct energy required = 151.32 MJ/t_{dm} (see Table A.J-38c).

h Mass depreciation of machinery = 0.073 kg/t_{dm} (see Table A.J-38c). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in machinery = 4.50 MJ/t_{dm} (see Table A.J-38c).

i Costs for human services = O & M costs = 96.37 SEK/t_{dm} (see Table A.J-38c).

j Capital costs = 19.98 SEK/t_{dm} (see Table A.J-38c).

Y_6 Tree biomass yield: HHV = 20.5 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (352.58 + 7.25 + 0.19 + 15.22 + 3.16) x 10^{12} sej/t_{dm} = 378.39 x 10^{12} sej/t_{dm}. Solar transformity = 378.39 x 10^{12} / 2.05 x 10^{10} sej/J = 18,458 sej/J.

Table A.I-11. *Emergy, energy and cost analysis of willow farming*

Willow farming (Short rotation forestry)		Emergy analysis				Energy analysis			Cost analysis	
		Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
I	**Environmental inputs**			**40.25**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature’s contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
F1	**Agriculture**			**88.26**	**772.81**		**67.61**	**457.74**		**1732.10**
d	Willow cuttings	3.88E+08 J/ha	8524 sej/J		3.31			47.39		
e	Fertilizers	93.77 kg/ha	4.88E+12 sej/kg		457.40			387.04		
f	Herbicides	1.34E+08 J/ha	66,000 sej/J		8.85			16.11		
g	Motor fuel	5.62E+08 J/ha	47,900 sej/J		26.94	1.14	67.61			
h	Machines	1.139 kg/ha	2.46E+12 sej/kg		2.81			7.21		
i	Expendables	1069.95 SEK/ha	1.58E+11 sej/SEK		168.95					1069.95
j	Human services	515.35 SEK/ha	1.58E+11 sej/SEK		81.38					515.35
k	Capital investment	146.80 SEK/ha	1.58E+11 sej/SEK		23.18					146.80
Y1	Willow production	1.72E+11 J/ha	6557 sej/J	128.51	1125.25	Sum of prim. en.	77.07	457.74	208.23	1732.10
F2	**Harvesting and field transport**			**12.61**	**104.91**		**49.94**	**4.06**	**49.02**	**407.74**
l	Motor fuel	4.15E+08 J/ha	47,900 sej/J		19.90	1.14	49.94			
m	Machines	0.744 kg/ha	2.01E+12 sej/kg		1.50			4.06		
n	Human serivces	230.70 SEK/ha	1.58E+11 sej/SEK		36.43					230.70
o	Capital investment	177.04 SEK/ha	1.58E+11 sej/SEK		27.95					177.04
p	Handling and storage losses	2.92E+09 J/ha	6557 sej/J		19.13					
Y2	Willow yield	1.63E+11 J/ha	7545 sej/J	141.12	1230.15	Sum of prim. en.	134.00	461.80	257.25	2139.83

Table A.I-11 *continued*

F3	**Road transport**			**25.96**			**146.47**	**4.75**	**219.68**
q	Motor fuel	1.46E+08 J/t_{dm}	47,900 sej/J	7.02		1.14	146.47		
r	Truck	0.077 kg/t_{dm}	2.60E+12 sej/kg	0.20				4.75	
s	Human services	98.69 SEK/t_{dm}	1.58E+11 sej/SEK	15.58					98.69
t	Capital investment	19.99 SEK/t_{dm}	1.58E+11 sej/SEK	3.16					19.99
Y3	Tree biomass yield	1.96E+10 J/t_{dm}	8524 sej/J	167.08	Sum of prim. en.		300.98	466.55	476.93
F4	**Comminution**			**7.02**			**54.78**		**27.65**
u	Motor fuel	5.48E+07 J/t_{dm}	47,900 sej/J	2.62		1.14	54.78		
v	Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/kg	0.03					
w	Human services	23.79 SEK/t_{dm}	1.58E+11 sej/SEK	3.76					23.79
x	Capital investment	3.85 SEK/t_{dm}	1.58E+11 sej/SEK	0.61					3.85
Y4	Tree biomass yield	1.96E+10 J/t_{dm}	8883 sej/J	174.10	Sum of prim. en.		363.43	466.55	504.58
					Direct + embodied prim. en.		829.98		
					E(output, primary)/E(input, primary)		23.6		

Table A.I-11 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	40.3	40.3	40.3	40.3	40.3
Inputs fed back from society (*i.e.* purchased)					
F1 [x 10^{12} sej/t_{dm}]	88.3	88.3	88.3	88.3	88.3
F2 [x 10^{12} sej/t_{dm}]	12.6	12.6	12.6	12.6	12.6
F3 [x 10^{12} sej/t_{dm}]	26.0	26.0	26.0	26.0	26.0
F4 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F5 (Conversion) [x 10^{12} sej/t_{dm}]	142.1	102.4	145.3	194.1	183.1
Solar emergy yields of products					
Y1 [x 10^{12} sej/t_{dm}]	128.5	128.5	128.5	128.5	128.5
Y2 [x 10^{12} sej/t_{dm}]	141.1	141.1	141.1	141.1	141.1
Y3 [x 10^{12} sej/t_{dm}]	167.1	167.1	167.1	167.1	167.1
Y4 [x 10^{12} sej/t_{dm}]	174.1	174.1	174.1	174.1	174.1
Y5 (Final product) [x 10^{12} sej/t_{dm}]	316.2	276.5	319.4	368.2	357.2
Solar transformities					
(a) Cultivation [sej/J]	6557	6557	6557	6557	6557
(b) After harvesting and field transp. [sej/J]	7545	7545	7545	7545	7545
(c) After road transport [sej/J]	8524	8524	8524	8524	8524
(d) After comminution [sej/J]	8883	8883	8883	8883	8883
(e) After conversion [sej/J]	19,536	47,556	34,899	26,559	30,925
(e) Heat generated at CHP [sej/J]		21,131			
Net solar emergy yield ratio					
I. Cultivation	1.46	1.46	1.46	1.46	1.46
II. After harvesting and field transport	1.40	1.40	1.40	1.40	1.40
III. After road transport	1.32	1.32	1.32	1.32	1.32
IV. After comminution	1.30	1.30	1.30	1.30	1.30
V. After conversion	1.15	1.17	1.14	1.12	1.13
Solar emergy investment ratio					
I. Cultivation	2.19	2.19	2.19	2.19	2.19
II. After harvesting and field transport	2.51	2.51	2.51	2.51	2.51
III. After road transport	3.15	3.15	3.15	3.15	3.15
IV. After comminution	3.33	3.33	3.33	3.33	3.33
V. After conversion	6.86	5.87	6.93	8.15	7.87
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1091.73	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	16.19	5.81	9.15	13.86	11.55
Amount of heat produced at CHP [GJ/t_{dm}]		13.08			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	132.49	47.59	74.91	113.48	94.54
Amount of heat produced at CHP [GJ/(ha x year)]		107.09			
E(final product)/E(primary energy input including biomass)	78.3%	88.9%	42.5%	62.9%	53.3%
E(output)/E(primary energy input excluding biomass)	15.0	11.5	4.8	5.7	5.6

Table A.I-11 *continued*

Cost of energy carrier					
SEK/GJ	81.55	64.81	117.28	87.95	109.62
SEK/MWh	293.59	233.30	422.21	316.61	394.63
€/GJ	8.94	7.11	12.86	9.64	12.02
Cost of heat at CHP					
SEK/GJ		39.14			
SEK/MWh		140.91			
€/GJ		4.29			

Footnotes to Table A.I-11

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).
Solar emergy = solar emergy of transpired rain = 352.44 x 10^{12} sej/(ha x year). The production of biomass was assumed as 5% greater than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). The biomass yield received during a 22-year rotation period was assumed as 183 t_{dm}/ha, according to the Swedish Energy Agency (2003c). Thus, the solar emergy = 352.44 x 10^{12} x 0.95 / (183 / 22) sej/t_{dm} = 40.25 x 10^{12} sej/t_{dm}.

F_1 Agricultural inputs:

d The number of cuttings planted = 14,000 ha^{-1} (Sjöström, 2004). Willow cuttings = [(14,000 cuttings/ha planted) / (60 cuttings/stool)] / [(14,000 stools/harvest) x (7 harvests/22 years rotation period)] = 0.24% of total harvested biomass.
(0.0024) x (183 t_{dm} produced/(ha x 22 years)) = 0.4357 t_{dm} cuttings/(ha x 22 years).
(0.4357 t_{dm} cuttings/(ha x 22 years)) x (19.6 x 10^9 J/t_{dm}) / (22 years/rotation period) = 3.882 x 10^8 J/(ha x year) = 388.2 MJ/(ha x year). The solar transformity was assumed as equal to the solar transformity of the willow yield after road transport (Y_3).
The amount of energy required for the production of cuttings was assumed as equal to the amount of diesel oil required for willow production. The total amount of diesel oil required (excluding comminution) = (67.61 + 49.94 + 146.47) MJ/t_{dm} = 264.02 MJ/t_{dm}.
$E_{primary} = E_{diesel\ oil}$ x (Primary energy conversion factor)$_{diesel\ oil}$. $E_{primary}$ = 264.02 x 1.14 MJ/t_{dm} = 300.98 MJ/t_{dm}. $E_{primary,\ total}$ = 300.98 x 0.4357 / 22 MJ/(ha x year = 5.96 MJ/(ha x year).
$E_{Cuttings,\ total}$ = (388.2 + 5.96) MJ/(ha x year) = 394.16 MJ/(ha x year).
$E_{Cuttings,\ total}$ = 394.16 / (183 / 22) MJ/t_{dm} = 47.39 MJ/t_{dm}.

e 80 kg/ha and 120 kg/ha of nitrogen were added seven times respectively during the rotation period (see Chapter 3). Thus, the annual amount of nitrogen added = (80 x 7 + 120 x 7) / 22 kg/(ha x year) = 63.6 kg/(ha x year). Solar transformity for nitrogen in nitrogen fertilizer = 4.60 x 10^{12} sej/kg (Odum, 1996). Solar emergy for N fertilizer = 63.6 x 4.60 x 10^{12} sej/(ha x year) = 292.43 x 10^{12} sej/(ha x year).
22 kg/ha of phosphorus was added seven times during the rotation period (see Chapter 3). Thus, the annual amount of phosphorus added = 22 x 7 / 22 kg/(ha x year) = 7.0 kg/(ha x year). Solar transformity for phosphorus in phosphorus fertilizer = 1.78 x 10^{13} sej/kg (Odum, 1996). Solar emergy for P fertilizer = 7.0 x 1.78 x 10^{13} sej/(ha x year) = 124.60 x 10^{12} sej/(ha x year).
73 kg/ha of potassium was added seven times during the rotation period (see Chapter 3). Thus, the annual amount of potassium added = 73 x 7 / 22 kg/(ha x year) = 23.2 kg/(ha x year). Solar transformity for potassium in potassium fertilizer = 1.74 x 10^{12} sej/kg (Odum, 1996). Solar emergy for K fertilizer = 23.2 x 1.74 x 10^{12} sej/(ha x year) = 40.37 x 10^{12} sej/(ha x year).
Total amount of fertilizer = (63.6 + 7.0 + 23.2) kg/(ha x year) = 93.77 kg/(ha x year).
Total solar emergy = (292.43 + 124.60 + 40.37) x 10^{12} sej/(ha x year) = 457.40 x 10^{12} sej/(ha x year). Total solar transformity for all fertilizers = 457.40 x 10^{12} / 93.77 sej/kg = 4.88 x 10^{12} sej/kg.
Energy embodied in the fertilizers is estimated by Börjesson (1996) to be 48 MJ/kg for

nitrogen, 7.9 MJ/kg for phosphorus and 4.8 MJ/kg for potassium. The energy amount embodied in fertilizers used per hectare and year = (63.6 x 48 + 7.0 x 7.9 + 23.2 x 4.8) MJ/(ha x year) = 3219.46 MJ/(ha x year). The energy amount embodied in fertilizers used per ton of dry matter = 3219.46 / (183 / 22) MJ/t_{dm} = 387.04 MJ/t_{dm}.

f Energy embodied in herbicides is estimated by Börjesson (1996) to be 120 MJ/kg. The total application dose during a rotation period of willow cultivation was 21.0 litre/ha. Density of Roundup Bio = 1.17 kg/l (Monsanto Crop Sciences, 2004 (URL)). The density of cougar was assumed as equal to the density of Roundup Bio. The energy amount embodied in herbicides used per hectare and year = 120 x 1.17 x 21.0 / 22 MJ/(ha x year) = 134.02 MJ/(ha x year). Solar transformity for herbicides = 66,000 sej/J (Doherty, Nilsson & Odum, 2002).
$E_{herbicides}$ = 134.02 / (183 / 22) MJ/t_{dm} = 16.11 MJ/t_{dm}.

g The sum of direct energy required at harrowing, mechanical weed control, clearing of stones, rolling, planting, trimming, spreading of herbicides and fertilizers and rotary cultivation = 562.36 MJ/(ha x year) (see Table A.J-15).The sum of direct energy required per metric ton of dry matter = 562.36 / (183 / 22) MJ/t_{dm} = 67.61 MJ/t_{dm}.

h The mass depreciation of machinery per hectare and year = the wear per hectare x number of operations per rotation period. The sum of mass depreciation of machinery at cultivation of willow = 1.139 kg/(ha x year). Solar transformity for machine equipment = 2.46 x10^{12} sej/kg (see Table A.J-15).
The sum of embodied energy in machinery at harrowing, mechanical weed control, clearing of stones, rolling, planting, trimming, spreading of herbicides, fertilization and rotary cultivation = 7.21 MJ/t_{dm} (see Table A.J-15).

i Total expendables (cuttings, herbicides and fertilizers) = 1069.95 SEK/(ha x year) (see Table A.J-15).

j Costs for human services = variable costs minus expendables = 515.35 SEK/(ha x year) (see Table A.J-15).

k Capital costs = 146.80 SEK/(ha x year) (see Table A.J-15).

Y_1 The production of biomass was assumed as 5% greater than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). Thus, the biomass production = 1.630 x 10^{11} / 0.95 J/(ha x year) = 1.716 x 10^{11} J/(ha x year). Solar emergy = solar emergy of transpired rain + solar emergy of silvicultural inputs = (352.44 x 10^{12} + 772.82 x 10^{12}) sej/(ha x year) = 1125.26 x 10^{12} sej/(ha x year). The yield of biomass = 183 t_{dm}/ha during a 22-year rotation period (see Table 3-2). The annual yield = 183 / 22 t_{dm}/ha = 8.318 t_{dm}/ha. Solar emergy = 1125.26 x 10^{12} x 0.95 / 8.318 sej/t_{dm} = 128.51 x 10^{12} sej/t_{dm}.
Solar transformity = 1.125 x 10^{15} / 1.716 x 10^{11} sej/J = 6557 sej/J.

F_2 Harvesting and field transport:

l The amount of direct energy required at harvesting and field transport of willow = 415.37 MJ/(ha x year) (see Table A.J-28). The sum of direct energy required per metric ton of dry matter = 415.37 / (183 / 22) MJ/t_{dm} = 49.94 MJ/t_{dm}.

m Wear at harvesting and field transport = 2.339 kg/ha (see Table A.J-28). The mass depreciation of machinery = 2.339 x 7 / 22 kg/(ha x year) = 0.744 kg/(ha x year). Solar transformity for machine equipment = 2.01 x 10^9 sej/g (see Table A.J-28).
The sum of embodied energy in machinery at harvesting and field transport = 4.06 MJ/t_{dm} (see Table A.J-28).

n Costs for human services = O & M costs = 230.70 SEK/(ha x year) (see Table A.J-28).

o Capital costs = 177.04 SEK/(ha x year) (see Table A.J-28).

p Dry matter losses at storage = 1.7% (see Table A.G-1, footnote g). 0.017 x 1.96 x 10^{10} J/t_{dm} = 2.92 x 10^9 J/t_{dm}.

Y_2 HHV_{willow} = 19.6 MJ/kg_{dm} (see Table A.B-1c). Thus, the annual yield of biomass = 183 x 19.6 x 10^9 / 22 J/(ha x year) = 1.630 x 10^{11} J/(ha x year). Solar emergy = solar emergy of (Y_1 + F_2) = (1125.26 + 19.90 + 1.50 + 36.43 + 27.95 + 19.13) x 10^{12} sej/(ha x year) = 1230.16 x 10^{12} sej/(ha x year). Solar emergy per metric ton of dry matter = (1125.26 x

0.95 + 19.90 + 1.50 + 36.43 + 27.95 + 19.13) x 10^{12} / 8.318 sej/t_{dm} = 141.12 sej/t_{dm}.
Solar transformity = 1230.16 x 10^{12} / 1.630 x 10^{11} sej/J = 7545 sej/J.

F_3 Road transport:

q Direct energy required per t_{dm} at road transport of willow = 146.47 MJ/t_{dm} (see Table A.J-38b).

r Mass depreciation of machinery = 0.077 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in trucks used = 4.75 MJ/t_{dm} (see Table A.J-38b).

s Costs for human services = O & M costs = 98.69 SEK/t_{dm} (see Table A.J-38b).

t Capital costs = 19.99 SEK/t_{dm} (see Table A.J-38b).

Y_3 HHV_{Willow} = 19.6 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (141.12 + 7.02 + 0.20 + 15.58 + 3.16) x 10^{12} sej/t_{dm} = 167.08 x 10^{12} sej/t_{dm}.
Solar transformity = 167.08 x 10^{12} / 1.96 x 10^{10} sej/J = 8524 sej/J.

F_4 Comminution:

u Direct energy required per t_{dm} at comminution of trees from early thinnings = 54.78 MJ/t_{dm} (see Table A.J-39).

v Mass depreciation of machinery = 0.015 kg/t_{dm}, and the solar transformity for machine equipment = 2.24 x 10^{12} sej/kg (See Table A.J-39).

w Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

x Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_4 HHV_{Willow} = 19.6 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (167.08 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 174.10 x 10^{12} sej/t_{dm}.
Solar transformity = 174.10 x 10^{12} / 1.96 x 10^{10} sej/J = 8883 sej/J.

Table A.I-12. *Emergy, energy and cost analysis of cultivation and handling of reed canary grass*

Reed canary grass		Average annual flows	Solar transformity [sej/unit]	Solar emergy (Emergy analysis) [10^{12} sej/t_{dm}]	Solar emergy (Emergy analysis) [10^{12} sej/ha/yr]	Prim. energy conv. factor (Energy analysis)	Direct energy (Energy analysis) MJ/t_{dm}	Embodied energy (Energy analysis) MJ/t_{dm}	Cost analysis [SEK/t_{dm}]	Cost analysis [SEK/ha/yr]
I	**Environmental inputs**			**54.56**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
F1	**Agriculture**			**95.29**	**615.52**		**84.36**	**455.96**		**1272.68**
d	Seed	1.33E+08 J/ha	16,100 sej/J		2.13			21.60		
e	Fertilizers	81.82 kg/ha	4.71E+12 sej/kg		384.96			422.92		
f	Motor fuel	5.18E+08 J/ha	47,900 sej/J		24.79	1.14	84.36			
g	Machines	1.126 kg/ha	2.37E+12 sej/kg		2.67			11.44		
h	Expendables	693.94 SEK/ha	1.58E+11 sej/SEK		109.58					693.94
i	Human services	459.56 SEK/ha	1.58E+11 sej/SEK		72.57					459.56
j	Capital investment	119.19 SEK/ha	1.58E+11 sej/SEK		18.82					119.19
Y1	Biomass production	1.18E+11 J/ha	8234 sej/J	149.85	967.96	Sum of prim. en.	96.17	455.96	207.40	1272.68
F2	**Harvesting**			**6.68**	**41.00**		**27.62**	**2.26**	**33.34**	**204.59**
k	Motor fuel	1.69E+08 J/ha	47,900 sej/J		8.12	1.14	27.62			
l	Machines	0.220 kg	2.63E+12 sej/kg		0.58			2.26		
m	Human serivces	161.14 SEK/ha	1.58E+11 sej/SEK		25.44					161.14
n	Capital investment	43.45 SEK/ha	1.58E+11 sej/SEK		6.86					43.45
Y2	Biomass yield	1.12E+11 J/ha	9034 sej/J	156.54	1008.96	Sum of prim. en.	127.65	458.23	240.74	1477.27
F3	**Baling. field transport and storage**			**53.88**	**330.63**		**108.70**	**14.60**	**304.03**	**1865.65**
o	Motor fuel	6.67E+08 J/ha	47,900 sej/J		31.95	1.14	108.70			
p	Machines	1.893 kg	2.16E+12 sej/kg		4.09			14.60		
q	Human services	998.45 SEK/ha	1.58E+11 sej/SEK		157.66					998.45
r	Capital investment	867.20 SEK/ha	1.58E+11 sej/SEK		136.93					867.20
Y3	Biomass yield	1.12E+11 J/ha	11,995 sej/J	210.42	1339.60	Sum of prim. en.	251.56	472.82	544.77	3342.91

Table A.I-12 *continued*

F4	**Road transport**			**33.07**		**208.87**	**5.47**	**144.59**
s	Motor fuel	2.09E+08 J/t_{dm}	47,900 sej/J	10.01	1.14	208.87		
t	Truck	0.088 kg/t_{dm}	2.60E+12 sej/kg	0.23			5.47	
u	Human services	121.55 SEK/t_{dm}	1.58E+11 sej/SEK	19.19				121.55
v	Capital investment	23.04 SEK/t_{dm}	1.58E+11 sej/SEK	3.64				23.04
Y4	Biomass yield	1.82E+10 J/t_{dm}	13,378 sej/J	243.48	Sum of prim. en.	489.68	478.29	689.37
F5	**Comminution**			**20.31**		**105.88**		**73.78**
w	Electricity	1.06E+08 J/t_{dm}	80,200 sej/J	8.49	1.59	105.88		
x	Machines, equipment	0.072 kg/t_{dm}	2.26E+12 sej/kg	0.16				
y	Human services	59.63 SEK/t_{dm}	1.58E+11 sej/SEK	9.42				59.63
z	Capital investment	14.15 SEK/t_{dm}	1.58E+11 sej/SEK	2.23				14.15
Y5	Biomass yield	1.82E+10 J/t_{dm}	14,494 sej/J	263.79	Sum of prim. en.	658.03	478.29	763.15
					Direct + embodied prim. en.	1136.32		
					E(output, primary)/E(input, primary)	16.0		

Table A.I-12 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	54.6	54.6	54.6	54.6	54.6
Inputs fed back from society (*i.e.* purchased)					
F1 [x 10^{12} sej/t_{dm}]	95.3	95.3	95.3	95.3	95.3
F2 [x 10^{12} sej/t_{dm}]	6.7	6.7	6.7	6.7	6.7
F3 [x 10^{12} sej/t_{dm}]	53.9	53.9	53.9	53.9	53.9
F4 [x 10^{12} sej/t_{dm}]	33.1	33.1	33.1	33.1	33.1
F5 [x 10^{12} sej/t_{dm}]	20.3	20.3	20.3	20.3	20.3
F6 (Conversion) [x 10^{12} sej/t_{dm}]	132.9	98.5	134.9	186.0	174.5
Solar emergy yields of products					
Y1 [x 10^{12} sej/t_{dm}]	149.9	149.9	149.9	149.9	149.9
Y2 [x 10^{12} sej/t_{dm}]	156.5	156.5	156.5	156.5	156.5
Y3 [x 10^{12} sej/t_{dm}]	210.4	210.4	210.4	210.4	210.4
Y4 [x 10^{12} sej/t_{dm}]	243.5	243.5	243.5	243.5	243.5
Y5 [x 10^{12} sej/t_{dm}]	263.8	263.8	263.8	263.8	263.8
Y6 (Final product) [x 10^{12} sej/t_{dm}]	396.7	362.3	398.7	449.8	438.2
Solar transformities					
(a) Cultivation [sej/J]	8234	8234	8234	8234	8234
(b) After harvesting [sej/J]	9034	9034	9034	9034	9034
(c) After baling, field transport and storage [sej/J]	11,995	11,995	11,995	11,995	11,995
(d) After road transport [sej/J]	13,378	13,378	13,378	13,378	13,378
(e) After comminution [sej/J]	14,494	14,494	14,494	14,494	14,494
(f) After conversion [sej/J]	26,391	67,111	46,917	34,941	40,863
(f) Heat generated at CHP [sej/J]		29,820			
Net solar emergy yield ratio					
I. Cultivation	1.57	1.57	1.57	1.57	1.57
II After harvesting	1.54	1.54	1.54	1.54	1.54
III. After baling, field transport and storage	1.35	1.35	1.35	1.35	1.35
IV. After road transport	1.29	1.29	1.29	1.29	1.29
V. After comminution	1.26	1.26	1.26	1.26	1.26
VI. After conversion	1.16	1.18	1.16	1.14	1.14
Solar emergy investment ratio					
I Cultivation	1.75	1.75	1.75	1.75	1.75
II. After harvesting	1.87	1.87	1.87	1.87	1.87
III. After baling, field transport and storage	2.86	2.86	2.86	2.86	2.86
IV. After road transport	3.46	3.46	3.46	3.46	3.46
V. After comminution	3.83	3.83	3.83	3.83	3.83
VI. After conversion	6.27	5.64	6.31	7.24	7.03
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1013.75	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	15.03	5.40	8.50	12.87	10.72
Amount of heat produced at CHP [GJ/t_{dm}]		12.15			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	92.58	33.25	52.34	79.29	66.06
Amount of heat produced at CHP [GJ/(ha x year)]		74.83			

Table A.I-12 *continued*

E(output)/E(primary energy input including biomass)	76.7%	87.1%	41.8%	61.5%	52.1%
E(output)/E(primary energy input excluding biomass)	10.8	9.0	4.0	4.7	4.5
Cost of energy carrier					
SEK/GJ	101.16	81.77	151.95	110.83	137.09
SEK/MWh	364.16	294.37	547.03	399.00	493.53
€/GJ	11.09	8.97	16.66	12.15	15.03
Cost of heat at CHP					
SEK/GJ		56.11			
SEK/MWh		201.99			
€/GJ		6.15			

Footnotes to Table A.I-12

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).
Solar emergy = solar emergy of transpired rain = 352.44 x 10^{12} sej/(ha x year). The production of biomass was assumed as 5% greater than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). The biomass yield received during an 11-year rotation period was assumed as 67.5 t_{dm}/ha, according to Olsson *et al.* (2001). Thus, the solar emergy = 352.44 x 10^{12} x 0.95 / (67.5 / 11) sej/t_{dm} = 54.56 x 10^{12} sej/t_{dm}.

F_1 Agricultural inputs:

d The amount of seeds used in reed canary grass cultivation = 15 kg/ha (Olsson *et al.,* 2001). HHV of the seeds was assumed as equal to the HHV of reed canary grass, *i.e.* 18.2 MJ/kg_{dm}. The moisture content of the seeds was assumed as 0%. $E_{Seeds,\ content}$ = 15 x 18.2 / 11 MJ/(ha x year) = 24.82 MJ/(ha x year).
The energy use in production of reed canary grass seeds was estimated by Börjesson (1996) to be 79 MJ/kg. $E_{Seed\ production}$ = 79 x 15 / 11 MJ/(ha x year) = 107.73 MJ/(ha x year).
$E_{Seeds,\ total}$ = (24.82 + 107.73) MJ/(ha x year) = 132.55 MJ/(ha x year). The solar transformity of seeds = 16,100 sej/J (Andresen, Björklund & Rydberg, 2000).
$E_{Seeds,\ total}$ = 132.55 / (67.5 / 11) MJ/t_{dm} = 21.60 MJ/t_{dm}.

e 540 kg/ha of nitrogen was added during the rotation period (see Chapter 3). Thus, the annual, average amount of nitrogen added = 540 / 11 kg/(ha x year) = 49.09 kg/(ha x year). Solar transformity for nitrogen in nitrogen fertilizer = 4.60 x 10^{12} sej/kg (Odum, 1996). Solar emergy for N fertilizer = 49.09 x 4.60 x 10^{12} sej/(ha x year) = 225.8 x 10^{12} sej/(ha x year).
70 kg/ha of phosphorus was added during the rotation period (see Chapter 3). Thus, the annual, average amount of phosphorus added = 70 / 11 kg/(ha x year) = 6.36 kg/(ha x year). Solar transformity for phosphorus in phosphorus fertilizer = 1.78 x 10^{13} sej/kg (Odum, 1996). Solar emergy for P fertilizer = 6.36 x 1.78 x 10^{13} sej/(ha x year) = 113.3 x 10^{12} sej/(ha x year).
290 kg/ha of potassium was added during the rotation period (see Chapter 3). Thus, the annual, average amount of potassium added = 290 / 11 kg/(ha x year) = 26.36 kg/(ha x year). Solar transformity for potassium in potassium fertilizer = 1.74 x 10^{12} sej/kg (Odum, 1996). Solar emergy for K fertilizer = 26.36 x 1.74 x 10^{12} sej/(ha x year) = 45.9 x 10^{12} sej/(ha x year).
Total amount of fertilizer = (49.09 + 6.36 + 26.36) kg/(ha x year) = 81.82 kg/(ha x year). Total solar emergy = (225.8 + 113.3 + 45.9) x 10^{12} sej/(ha x year) = 385.0 x 10^{12} sej/(ha x year). Total solar transformity for all fertilizers = 385.0 x 10^{12} / 81.82 sej/kg = 4.71 x 10^{12} sej/kg.
Energy embodied in the fertilizers is estimated by Börjesson (1996) to be 48 MJ/kg for

nitrogen, 7.9 MJ(kg for phosphorus and 4.8 MJ/kg for potassium. The energy amount embodied in fertilizers used per hectare and year = (49.1 x 48 + 6.4 x 7.9 + 26.4 x 4.8) MJ/(ha x year) = 2595.18 MJ/(ha x year). The energy amount embodied in fertilizers used per ton of dry matter = 2595.18 / (67.5 / 11) MJ/t_{dm} = 422.92 MJ/t_{dm}.

f The sum of direct energy required at harrowing, rolling, sowing, fertilization, disk harrow ploughing and ploughing = 517.64 MJ/(ha x year) (see Table A.J-16a).The sum of direct energy required per metric ton of dry matter = 517.64 / (67.5 / 11) MJ/t_{dm} = 84.36 MJ/t_{dm}.

g The mass depreciation of machinery per hectare and year = the wear per hectare x number of operations per rotation period. The sum of mass depreciation of machinery at cultivation of reed canary grass = 1.126 kg/(ha x year). Solar transformity for machine equipment = 2.37 x10^{12} sej/kg (see Table A.J-16a).
The sum of embodied energy in machinery at harrowing, rolling, sowing, fertilization, disk harrow ploughing and ploughing = 11.44 MJ/t_{dm} (see Table A.J-16a).

h Total expendables (seeds and fertilizers) = 693.94 SEK/(ha x year) (see Table A.J-16a).

i Costs for human services = variable costs minus expendables = 459.56 SEK/(ha x year) (see Table A.J-16a).

j Capital costs = 119.19 SEK/(ha x year) (see Table A.J-16a).

Y_1 The production of biomass was assumed as 5% greater than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). Thus, the biomass production = 1.117 x 10^{11} / 0.95 J/(ha x year) = 1.176 x 10^{11} J/(ha x year). Solar emergy = solar emergy of transpired rain + solar emergy of agricultural inputs = (352.44 x 10^{12} + 615.52 x 10^{12}) sej/(ha x year) = 967.96 x 10^{12} sej/(ha x year). The yield of biomass = 67.5 t_{dm}/ha during a 11-year rotation period (see Table 3-3). The annual yield = 67.5 / 11 t_{dm}/ha = 6.136 t_{dm}/ha. Solar emergy = 967.96 x 10^{12} x 0.95 / 6.136 sej/t_{dm} = 149.85 x 10^{12} sej/t_{dm}.
Solar transformity = 967.96 x 10^{12} / 1.176 x 10^{11} sej/J = 8234 sej/J.

F_2 Harvesting:

k The amount of direct energy required = 169.46 MJ/(ha x year) (see Table A.J-29). The sum of direct energy required per metric ton of dry matter = 169.46 / (67.5 / 11) MJ/t_{dm} = 27.62 MJ/t_{dm}.

l Wear = 0.269 kg/ha (see Table A.J-29). Mass depreciation of machinery = 0.269 x 9 / 11 kg/(ha x year) = 0.220 kg/(ha x year). Solar transformity for machine equipment = 2.63 x10^{12} sej/kg, and the sum of embodied energy in machinery = 2.26 MJ/t_{dm} (see Table A.J-29).

m Costs for human services = O & M costs = 161.14 SEK/(ha x year) (see Table A.J-29).

n Capital costs = 43.45 SEK/(ha x year) (see Table A.J-29**)**.

Y_2 HHV_{reed} canary grass = 18.2 MJ/kg_{dm} (see Table A.B-1c). Thus, the annual yield of biomass = 67.5 x 18.2 x 10^9 / 11 J/(ha x year) = 1.117 x 10^{11} J/(ha x year). Solar emergy = solar emergy of (Y_1 + F_2) = (967.96 + 8.12 + 0.58 + 25.44 + 6.86) x 10^{12} sej/(ha x year) = 1008.96 x 10^{12} sej/(ha x year). Solar emergy per metric ton of dry matter = (967.96 x 0.95 + 8.12 + 0.58 + 25.44 + 6.86) x 10^{12} / 6.136 sej/t_{dm} = 156.54 x 10^{12} sej/t_{dm}.
Solar transformity = 1008.96 x 10^{12} / 1.117 x 10^{11} sej/J = 9034 sej/J.

F_3 Baling, field transport and storage:

o The amount of direct energy required at baling and field transport of reed canary grass = 667.01 MJ/(ha x year) (see Table A.J-16b). The sum of direct energy required per metric ton of dry matter = 667.01 / (67.5 / 11) MJ/t_{dm} = 108.70 MJ/t_{dm}.

p Mass depreciation of machinery at baling and field transport = 1.893 kg/(ha x year), the solar transformity for machine equipment = 2.16 x 10^9 sej/g and the sum of embodied energy in machinery at baling and field transport = 14.60 MJ/t_{dm} (see Table A.J-16b).

q Costs for human services = O & M costs = 998.45 SEK/(ha x year) (see Table A.J-16b**)**.

r Capital costs = 867.20 SEK/(ha x year) (see Table A.J-16b**)**.

Y_3 The annual yield of biomass = 1.117 x 10^{11} J/(ha x year) (see Y_2). Solar emergy = solar emergy of (Y_2 + F_3) = (1008.96 + 31.95 + 4.09 + 157.66 + 136.93) x 10^{12} sej/(ha x year)

= 1339.60 x 10^{12} sej/(ha x year). Solar emergy per metric ton of dry matter = (156.54 + (31.95 + 4.09 + 157.66 + 136.93) / 6.136) x 10^{12} sej/t_{dm} = 210.42 x 10^{12} sej/t_{dm}.
Solar transformity = 1339.60 x 10^{12} / 1.117 x 10^{11} sej/J = 11,995 sej/J.

F_4 Road transport:

s Direct energy required = 208.87 MJ/t_{dm} (see Table A.J-38b).

t Mass depreciation of machinery = 0.088 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7).
The amount of embodied energy in trucks used = 5.47 MJ/t_{dm} (see Table A.J-38b).

u Costs for human services = O & M costs = 121.55 SEK/t_{dm} (see Table A.J-38b).

v Capital costs = 23.04 SEK/t_{dm} (see Table A.J-38b).

Y_4 $HHV_{reed\ canary\ grass}$ = 18.2 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (210.42 + 10.01 + 0.23 + 19.19 + 3.64) x 10^{12} sej/t_{dm} = 243.48 x 10^{12} sej/t_{dm}.
Solar transformity = 243.48 x 10^{12} / 1.82 x 10^{10} sej/J = 13,378 sej/J.

F_5 Comminution:

w Direct energy required = 105.88 MJ/t_{dm} (see Table A.J-40).

x Mass depreciation of machinery = 0.072 kg/t_{dm}, and the solar transformity for machine equipment = 2.26 x 10^{12} sej/kg (See Table A.J-40).

y Costs for human services = O & M costs = 59.63 SEK/t_{dm} (see Table A.J-40).

z Capital costs = 14.15 SEK/t_{dm} (see Table A.J-40).

Y_5 $HHV_{reed\ canary\ grass}$ = 18.2 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_4 + F_5) = (243.48 + 8.49 + 0.16 + 9.42 + 2.23) x 10^{12} sej/t_{dm} = 263.79 x 10^{12} sej/t_{dm}.
Solar transformity = 263.79 x 10^{12} / 1.82 x 10^{10} sej/J = 14,494 sej/J.

Table A.I-13. *Emergy, energy and cost analysis of handling of straw*

Straw			Emergy analysis			Energy analysis			Cost analysis	
		Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
I	**Environmental inputs**			**62.02**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
F1	**Agriculture**			**347.05**	**1972.09**		**510.73**	**2226.59**		**3375.25**
d	Wheat seeds	4.70E+09 J/ha	16,100 sej/J		75.67			870.64		
e	Fertilizers	323.00 kg/ha	3.78E+12 sej/kg		1220.80			1320.72		
f	Herbicides	1.20E+08 J/ha	66,000 sej/J		7.92			22.23		
g	Motor fuel	2.76E+09 J/ha	47,900 sej/J		132.07	1.14	510.73			
h	Machines	1.126 kg/ha	2.37E+12 sej/kg		2.67			13.00		
i	Expendables	2796.50 SEK/ha	1.58E+11 sej/SEK		441.58					2796.50
j	Human services	459.56 SEK/ha	1.58E+11 sej/SEK		72.57					459.56
k	Capital investment	119.19 SEK/ha	1.58E+11 sej/SEK		18.82					119.19
Y1	Biomass production	1.05E+11 J/ha	22,112 sej/J	409.07	2324.53	Sum of prim. en.	582.24	2226.59	625.24	3375.25
F2	**Harvesting**			**20.11**	**108.54**		**108.30**	**5.89**	**92.91**	**501.55**
l	Motor fuel	5.85E+08 J/ha	47,900 sej/J		28.01	1.14	108.30			
m	Machines	0.738 kg	1.81E+12 sej/kg		1.34			5.89		
n	Human serivces	297.60 SEK/ha	1.58E+11 sej/SEK		46.99					297.60
o	Capital investment	203.94 SEK/ha	1.58E+11 sej/SEK		32.20					203.94
Y2	Biomass yield	9.99E+10 J/ha	24,362 sej/J	429.18	2433.07	Sum of prim. en.	705.70	2232.47	718.14	3876.79
F3	**Baling. field transport and storage**			**80.82**	**349.03**		**188.77**	**60.21**	**304.10**	**1931.40**
p	Motor fuel	8.15E+08 J/ha	47,900 sej/J		39.05	1.14	188.77			
q	Machines	2.313 kg	2.16E+12 sej/kg		5.00			60.21		
r	Human services	1218.59 SEK/ha	1.58E+11 sej/SEK		192.42				181.52	1218.59
s	Capital investment	712.81 SEK/ha	1.58E+11 sej/SEK		112.56				122.57	712.81
Y3	Biomass yield	9.99E+10 J/ha	27,857 sej/J	509.99	2782.09	Sum of prim. en.	920.90	2292.69	1022.24	5808.19

Table A.I-13 *continued*

F4	**Road transport**			**36.37**		**229.76**	**6.02**	**159.05**
t	Motor fuel	2.30E+08 J/t_{dm}	47,900 sej/J	11.01	1.14	229.76		
u	Truck	0.097 kg/t_{dm}	2.60E+12 sej/kg	0.25			6.02	
v	Human services	133.71 SEK/t_{dm}	1.58E+11 sej/SEK	21.11				133.71
w	Capital investment	25.35 SEK/t_{dm}	1.58E+11 sej/SEK	4.00				25.35
Y4	Biomass yield	1.87E+10 J/t_{dm}	29,217 sej/J	546.37	Sum of prim. en.	1182.82	2298.70	1181.29
F5	**Comminution**			**20.31**		**105.88**		**73.78**
x	Electricity	1.06E+08 J/t_{dm}	80,200 sej/J	8.49	1.59	105.88		
y	Machines, equipment	0.072 kg/t_{dm}	2.26E+12 sej/kg	0.16				
z	Human services	59.63 SEK/t_{dm}	1.58E+11 sej/SEK	9.42				59.63
aa	Capital investment	14.15 SEK/t_{dm}	1.58E+11 sej/SEK	2.23				14.15
Y5	Biomass yield	1.87E+10 J/t_{dm}	30,303 sej/J	566.67	Sum of prim. en.	1351.18	2298.70	1255.08
					Direct + embodied prim. en.	3649.88		
					E(output, primary)/E(input, primary)	5.1		

Table A.I-13 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	62.0	62.0	62.0	62.0	62.0
Inputs fed back from society (*i.e.* purchased)					
F1 [x 10^{12} sej/t_{dm}]	347.0	347.0	347.0	347.0	347.0
F2 [x 10^{12} sej/t_{dm}]	20.1	20.1	20.1	20.1	20.1
F3 [x 10^{12} sej/t_{dm}]	80.8	80.8	80.8	80.8	80.8
F4 [x 10^{12} sej/t_{dm}]	36.4	36.4	36.4	36.4	36.4
F5 [x 10^{12} sej/t_{dm}]	20.3	20.3	20.3	20.3	20.3
F6 (Conversion) [x 10^{12} sej/t_{dm}]	136.2	99.9	138.6	188.9	177.5
Solar emergy yields of products					
Y1 [x 10^{12} sej/t_{dm}]	409.1	409.1	409.1	409.1	409.1
Y2 [x 10^{12} sej/t_{dm}]	429.2	429.2	429.2	429.2	429.2
Y3 [x 10^{12} sej/t_{dm}]	510.0	510.0	510.0	510.0	510.0
Y4 [x 10^{12} sej/t_{dm}]	546.4	546.4	546.4	546.4	546.4
Y5 [x 10^{12} sej/t_{dm}]	566.7	566.7	566.7	566.7	566.7
Y6 (Final product) [x 10^{12} sej/t_{dm}]	702.8	666.5	705.3	755.5	744.2
Solar transformities					
(a) Cultivation of wheat [sej/J]	22,112	22,112	22,112	22,112	22,112
(b) After harvesting of wheat [sej/J]	24,362	24,362	24,362	24,362	24,362
(c) After baling, field transport and storage of straw [sej/J]	27,857	27,857	27,857	27,857	27,857
(d) After road transport of straw [sej/J]	29,217	29,217	29,217	29,217	29,217
(e) After comminution of straw [sej/J]	30,303	30,303	30,303	30,303	30,303
(f) After conversion of straw [sej/J]	45,513	120,175	80,778	57,125	67,536
(f) Heat generated at CHP [sej/J]		53,399			
Net solar emergy yield ratio					
I. Cultivation of wheat	1.18	1.18	1.18	1.18	1.18
II. After harvesting of wheat	1.17	1.17	1.17	1.17	1.17
III. After baling, field transport and storage of straw	1.14	1.14	1.14	1.14	1.14
IV. After road transport of straw	1.13	1.13	1.13	1.13	1.13
V. After comminution of straw	1.12	1.12	1.12	1.12	1.12
VI. After conversion of straw	1.10	1.10	1.10	1.09	1.09
Solar emergy investment ratio					
I. Cultivation of wheat	5.60	5.60	5.60	5.60	5.60
II. After harvesting of wheat	5.92	5.92	5.92	5.92	5.92
III. After baling, field transport and storage of straw	7.22	7.22	7.22	7.22	7.22
IV. After road transport of straw	7.81	7.81	7.81	7.81	7.81
V. After comminution of straw	8.14	8.14	8.14	8.14	8.14
VI. After conversion of straw	10.33	9.75	10.37	11.18	11.00
Primary energy required at conversion [MJ/t_{dm}]	251.05	818.88	1041.60	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	15.44	5.55	8.73	13.23	11.02
Amount of heat produced at CHP [GJ/t_{dm}]		12.48			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	28.08	10.08	15.87	24.05	20.04

Table A.I-13 *continued*

Amount of heat produced at CHP					
[GJ/(ha x year)]		22.70			
E(output)/E(primary energy input including biomass)	68.3%	77.8%	37.3%	55.2%	46.7%
E(output)/E(primary energy input excluding biomass)	4.0	4.0	1.9	2.5	2.3
Cost of energy carrier					
SEK/GJ	131.65	107.83	205.89	146.44	179.83
SEK/MWh	473.96	388.18	741.22	527.19	647.39
€/GJ	14.44	11.82	22.58	16.06	19.72
Cost of heat at CHP					
SEK/GJ		82.17			
SEK/MWh		295.80			
€/GJ		9.01			

Footnotes to Table A.I-13

I Environmental inputs:

a–c Data from Doherty, Nilsson & Odum (2002).

Solar emergy = solar emergy of transpired rain = 352.44×10^{12} sej/(ha x year). The production of biomass was assumed as 5% greater than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). The standard yield per hectare for autumn wheat in Sweden in 2002 was 6.351 t/ha (The Swedish Board of Agriculture, 2003). The moisture content was assumed as 15%. Thus, the wheat production = 6.351 x 0.85 / 0.95 t_{dm}/ha = 5.682 t_{dm}/ha. The solar emergy = 352.44×10^{12} / 5.682 sej/t_{dm} = 62.02×10^{12} sej/t_{dm}.

F_1 Agricultural inputs:

d The energy content of wheat seeds = 3.1 GJ/(ha x year) and the energy amount required in the production of wheat seeds = 1.6 GJ/(ha x year) (Börjesson, 1996). Total amount of energy input = (3.1 + 1.6) GJ/(ha x year) = 4.7 GJ/(ha x year).
Solar transformity of seeds = 16,100 sej/J (Andresen, Björklund & Rydberg, 2000).
$E_{seeds, total}$ = 4.7 / (6.351 x 0.85) GJ/t_{dm} = 870.64 MJ/t_{dm}.

e The amount of nitrogen added was 140 kg/(ha x year) (Börjesson, 1996). Solar transformity for nitrogen in nitrogen fertilizer = 4.60×10^{12} sej/kg (Odum, 1996). Solar emergy for N fertilizer = 140 x 4.60×10^{12} sej/(ha x year) = 644.00×10^{12} sej/(ha x year).
The amount of phosphorus added was 23.0 kg/(ha x year) (Börjesson, 1996). Solar transformity for phosphorus in phosphorus fertilizer = 1.78×10^{13} sej/kg (Odum, 1996). Solar emergy for P fertilizer = 23.0 x 1.78×10^{13} sej/(ha x year) = 409.40×10^{12} sej/(ha x year).
The amount of potassium added was 10.0 kg/(ha x year) (Börjesson, 1996). Solar transformity for potassium in potassium fertilizer = 1.74×10^{12} sej/kg (Odum, 1996). Solar emergy for K fertilizer = 10.0 x 1.74×10^{12} sej/(ha x year) = 17.40×10^{12} sej/(ha x year).
The amount of lime added was 150.0 kg/(ha x year) (Börjesson, 1996). Solar transformity for lime = 1.00×10^{12} sej/kg (Odum, 1996). Solar emergy for lime = 150.0 x 1.00×10^{12} sej/(ha x year) = 150.00×10^{12} sej/(ha x year).
Total amount of fertilizer = (140.0 + 23.0 + 10.0 + 150.0) kg/(ha x year) = 323.0 kg/(ha x year).
Total solar emergy = (644.00 + 409.40 + 17.40 + 150.00) x 10^{12} sej/(ha x year) = 1220.80 x 10^{12} sej/(ha x year). Total solar transformity for all fertilizers = 1220.80 x10^{12} / 323.0 sej/kg = 3.78×10^{12} sej/kg.
Energy embodied in the fertilizers is estimated by Börjesson (1996) to be 48 MJ/kg for nitrogen, 7.9 MJ/kg for phosphorus, 4.8 MJ/kg for potassium and 1.2 MJ/kg for lime. The energy amount embodied in fertilizers used per hectare and year = (140 x 48 + 23.0 x 7.9 + 10.0 x 4.8 + 150.0 x 1.2) MJ/(ha x year) = 7129.70 MJ/(ha x year). The energy amount

embodied in fertilizers used per ton of dry matter = 7129.70 / (6.351 x 0.85) MJ/t_{dm} = 1320.72 MJ/t_{dm}.

f The application dose of herbicides was estimated by Börjesson (1996) to be 1.0 kg/(ha x year), corresponding to 120 MJ/(ha x year). Solar transformity for herbicides = 66,000 sej/J (Doherty, Nilsson & Odum, 2002).
The amount of herbicides per ton of dry matter = 120 / (6.351 x 0.85) MJ/t_{dm} = 22.23 MJ/t_{dm}.

g Number of machine hours required = 8 h/(ha x year) and average diesel oil consumption = 9.6 l/h (Börjesson, 1996). $LHV_{diesel\ oil}$ = 35.9 MJ/l (Swedish Energy Agency, 2004a). The amount of diesel oil = 8 x 9.6 x 35.9 x 10^6 GJ/(ha x year) = 2.757 GJ/(ha x year).
The amount of diesel oil per ton of dry matter = 2.757 / (6.351 x 0.85) GJ/t_{dm} = 510.73 MJ/t_{dm}.

h The sum of mass depreciation of machinery and the solar transformity for machine equipment at cultivation of wheat was assumed as equal to the sum of mass depreciation and the solar transformity for machine equipment at cultivation of reed canary grass, *i.e.* 1.126 kg/(ha x year) and 2.37 x10^{12} sej/kg respectively (see Table A.J-16a).
The amount of embodied energy in machinery at cultivation of wheat was assumed as equal to the amount of embodied energy in machinery at cultivation of reed canary grass. The specific amount of embodied energy in machinery at cultivation of reed canary grass = 11.44 MJ/t_{dm} (see Table A.I-12, footnote g). The yield of reed canary grass = 6.136 t_{dm}/(ha x year) (see Table A.I-12, footnote Y_1). The yield of wheat = 6.351 x 0.85 t_{dm}/(ha x year) = 5.398 t_{dm}/(ha x year). Thus, the specific amount of embodied energy in machinery at cultivation of wheat = 11.44 x 6.136 / 5.398 MJ/t_{dm} = 13.00 MJ/t_{dm}.

i The amount of seeds required = 200 kg/ha, and the cost of seeds is 3 SEK/kg (Lindström, 2005). Thus, the annual cost of seeds per hectare = 200 x 3 SEK/(ha x year) = 600 SEK/(ha x year).
The cost of herbicides used for spring-sown grain (1.0 litre/ha of Event Super and 0.1 litre/ha of wetting agent) is 428 SEK/ha (Swedish database of weeds, 2005 (URL)). These herbicides were assumed to be used once per year.
The dosages of fertilizers at cultivation of wheat are 140 kg/(ha x year) of nitrogen, 23 kg/(ha x year) of phosphorus, 10 kg/(ha x year) of potassium and 150 kg/(ha x year) of lime (Börjesson, 1996). The cost of the nitrogen in urea (N 46) = 7.61 SEK/kg, the cost of the phosphorus in superphosphate (P 20) = 12.00 SEK/kg, and the cost of the potassium in potassium chloride (K 50) = 3.71 SEK/kg (see Table A.J-26). The cost of lime is 2.60 SEK/kg (Lundh, 2005). Thus, the cost of NPK and lime fertilization at cultivation of wheat = (7.61 x 140 + 12.00 x 23 + 3.71 x 10 + 2.60 x 150) SEK/(ha x year) = 1768.50 SEK/year.
The total cost for expendables (seeds, herbicides and fertilizers) = (600 + 428 + 1768.50) SEK/(ha x year) = 2796.50 SEK/(ha x year).

j Costs for human services (*i.e.* variable costs minus expendables) in agricultural inputs were assumed as equal to the costs for human services in agricultural inputs for reed canary grass, *i.e.* 459.56 SEK/(ha x year) (see Table A.J-16a).

k The capital cost was assumed to be equal to the capital cost in agricultural inputs for reed canary grass, *i.e.* 119.19 SEK/(ha x year) (see Table A.J-16a).

Y_1 The production of biomass was assumed to be 5% larger than the yield (Y_2), according to Doherty, Nilsson & Odum (2002). Wheat production = 5.682 t_{dm}/ha (see footnote I). HHV_{wheat} = 18.5 GJ/t_{dm} (Börjesson, 1996). Thus, the biomass production = 18.5 x 5.682 x 10^9 J/(ha x year) = 1.051 x 10^{11} J/(ha x year). Solar emergy = solar emergy of transpired rain + solar emergy of agricultural inputs = (352.44 x 10^{12} + 1972.09 x 10^{12}) sej/(ha x year) = 2324.53 x 10^{12} sej/(ha x year). Solar emergy = 2324.53 x 10^{12} / 5.682 sej/t_{dm} = 409.07 x 10^{12} sej/t_{dm}.
Solar transformity = 2324.53 x 10^{12} / 1.051 x 10^{11} sej/J = 22,112 sej/J.

F_2 Harvesting:

l The amount of direct energy required = 584.66 MJ/(ha x year) (see Table A.J-30). The sum of direct energy required per metric ton of dry matter = 584.66 / (6.351 x 0.85) MJ/t_{dm} = 108.30 MJ/t_{dm}.

m Mass depreciation (*i.e.* wear) of machinery = 0.738 kg/(ha x year) (see Table A.J-30). Solar transformity for machine equipment = 1.81 x 10^{12} sej/kg (see Table A.H-7). The amount of embodied energy in machinery = 5.89 MJ/t_{dm} (see Table A.J-30).

n Costs for human services = O & M costs = 297.60 SEK/(ha x year) (see Table A.J-30).

o Capital costs = 203.94 SEK/(ha x year) (see Table A.J-30**)**.

Y_2 The annual yield of wheat = 6.351 x 0.85 t_{dm}/ha = 5.398 t_{dm}/ha. HHV_{wheat} = 18.5 MJ/kg_{dm} (Börjesson, 1996). Thus, the annual yield of biomass = 5.398 x 18.5 x 10^9 J/(ha x year) = 9.987 x 10^{10} J/(ha x year). Solar emergy = solar emergy of (Y_1 + F_2) = (2324.53 + 28.01 + 1.34 + 46.99 + 32.20) x 10^{12} sej/(ha x year) = 2433.07 x 10^{12} sej/(ha x year). Solar emergy per metric ton of dry matter = (409.07 + (28.01 + 1.34 + 46.99 + 32.20) / 5.398) x 10^{12} sej/t_{dm} = 429.18 x 10^{12} sej/t_{dm}.
Solar transformity = 2433.07 x 10^{12} / 9.987 x 10^{10} sej/J = 24,362 sej/J.

F_3 Baling, field transport and storage:

p The amount of direct energy required at baling and field transport of straw = 815.23 MJ/(ha x year) (see Table A.J-17). The yield of straw = 1.818 t_{dm}/(ha x year) (see Chapter 3). The sum of direct energy required per metric ton of dry matter = 815.23 / 1.818 MJ/t_{dm} = 448.38 MJ/t_{dm}.

q Mass depreciation of machinery at baling and field transport = the total wear at baling and field transport = 2.313 kg/(ha x year), the solar transformity for machine equipment = 2.16 x10^{12} sej/kg, and the sum of embodied energy in machinery at baling and field transport = 60.21 MJ/t_{dm} (see Table A.J-17).

r Total costs for human services = O & M costs = (1024.69 + 192.86 + 1.04) SEK/(ha x year) = 1218.59 SEK/(ha x year) (see Table A.J-17**)**. The O & M costs per metric ton of dry matter at baling of straw was assumed as equal to the O & M costs per metric ton of dry matter at baling of reed canary grass. The O & M costs at baling of reed canary grass = 838.38 SEK/(ha x year) (see Table A.J-31). The yield of reed canary grass during a rotation period of 11 years was 67.5 t_{dm} (see Chapter 3), leading to that the O & M costs per metric ton of dry matter at baling of reed canary grass = 838.38 / (67.5 / 11) SEK/t_{dm} = 136.63 SEK/t_{dm}. The yield of straw = 4.318 t_{dm}/ha (see footnote Y_3). Thus, costs for human services per metric ton of dry matter at baling, field transport and storage of straw = (136.63 + (192.86 + 1.04) / 4.318) SEK/t_{dm} = 181.52 SEK/t_{dm}.

s Total capital costs = (432.50 + 72.04 + 208.26) SEK/(ha x year) = 712.81 SEK/(ha x year) (see Table A.J-17**)**. The capital costs per metric ton of dry matter at baling of straw was assumed as equal to the capital costs per metric ton of dry matter at baling of reed canary grass. The capital costs at baling of reed canary grass = 353.87 SEK/(ha x year) (see Table A.J-31). The yield of reed canary grass during a rotation period of 11 years was 67.5 t_{dm} (see Chapter 3), leading to that the capital costs per metric ton of dry matter at baling of reed canary grass = 353.87 / (67.5 / 11) SEK/t_{dm} = 57.67 SEK/t_{dm}. The yield of straw = 4.318 t_{dm}/ha (see footnote Y_3). Thus, capital costs per metric ton of dry matter at baling, field transport and storage of straw = (57.67 + (72.04 + 208.26) / 4.318) SEK/t_{dm} = 122.57 SEK/t_{dm}.

Y_3 The annual yield of biomass = 9.987 x 10^{10} J/(ha x year) (see Y_2). Solar emergy = solar emergy of (Y_2 + F_3) = (2433.07 + 39.05 + 5.00 + 192.42 + 112.56) x 10^{12} sej/(ha x year) = 2782.09 x 10^{12} sej/(ha x year). The yield of straw for spring wheat and autumn wheat is estimated by Nilsson & Ekström (1982) as 80% and 85% respectively of the yield of wheat received. However, the yield of straw for autumn wheat was assumed as 80% of the yield of wheat received, as the yield of grain is maximized by plant breeding. Thus, the yield of straw = 0.80 x 5.398 t_{dm}/ha = 4.318 t_{dm}/ha. Solar emergy per metric ton of dry matter = (429.18 + (39.05 + 5.00 + 192.42 + 112.56) / 4.318) x 10^{12} sej/t_{dm} = 509.99 x

10^{12} sej/t_{dm}.
Solar transformity = 2782.09 x 10^{12} / 9.987 x 10^{10} sej/J = 27,857 sej/J.

F_4 Road transport:

t Direct energy required = 229.76 MJ/t_{dm} (see Table A.J-38b).

u Mass depreciation of machinery = 0.097 kg/t_{dm} (see Table A.J-38b). Solar transformity for machine equipment = 2.60 x 10^{12} sej/kg (See Table A.H-7). The amount of embodied energy in trucks used = 6.02 MJ/t_{dm} (see Table A.J-38b).

v Costs for human services = O & M costs = 133.71 SEK/t_{dm} (see Table A.J-38b).

w Capital costs = 25.35 SEK/t_{dm} (see Table A.J-38b).

Y_4 HHV_{straw} = 18.7 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (509.99 + 11.01 + 0.25 + 21.11 + 4.00) x 10^{12} sej/t_{dm} = 546.37 x 10^{12} sej/t_{dm}.
Solar transformity = 546.37 x 10^{12} / 1.87 x 10^{10} sej/J = 29,217 sej/J.

F_5 Comminution:

x Direct energy required = 105.88 MJ/t_{dm} (see Table A.J-40).

y Mass depreciation of machinery = 0.072 kg/t_{dm}. Solar transformity for machine equipment = 2.26 x 10^{12} sej/kg (See Table A.J-40).

z Costs for human services = O & M costs = 59.63 SEK/t_{dm} (see Table A.J-40).

aa Capital costs = 14.15 SEK/t_{dm} (see Table A.J-40).

Y_5 HHV_{straw} = 18.7 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_4 + F_5) = (546.37 + 8.49 + 0.16 + 9.42 + 2.23) x 10^{12} sej/t_{dm} = 566.67 x 10^{12} sej/t_{dm}.
Solar transformity = 566.67 x 10^{12} / 1.87 x 10^{10} sej/J = 30,303 sej/J.

Table A.I-14. *Emergy, energy and cost analysis of recovered wood*

Recovered wood		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
Wood at recycling station	**1.99E+10 J/t_{dm}**	**7009 sej/J**	**139.47**						
F1 Collecting			**0.88**			**2.96**	**0.27**	**4.62**	
a Motor fuel	2.96E+06 J/t_{dm}	47,900 sej/J	0.14		1.14	2.96			
b Machines, equipment	0.004 kg/t_{dm}	2.60E+12 sej/kg	0.01				0.27		
c Human services	4.19 SEK/t_{dm}	1.58E+11 sej/SEK	0.66					4.19	
d Capital investment	0.43 SEK/t_{dm}	1.58E+11 sej/SEK	0.07					0.43	
Y1 Tree biomass yield	1.99E+10 J/t_{dm}	7053 sej/J	140.35		Sum of prim. en.	3.37	0.27	4.62	
F2 Sorting and comminution			**7.02**			**54.78**		**27.65**	
e Motor fuel	5.48E+07 J/t_{dm}	47,900 sej/J	2.62		1.14	54.78			
f Machines, equipment	0.015 kg/t_{dm}	2.24E+12 sej/kg	0.03						
g Human services	23.79 SEK/t_{dm}	1.58E+11 sej/SEK	3.76					23.79	
h Capital investment	3.85 SEK/t_{dm}	1.58E+11 sej/SEK	0.61					3.85	
Y2 Tree biomass yield	1.99E+10 J/t_{dm}	7406 sej/J	147.38		Sum of prim. en.	65.83	0.27	32.26	
F3 Road transport			**14.11**			**82.72**	**2.46**	**63.60**	
i Motor fuel	8.27E+07 J/t_{dm}	47,900 sej/J	3.96		1.14	82.72			
j Machines, equipment	0.040 kg/t_{dm}	2.60E+12 sej/kg	0.10				2.46		
k Human services	52.68 SEK/t_{dm}	1.58E+11 sej/SEK	8.32					52.68	
l Capital investment	10.92 SEK/t_{dm}	1.58E+11 sej/SEK	1.72					10.92	
Y3 Tree biomass yield	1.99E+10 J/t_{dm}	8115 sej/J	161.48		Sum of prim. en.	160.13	2.73	95.87	
					Direct + embodied prim. en.	162.85			
					E(output, primary)/E(input, primary)	122.2			

Table A.I-14 *continued: Summary of inputs, yields, solar transformities and investment indices*

	District heating	CHP	Electric power	Hydrogen	Methanol
Environmental inputs					
I from FinalFell [x 10^{12} sej/t_{dm}]	124.5	124.5	124.5	124.5	124.5
Inputs fed back from society (*i.e.* purchased)					
F1 [x 10^{12} sej/t_{dm}]	0.9	0.9	0.9	0.9	0.9
F2 [x 10^{12} sej/t_{dm}]	7.0	7.0	7.0	7.0	7.0
F3 [x 10^{12} sej/t_{dm}]	14.1	14.1	14.1	14.1	14.1
F4 (Conversion) [x 10^{12} sej/t_{dm}]	144.1	103.2	147.5	195.8	184.9
Solar emergy yields of products					
Y1 [x 10^{12} sej/t_{dm}]	140.4	140.4	140.4	140.4	140.4
Y2 [x 10^{12} sej/t_{dm}]	147.4	147.4	147.4	147.4	147.4
Y3 [x 10^{12} sej/t_{dm}]	161.5	161.5	161.5	161.5	161.5
Y4 (Final product) [x 10^{12} sej/t_{dm}]	305.6	264.7	309.0	357.3	346.4
Solar transformities					
(a) After collecting [sej/J]	7053	7053	7053	7053	7053
(b) After sorting and comminution [sej/J]	7406	7406	7406	7406	7406
(c) After road transport [sej/J]	8115	8115	8115	8115	8115
(d) After conversion [sej/J]	18,595	44,842	33,254	25,385	29,540
(d) Heat generated at CHP [sej/J]		19,925			
Net solar emergy yield ratio					
I. After collecting	159.17	159.17	159.17	159.17	159.17
II. After sorting and comminution	18.64	18.64	18.64	18.64	18.64
III. After road transport	7.34	7.34	7.34	7.34	7.34
IV. After conversion	1.84	2.11	1.82	1.64	1.67
Solar emergy investment ratio					
I. After collecting	0.01	0.01	0.01	0.01	0.01
II. After sorting and comminution	0.06	0.06	0.06	0.06	0.06
III. After road transport	0.18	0.18	0.18	0.18	0.18
IV. After conversion	1.33	1.01	1.36	1.75	1.66
Prim. energy required at conversion [MJ/t_{dm}]	251.05	818.88	1108.44	1602.72	1237.82
Amount of final product produced (electric power at CHP) [GJ/t_{dm}]	16.43	5.90	9.29	14.07	11.73
Amount of heat produced at CHP [GJ/t_{dm}]		13.28			
Amount of final product produced (electric power at CHP) [GJ/(ha x year)]	0.60	0.22	0.34	0.52	0.43
Amount of heat produced at CHP [GJ/(ha x year)]		0.49			
E(output)/E(primary energy input including biomass)	80.9%	91.9%	43.9%	65.0%	55.1%
E(output)/E(primary energy input excluding biomass)	39.7	19.5	7.3	8.0	8.4
Cost of energy carrier					
SEK/GJ	56.21	43.07	72.46	58.36	74.11
SEK/MWh	202.37	155.04	260.86	210.09	266.79
€/GJ	6.16	4.72	7.95	6.40	8.13

Table A.I-4 *continued*

Cost of heat at CHP	
SEK/GJ	17.40
SEK/MWh	62.65
€/GJ	1.91

Footnotes to Table A.I-14

Biomass input:

HHV_{wood} = 19.9 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of the tree biomass production in forestry (Y_0 in Table A.I-1). Solar emergy = (annual flow) x (solar transformity)

F_1 Collecting:

a The amount of motor fuel required = 2.96 x 10^6 J/t_{dm} (see Table A.J-37).

b Mass depreciation (*i.e.* wear) of machinery = 0.004 kg/t_{dm}, the solar transformity for machine equipment (loader) = 2.60 x 10^{12} sej/kg, and the amount of embodied energy in machinery equipment = 0.27 MJ/t_{dm} (see Table A.J-37).

c Costs for human services = O & M costs = 4.19 SEK/t_{dm} (see Table A.J-37).

d Capital costs = 0.43 SEK/t_{dm} (see Table A.J-37).

Y_1 $HHV_{Recovered\ wood}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_0 + F_1) = (139.47 + 0.14 + 0.01 + 0.66 + 0.07) x 10^{12} sej/t_{dm} = 140.35 x 10^{12} sej/t_{dm}.
Solar transformity = 140.35 x 10^{12} / 1.99 x 10^{10} sej/J = 7053 sej/J.

F_2 Sorting and comminution:

e Direct energy required per t_{dm} at sorting and comminution of recovered wood = 54.78 MJ/t_{dm} (see Table A.J-39).

f Mass depreciation of machinery = 0.015 kg/t_{dm}. Solar transformity for machine equipment = 2.30 x 10^{12} sej/kg (See Table A.J-39).

g Costs for human services = O & M costs = 23.79 SEK/t_{dm} (see Table A.J-39).

h Capital costs = 3.85 SEK/t_{dm} (see Table A.J-39).

Y_2 $HHV_{Recovered\ wood}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_1 + F_2) = (140.35 + 2.62 + 0.03 + 3.76 + 0.61) x 10^{12} sej/t_{dm} = 147.38 x 10^{12} sej/t_{dm}.
Solar transformity = 147.38 x 10^{12} / 1.99 x 10^{10} sej/J = 7406 sej/J.

F_6 Road transport:

i Direct energy required for road transport of comminuted recovered wood = 82.72 MJ/t_{dm} (see Table A.J-38c).

j Mass depreciation of machinery = 0.040 kg/t_{dm}, the solar transformity for machine equipment = 2.60 x 10^9 sej/g, and the amount of embodied energy in machinery equipment = 2.46 MJ/t_{dm} (see Table A.J-38c).

k Costs for human services = O & M costs = 52.68 SEK/t_{dm} (see Table A.J-38c).

l Capital costs = 10.92 SEK/t_{dm} (see Table A.J-38c).

Y_3 $HHV_{Recovered\ wood}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (147.38 + 3.96 + 0.10 + 8.32 + 1.72) x 10^{12} sej/t_{dm} = 161.48 x 10^{12} sej/t_{dm}.
Solar transformity = 161.48 x 10^{12} / 1.99 x 10^{10} sej/J = 8115 sej/J.

Table A.I-15. The emergy, energy and cost analysis of direct fuel wood cuttings

Direct fuel wood cuttings		Average annual flows	Emergy analysis: Solar transformity [sej/unit]	Emergy analysis: Solar emergy [10^{12} sej/t_{dm}]	Solar emergy [10^{12} sej/ha/yr]	Energy analysis: Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	Cost analysis: [SEK/t_{dm}]	[SEK/ha/yr]
I	**Environmental inputs**			**124.51**	**352.44**					
a	Sunlight	2.57E+13 J/ha	1 sej/J		25.74		Not included		Not included	
b	Wind, kinetic	8.73E+10 J/ha	1500 sej/J		130.91		Nature´s contribution		Nature's contribution	
c	Rain, transpired	1.94E+10 J/ha	18,200 sej/J		352.44		considered free		considered free	
Y0	Tree biomass production	5.03E+10 J/ha	7009 sej/J	124.51	352.44					
F1	**Silvicultural inputs**			**7.53**	**21.30**		**6.03**	**18.40**		**114.00**
d	Seed. plants	21.6 plants/ha	8.15E+09 sej/plant		1.76			15.70		
e	Fertilizers	0.137 kg/ha	4.60E+12 sej/kg		0.63			2.33		
f	Pesticides, herbicides	4.17E+04 J/ha	66,000 sej/J		0.00			0.02		
g	Motor fuel	1.71E+07 J/ha	47,900 sej/J		0.82	1.14	6.03			
h	Machines, equipment	0.031 kg/ha	2.97E+12 sej/kg		0.09			0.35		
i	Expendables	5.83 SEK/ha	1.58E+11 sej/SEK		0.92					5.83
j	Human services	85.14 SEK/ha	1.58E+11 sej/SEK		13.44					85.14
k	Capital investment	23.04 SEK/ha	1.58E+11 sej/SEK		3.64					23.04
Y1	Tree biomass production	5.92E+10 J/ha	6317 sej/J	132.03	373.74	Sum of prim. en.	6.88	18.40	40.27	114.00
F2	**Felling. delimbing and cutting**			**38.93**			**30.78**	**0.97**	**236.93**	
l	Motor fuel	3.08E+07 J/t_{dm}	47,900 sej/J	1.47		1.18	30.78			
m	Machines, equipment	0.019 kg/t_{dm}	2.15E+12 sej/kg	0.04				0.97		
n	Human services	222.62 SEK/t_{dm}	1.58E+11 sej/SEK	35.15					222.62	
o	Capital investment	14.32 SEK/t_{dm}	1.58E+11 sej/SEK	2.26					14.32	
Y2	Tree biomass yield	2.09E+10 J/t_{dm}	8180 sej/J	170.96		Sum of prim. en.	43.20	19.37	277.21	

Table A.I-15 *continued*

F3	**Forwarding**			**35.99**		**59.49**	**7.17**	**146.48**
p	Motor fuel	5.95E+07 J/t_{dm}	47,900 sej/J	2.85	1.14	59.49		
q	Machines, equipment	2.229 kg/t_{dm}	2.50E+12 sej/kg	5.56			7.17	
r	Human services	123.61 SEK/t_{dm}	1.58E+11 sej/SEK	19.52				123.61
s	Capital investment	22.87 SEK/t_{dm}	1.58E+11 sej/SEK	3.61				22.87
t	Handling and storage losses	5.43E+08 J/t_{dm}	8180 sej/J	4.44				
Y3	Tree biomass yield	2.09E+10 J/t_{dm}	9902 sej/J	206.95	Sum of prim. en.	111.01	26.54	423.68
F4	**Small-scale wood firing**			**419.76**				**2421.01**
u	Machines, equipment	14.40 kg/t_{dm}	2.60E+12 sej/kg	37.47				
v	Human services	864.08 SEK/t_{dm}	1.58E+11 sej/SEK	136.44				864.08
w	Capital investment	1556.93 SEK/t_{dm}	1.58E+11 sej/SEK	245.85				1 556.93
Y4	Final product	1.56E+10 J/t_{dm}	40,294 sej/J	626.70	Sum of prim. en.	111.01	26.54	2844.69
					Direct + embodied prim. en.	137.55		
					E(output, primary)/E(input, primary)	152.0		

Table A.I-15 *continued: Summary of inputs, yields, solar transformities and investment indices*

	Small-scale wood firing
Environmental inputs	
I Item c	124.5 x 10^{12} sej/t_{dm}
Inputs fed back from society (*i.e.* purchased)	
F1 Item d - k	7.5 x 10^{12} sej/t_{dm}
F2 Item l - o	38.9 x 10^{12} sej/t_{dm}
F3 Item p - t	36.0 x 10^{12} sej/t_{dm}
F4 Item u - y	419.8 x 10^{12} sej/t_{dm}
Solar emergy yields of products	
Y1 Standing biomass	132.0 x 10^{12} sej/t_{dm}
Y2 Harvested biomass in field	171.0 x 10^{12} sej/t_{dm}
Y3 Forwarded biomass	206.9 x 10^{12} sej/t_{dm}
Y4 Heat generated at conversion	626.7 x 10^{12} sej/t_{dm}
Solar transformities	
(a) Standing biomass	6317 sej/J
(b) Harvested biomass in field	8180 sej/J
(c) Forwarded biomass	9902 sej/J
(d) Heat generated at conversion	40,294 sej/J
Net solar emergy yield ratio	
I. Standing biomass = Y1 / F1	17.54
II. Harvested biomass in field = Y2 / (F1+F2)	3.68
III. Forwarded biomass = Y3 / (F1+F2+F3)	2.51
IV. Final product after conversion = Y4 / (F1+F2+F3+F4)	1.25
Solar emergy investment ratio	
I. Standing biomass = F1 / I	0.06
II. Harvested biomass = (F1+F2) / I	0.37
III. Forwarded biomass = (F1+F2+F3) / I	0.66
IV. Final product after conversion = (F1+F2+F3+F4) / I	4.03
E(output)/E(primary energy input including biomass)	73.93%
E(output)/E(primary energy input excluding biomass)	113.1
Cost of energy carrier	182.90 SEK/GJ 658.44 SEK/MWh 20.06 €/GJ

Footnotes to Table A.I-15

I Environmental inputs:
a–c Data from Doherty, Nilsson & Odum (2002).
Y_0 See footnote to Table A.I-1.
F_1 Silvicultural inputs:
d–k See footnotes to Table A.I-1.
Y_1 See footnote to Table A.I-1.
F_2 Felling, delimbing and cutting:
l The required amount of petrol at felling, delimbing and cutting with power saw = 23.46 MJ/t_{dm}, and corresponding amount at merely felling with power saw = 4.79 MJ/t_{dm} (see Table A.J-9). Corresponding amount of diesel oil required for tractor with delimbing-cutting processor = 21.92 MJ/t_{dm} (see Table A.J-10). The amount of diesel oil required for harvester used for final felling = 53.73 MJ/t_{dm} and corresponding amount for harvester used for thinning = 63.18 MJ/t_{dm} (see Table A.J-8). Weighted value for the amount of petrol required = (0.70 x 23.46 + 0.10 x 4.79) MJ/t_{dm} = 16.90 MJ/t_{dm}, and weighted value for the amount of diesel oil required = (0.10 x 21.92 + 0.10 x 53.73 + 0.10 x 63.18) MJ/t_{dm} = 13.88 MJ/t_{dm}. Total amount of motor fuel required = (16.90 + 13.88) MJ/t_{dm} = 30.78

MJ/t_{dm}.

The primary energy conversion factor was weighted by the amounts of diesel oil and petrol required. The weighted primary energy conversion factor = (13.88 x 1.14 + 16.90 x 1.21) / 30.78 = 1.18.

m Mass depreciation of machinery at felling, delimbing and cutting with power saw = 0.006 kg/t_{dm}, and corresponding amount at merely felling with power saw = 0.0003 kg/t_{dm} (see Table A.J-9). Mass depreciation of machinery for tractor with delimbing-cutting processor = 0.061 kg/t_{dm} (see Table A.J-10). Mass depreciation of machinery for harvesters used for both final felling and thinning = 0.042 kg/t_{dm} (see Table A.J-8). Weighted value for the mass depreciation of machinery = (0.70 x 0.006 + 0.10 x 0.0003 + 0.10 x 0.061 + 0.10 x 0.042 x 2) kg/t_{dm} = 0.019 kg/t_{dm}.

Solar transformity for machine equipment at felling, delimbing and cutting with power saw and at merely felling with power saw = 1.64 x 10^{12} sej/kg (see Table A.J-8). Solar transformity for tractor with delimbing-cutting processor = 2.38 x 10^{12} sej/kg (see Table A.J-9). Solar transformity for harvesters used for final felling and thinning = 2.97 x 10^{12} sej/kg (see Table A.H-7). Weighted value for the solar transformity = ((0.70 + 0.10) x 1.64 x 10^{12} + 0.10 x 2.38 x 10^{12} + 0.10 x 2.97 x 10^{12} x 2) sej/kg = 2.15 x 10^{12} sej/kg.

The embodied, primary energy at felling, delimbing and cutting with power saw = 0.240 MJ/t_{dm}, and corresponding value at merely felling with power saw = 0.010 MJ/t_{dm} (see Table A.J-9). Corresponding amount of embodied, primary energy for tractor with delimbing-cutting processor = 2.07 MJ/t_{dm} (see Table A.J-10). The embodied, primary energy for harvester used for final felling = 2.95 MJ/t_{dm} and corresponding value for harvester used for thinning = 3.00 MJ/t_{dm} (see Table A.J-8).

Weighted value for the embodied, primary energy = (0.70 x 0.240 + 0.10 x 0.010 + 0.10 x 2.07 + 0.10 x 2.95 + 0.10 x 3.00) MJ/t_{dm} = 0.97 MJ/t_{dm}.

n The specific O & M cost at felling with power saw was 58.07 SEK/t_{dm} and 40.06 SEK/t_{dm} for tractor with delimbing-cutting processor (see Tables A.J-9 through A.J-10). The specific O & M cost for harvester used for final felling and for harvester used for thinning was 45.00 SEK/t_{dm} and 58.92 SEK/t_{dm} respectively (see Table A.J-8). The specific O & M cost at felling - delimbing and cutting with power saw = 289.16 SEK/t_{dm} (see Table A.J-9). The costs for human services = the weighted value for the specific O & M costs = (0.10 x (58.07 + 40.06) + 0.10 x 45.00 + 0.10 x 58.92 + 0.70 x 289.16) SEK/t_{dm} = 222.62 SEK/t_{dm}.

o The specific capital cost at felling with power saw = 0.61 SEK/t_{dm} (see Table A.J-9) and the specific capital cost for tractor with delimbing-cutting processor = 11.15 SEK/t_{dm} (see Table A.J-10). The specific capital cost for harvester used for final felling = 14.60 SEK/t_{dm} and corresponding specific cost for harvester used for thinning = 17.26 SEK/t_{dm} (see Table A.J-8). The corresponding specific cost at felling - delimbing and cutting with power saw = 14.22 SEK/t_{dm} (see Table A.J-9). Weighted value for the specific capital costs = (0.10 x (0.61 + 11.15) + 0.10 x 14.60 + 0.10 x 17.26 + 0.70 x 14.22) SEK/t_{dm} = 14.32 SEK/t_{dm}.

Y_2 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_1 + F_2) = (132.03 + 1.47 + 0.04 + 35.15 + 2.26) x 10^{12} sej/t_{dm} = 170.96 x 10^{12} sej/t_{dm}. Solar transformity = 170.96 x 10^{12} / 2.09 x 10^{10} sej/J = 8180 sej/J.

F_3 Forwarding:

p The required amount of diesel oil for forwarder used for final felling = 52.76 MJ/t_{dm} and corresponding amount for forwarder used for thinning = 96.26 MJ/t_{dm} (see Table A.J-11). Corresponding amount for tractor and trailer with grapple loader = 49.31 MJ/t_{dm} (see Table A.J-12) and corresponding amount for tractor and hanger with grapple loader = 50.26 MJ/t_{dm} (see Table A.J-13). Weighted value for the amount of diesel oil required = (0.20 x 52.76 + 0.20 x 96.26 + 0.50 x 49.31 + 0.10 x 50.26) MJ/t_{dm} = 59.49 MJ/t_{dm}.

q Mass depreciation of machinery for forwarder used for final felling = 0.037 kg/t_{dm} and corresponding amount for forwarder used for thinning = 0.089 kg/t_{dm} (see Table A.J-11). Mass depreciation of machinery for tractor and trailer with grapple loader = 0.997 kg/t_{dm}

(see Table A.J-12) and corresponding amount for tractor and hanger with grapple loader = 17.059 kg/t_{dm} (see Table A.J-13). Weighted value for the mass depreciation of machinery = (0.20 x 0.037 + 0.20 x 0.089 + 0.50 x 0.997 + 0.10 x 17.059) kg/t_{dm} = 2.229 kg/t_{dm}.
Solar transformity for forwarders used for both final felling and thinning = 2.97 x 10^{12} sej/kg (see Table A.H-7). Corresponding value for tractor and trailer with grapple loader = 2.16 x 10^{12} sej/kg (see Table A.J-12) and corresponding value for tractor and hanger with grapple loader = 2.25 x 10^{12} sej/kg (see Table A.J-13). Weighted value for the solar transformity = (0.20 x 2 x 2.97 x 10^{12} + 0.50 x 2.16 x 10^{12} + 0.10 x 2.25 x 10^{12}) kg/t_{dm} = 2.50 x 10^{12} sej/kg.
The embodied, primary energy in forwarders used for final felling was 2.98 MJ/t_{dm} and 4.31 MJ/t_{dm} in forwarders used for thinning (see Table A.J-11). The embodied, primary energy in tractor and trailer with grapple loader = 6.11 MJ/t_{dm} (see Table A.J-12), and the corresponding amount of energy in tractor and hanger with grapple loader = 26.60 MJ/t_{dm} (see Table A.J-13). Weighted value for the embodied, primary energy = (0.20 x 2.98 + 0.20 x 4.31 + 0.50 x 6.11 + 0.10 x 26.60) MJ/t_{dm} = 7.17 MJ/t_{dm}.

r The specific O & M cost for forwarding at final felling was 38.15 SEK/t_{dm} and 82.64 SEK/t_{dm} for forwarding at thinning (see Table A.J-11), the specific O & M cost for forwarding with tractor and trailer with grapple loader was 99.83 SEK/t_{dm} (see Table A.J-12) and the specific O & M cost for tractor and hanger with grapple loader was 495.36 SEK/t_{dm} (see Table A.J-13). The costs for human services = the weighted value for the specific O & M costs = (0.20 x 38.15 + 0.20 x 82.64 + 0.50 x 99.83 + 0.10 x 495.36) SEK/t_{dm} = 123.61 SEK/t_{dm}.

s The specific capital cost for forwarding at final felling = 9.48 SEK/t_{dm} and the specific capital cost for forwarding at thinning = 17.35 SEK/t_{dm} (see Table A.J-11). The specific capital cost for forwarding with tractor and trailer with grapple loader = 16.21 SEK/t_{dm} (see Table A.J-12) and the specific capital cost for tractor and hanger with grapple loader = 93.98 SEK/t_{dm} (see Table A.J-13). Thus, the weighted value for the specific capital costs = (0.20 x 9.48 + 0.20 x 17.35 + 0.50 x 16.21 + 0.10 x 93.98) SEK/t_{dm} = 22.87 SEK/t_{dm}.

t Dry matter losses at storage = 2.6% of forwarded biomass (see Table A.G-1, footnote c). 0.026 x 2.09 x 10^{10} J/t_{dm} = 5.43 x 10^{8} J/t_{dm}.

Y_3 Tree biomass yield: HHV = 20.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_2 + F_3) = (170.96 + 2.85 + 5.56 + 19.52 + 3.61 + 4.44) x 10^{12} sej/t_{dm} = 206.95 x 10^{12} sej/t_{dm}. Solar transformity = 206.95 x 10^{12} / 2.09 x 10^{10} sej/J = 9902 sej/J.

F_4 Small-scale wood firing:

u The mass depreciation of the equipment = 14.40 kg/t_{dm} (see Table A.J-42). The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

v Costs for human services = O & M costs = 864.08 SEK/t_{dm} (see Table A.J-42).

w Capital costs = 1556.93 SEK/t_{dm} (see Table A.J-42).

Y_4 The amount of heat produced = 15.553 GJ/t_{dm} (see Table A.J-42). Solar emergy = solar emergy of (Y_3 + F_4) = (206.95 + 37.47 + 136.44 + 245.85) x 10^{12} sej/t_{dm} = 626.70 x 10^{12} sej/t_{dm}. Solar transformity = 626.70 x 10^{12} / 1.555 x 10^{10} sej/J = 40,294 sej/J.

Table A.I-16. *Emergy, energy and cost analysis of small-scale firing of pellets*

Small-scale firing of pellets		Emergy analysis			Energy analysis			Cost analysis	
	Average annual flows	Solar transformity [sej/unit]	Solar emergy [10^{12} sej/t_{dm}]	[10^{12} sej/ha/yr]	Prim. energy conv. factor	Direct energy MJ/t_{dm}	Embodied energy MJ/t_{dm}	[SEK/t_{dm}]	[SEK/ha/yr]
Biomass input (sawdust)	**1.99E+10 J/t_{dm}**	**18,755 sej/J**	**373.22**		**Primary energy**	**897.35**	**31.64**	**1052.15**	
F7 Pelletizing			**180.64**			**4437.55**		**445.25**	
a Fuels (oil or biomass)	4.00E+09 J/t_{dm}	18,755 sej/J	75.09			4004.00			
b Electricity	4.34E+08 J/t_{dm}	80,200 sej/J	34.77		1.59	433.55			
c Machines, equipment	0.039 kg/t_{dm}	2.60E+12 sej/kg	0.10						
d Expendables	18.77 SEK/t_{dm}	1.58E+11 sej/SEK	2.96					18.77	
e Operating costs	347.60 SEK/t_{dm}	1.58E+11 sej/SEK	54.89					347.60	
f Capital investment	78.89 SEK/t_{dm}	1.58E+11 sej/SEK	12.46					78.89	
g Handling and storage losses	1.99E+07 J/t_{dm}	18,755 sej/J	0.37						
Y7 Final product	1.99E+10 J/t_{dm}	27,832 sej/J	553.86		Sum of prim. en.	5590.70	31.64	1497.41	
F8 PellBoilSmall			**157.15**			**96.92**		**2359.13**	
h Electricity	9.69E+07 J/t_{dm}	80,200 sej/J	7.77		1.59	96.92			
i Machines, equipment	13.99 kg/t_{dm}	2.60E+12 sej/kg	36.39						
j Operating costs	847.18 SEK/t_{dm}	1.58E+11 sej/SEK	133.77					847.18	
k Capital investment	1511.94 SEK/t_{dm}	1.58E+11 sej/SEK	238.74					1511.94	
Y8 Final product	1.51E+10 J/t_{dm}	47,075 sej/J	711.01		Sum of prim. en.	5744.79	31.64	3856.53	
					Direct + embodied prim. en.	5776.44			
					E(output, primary)/E(input, primary)	3.5			

Table A.I-16 *continued: Summary of inputs, yields, solar transformities and investment indices*

	Small-scale pellets firing
Environmental inputs	
I from FinalFell	124.5 x 10^{12} sej/t_{dm}
Inputs fed back from society (*i.e.* purchased)	
F1+F2+F3+F4 from FinalFell	47.0 x 10^{12} sej/t_{dm}
F5+F6 from Sawdust	201.7 x 10^{12} sej/t_{dm}
F7 Item 1 to 6	180.6 x 10^{12} sej/t_{dm}
F8 Item 7 to 12	157.2 x 10^{12} sej/t_{dm}
Solar emergy yields of products	
Y7 Biomass after pelletizing	553.9 x 10^{12} sej/t_{dm}
Y8 Heat generated at conversion	711.0 x 10^{12} sej/t_{dm}
Solar transformities	
(a) Biomass after pelletizing	27,832 sej/J
(b) Heat generated at conversion	47,075 sej/J
Net solar emergy yield ratio	
I. Biomass after pelletizing = Y7 / (F1+F2+F3+F4+F5+F6+F7)	1.29
II. Final product after conversion = Y8 / (F1+F2+F3+F4+F5+F6+F7+F8)	1.21
Solar emergy investment ratio	
I. Biomass after pelletizing =(F1+F2+F3+F4+F5+F6+F7) / I	3.45
II. Final product after conversion = (F1+F2+F3+F4+F5+F6+F7+F8) / I	4.71
E(output)/E(primary energy input including biomass)	58.8%
E(output)/E(primary energy input excluding biomass)	2.6
Cost of energy carrier	255.33 SEK/GJ 919.20 SEK/MWh 28.00 €/GJ

Footnotes to Table A.I-16

Biomass input:

$HHV_{sawdust}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). The solar transformity was assumed as equal to the solar transformity of sawdust after road transport (Y_6 in Table A.I-9). Solar emergy = (annual flow) x (solar transformity)

F_7 Pelletizing:

a The amount of biomass required at flue gas drying = 4.004 GJ/t_{dm} (See Table A.J-41b).

b The amount of electricity required = 433.55 MJ/t_{dm} (See Table A.J-41b).

c The mass depreciation (*i.e.* wear) of machinery equipment = 0.039 kg/t_{dm} (see Table A.J-41b). The solar transformity for the pellets plant was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

d Total expendables = 18.77 SEK/t_{dm} (see Table A.J-41b).

e Costs for human services = O & M costs = 347.60 SEK/t_{dm} (see Table A.J-41b).

f Capital costs = 78.89 SEK/t_{dm} (see Table A.J-41b).

g Dry matter losses at milling were assumed as 0.1% of the biomass input. 0.01 x 1.99 x 10^{10} J/t_{dm} = 1.99 x 10^7 J/t_{dm}.

Y_7 $HHV_{pellets\ made\ of\ sawdust}$ = 19.9 MJ/kg_{dm} (see Table A.B-1c). Solar emergy = solar emergy of (Y_3 + F_4) = (373.22 + 75.09 + 34.77 + 0.10 + 2.96 + 54.89 + 12.46 + 0.37) x 10^{12} sej/t_{dm} = 553.86 x 10^{12} sej/t_{dm}. Solar transformity = 553.86 x 10^{12} / 1.99 x 10^{10} sej/J = 27,832 sej/J.

F_8 Small-scale pellet firing:

h The amount of electricity required = 96.92 MJ/t_{dm} (See Table A.J-42).

i Mass depreciation of equipment = 13.99 kg/t_{dm} (see Table A.J-42). The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

j Costs for human services = O & M costs = 847.18 SEK/t_{dm} (see Table A.J-42).

k Capital costs = 1511.94 SEK/t_{dm} (see Table A.J-42).

Y_8 The amount of heat produced = 15.104 GJ/t_{dm} (see Table A.J-42). Solar emergy = solar emergy of (Y_7 + F_8) = (553.86 + 7.77 + 36.39 + 133.77 + 238.74) x 10^{12} sej/t_{dm} = 711.01 x 10^{12} sej/t_{dm}. Solar transformity = 711.01 x 10^{12} / 1.510 x 10^{10} sej/J = 47,075 sej/J.

Table A.I-17. *Emergy, energy and cost analysis of large-scale firing of pellets*

Large-scale firing of pellets	Average annual flows	Emergy analysis: Solar transformity [sej/unit]	Emergy analysis: Solar emergy [10^{12} sej/t_{dm}]	Emergy analysis: Solar emergy [10^{12} sej/ha/yr]	Energy analysis: Prim. energy conv. factor	Energy analysis: Direct energy MJ/t_{dm}	Energy analysis: Embodied energy MJ/t_{dm}	Cost analysis [SEK/t_{dm}]	Cost analysis [SEK/ha/yr]
Biomass input (sawdust)	**1.99E+10 J/t_{dm}**	**18,755 sej/J**	**373.22**		**Primary energy**	**898.35**	**31.64**	**1052.15**	
F7 Pelletizing			**180.64**			**4437.55**		**445.25**	
a Fuels (oil or biomass)	4.00E+09 J/t_{dm}	18,755 sej/J	75.09			4004.00			
b Electricity	4.34E+08 J/t_{dm}	80,200 sej/J	34.77		1.59	433.55			
c Machines, equipment	0.039 kg/t_{dm}	2.60E+12 sej/kg	0.10						
d Expendables	18.77 SEK/t_{dm}	1.58E+11 sej/SEK	2.96					18.77	
e Operating costs	347.60 SEK/t_{dm}	1.58E+11 sej/SEK	54.89					347.60	
f Capital investment	78.89 SEK/t_{dm}	1.58E+11 sej/SEK	12.46					78.89	
g Handling and storage losses	1.99E+07 J/t_{dm}	18,755 sej/J	0.37						
Y7 Final product	1.99E+10 J/t_{dm}	27,832 sej/J	553.86		Sum of prim. en.	5590.70	31.64	1497.41	
F8 PellBoilLarge			**77.55**			**248.19**		**362.98**	
h Electricity	2.48E+08 J/t_{dm}	80,200 sej/J	19.91		1.59	248.19			
i Machines, equipment	0.1280 kg/t_{dm}	2.60E+12 sej/kg	0.33						
j Human services	46.79 SEK/t_{dm}	1.58E+11 sej/SEK	7.39					46.79	
k Capital investment	316.19 SEK/t_{dm}	1.58E+11 sej/SEK	49.93					316.19	
Y8 Final product	1.79E+10 J/t_{dm}	35,307 sej/J	631.41		Sum of prim. en.	5985.32	31.64	1860.38	
					Direct + embodied prim. en.	6016.97			
					E(output, primary)/E(input, primary)	3.5			

Table A.I-17 *continued: Summary of inputs, yields, solar transformities and investment indices*

	Large-scale pellets firing
Environmental inputs	
I from FinalFell	124.5 x 10^{12} sej/t_{dm}
Inputs fed back from society (*i.e.* purchased)	
F1+F2+F3+F4 from FinalFell	47.0 x 10^{12} sej/t_{dm}
F5+F6 from Sawdust	201.7 x 10^{12} sej/t_{dm}
F7 Item 1 to 6	180.6 x 10^{12} sej/t_{dm}
F8 Item 7 to 12	77.6 x 10^{12} sej/t_{dm}
Solar emergy yields of products	
Y7 Biomass after pelletizing	553.9 x 10^{12} sej/t_{dm}
Y8 Heat generated at conversion	631.4 x 10^{12} sej/t_{dm}
Solar transformities	
(a) Biomass after pelletizing	27,832 sej/J
(b) Heat generated at conversion	35,307 sej/J
Net solar emergy yield ratio	
I. Biomass after pelletizing = Y7 / (F1+F2+F3+F4+F5+F6+F7)	1.29
II. Final product after conversion = Y8 / (F1+F2+F3+F4+F5+F6+F7+F8)	1.25
Solar emergy investment ratio	
I. Biomass after pelletizing =(F1+F2+F3+F4+F5+F6+F7) / I	3.45
II. Final product after conversion = (F1+F2+F3+F4+F5+F6+F7+F8) / I	4.07
E(output)/E(primary energy input including biomass)	69.0%
E(output)/E(primary energy input excluding biomass)	3.0
Cost of energy carrier	104.03 SEK/GJ 374.50 SEK/MWh 11.41 €/GJ

Footnotes to Table A.I-17

Biomass input: See Table A.I-16.

F_7 Pelletizing:

a–g See footnotes to Table A.I-16.

Y_7 See Table A.I-16.

F_8 Large-scale pellet firing:

h The amount of electricity required = 248.19 MJ/t_{dm} (See Table A.J-43).

i Mass depreciation of equipment = 0.128 kg/t_{dm} (see Table A.J-43).

j Costs for human services = O & M costs = 46.79 SEK/t_{dm} (see Table A.J-43).

k Capital costs = 316.19 SEK/t_{dm} (see Table A.J-43).

Y_8 The amount of heat produced = 17.884 GJ/t_{dm} (see Table A.J-43). Solar emergy = solar emergy of ($Y_7 + F_8$) = (553.86 + 19.91 + 0.33 + 7.39 + 49.93) x 10^{12} sej/t_{dm} = 631.41 x 10^{12} sej/t_{dm}. Solar transformity = 631.41 x 10^{12} / 1.788 x 10^{10} sej/J = 35,307 sej/J.

Appendix J: Data for silviculture, agriculture, machinery and process equipment

Calculations of common items

Item	Calculation
Effective operating time [h_{G15}/year]	(The operating time [h_u/year]) x (utilization factor)
Annual production [t_{dm}/year]	(The operating time) x (utilization factor) x (production per effective hour)
Cost/metric ton of dry matter [SEK/t_{dm}]	The quotient of the total annual cost and the annual production.
Specific capital costs [SEK/(ha x year)]	(Total capital costs) / (treated area) x (number of occasions per rotation period) / (length of rotation period)
Specific O & M costs [SEK/(ha x year)]	(Total O & M costs) / (treated area) x (number of occasions per rotation period) / (length of rotation period)
Specific costs for expendables [SEK/(ha x year)]	(Total costs for expendables) / (treated area) x (number of occasions per rotation period) / (length of rotation period)
Technical life time [hours]	(The technical life time in years) x (the operating time per year)
Wear per hour [kg/h_u]	The quotient of the weight and the technical lifetime.
Wear per produced ton biomass [kg/t_{dm}]	(Wear per hour) x (actual operating time per year) / (annual production of biomass)
Wear per ha [kg/ha]	(Wear per hour) / (treated area per hour)
Direct energy required / (ha x year) [MJ/(ha x year)]	The quotient of the annual amount of direct energy required and the annual treated area.
Direct energy required / metric ton of dry matter [MJ/t_{dm}]	The quotient of the annual amount of direct energy required and the annual production of biomass.
Embodied energy [MJ/t_{dm}]	$E_{embodied}$ [GJ] x 10^3 / (Technical life time [years] x production per effective hour [t_{dm}/h_{G15}] x effective operating time [h_{G15}/year])
Embodied energy [MJ/(ha x year)]	$E_{embodied}$ [GJ] x 10^3 / (Technical life time [years] x production per effective hour [ha/h_{G15}] x effective operating time [h_{G15}/year])

Table A.J-1. *Data for plant production – commodities and energy used per 1000 seedlings at four Swedish nurseries in 1996, according to Aldentun (2002)*

Item	Kilåmon[a]	SörAms-berg[a]	Lugnet[a]	Hillet[a]	Average value	Solar transformity	Unit	Emergy [sej/1000 seedlings]	Primary energy conversion factor	Embodied energy [MJ/1000 seedlings]
Commodities [kg/1000 seedlings]										
Peat	12.60	15.14	15.87	14.18	14.45	1.824E+11[b]	sej/kg	2.64E+12	20.5[c]	296.17
Fertilizer	1.70	1.50	0.80	4.13	2.03	4.60E+12[d]	sej/kg	2.54E+12[e]	48.0[f]	97.56
Styrofoam	0.02	0.03	0.05	0.08	0.05					
Plant boxes	4.53	3.81	5.50	0.77	3.65					
Stretch wrap		0.04	0.03	0.14	0.05					
Greenhouse film	0.05	0.05	0.06	0.06	0.06					
Growing trays	0.53	1.68	0.61	1.39	1.05					
Wrapping	0.11	0.11	0.11	0.12	0.11	47,900[g]	sej/J	1.10E+13[h]	44.9[i]	223.21[j]
Diesel oil [MJ/1000 seedlings]										
Peat, road	6.26	4.69	2.63	2.26						
Peat, boat		1.84	1.14							
Peat harvest	2.56	1.71	2.56	2.99						
Fertiliser, road	1.74	0.03	0.11	1.52						
Fertiliser, boat			0.10							
Styrofoam, road		0.01	0.02	0.02						
Plant boxes, road	3.59	1.41	2.02	0.09						
Stretch wrap, road		0.04	0.03	0.06						
Stretch wrap, boat		0.002	0.002	0.03						
Greenhouse film, road	0.02	0.03	0.04	0.06						

Table A.J-1 *continued*

Item	Kilåmon[a]	SörAms-berg[a]	Lugnet[a]	Hillet[a]	Average value	Solar transformity	Unit	Emergy [sej/1000 seedlings]	Primary energy conversion factor	Embodied energy [MJ/1000 seedlings]
Greenhouse film, boat			0.03	0.03						
Growing trays, road	0.42	0.07	0.17	0.34						
Internal transports	8.90	11.63	33.48	19.49						
Seedling transportation	100.37	71.26	83.25	169.78						
Sum of diesel oil use	123.86	92.72	125.58	196.67	134.71	47,900[k]	sej/J	6.45E+12	1.14[l]	153.57
Electricity [MJ/1000 seedlings]										
Seed treatment	2.70	2.70	2.70	2.70						
Seedling production	102.13	228.84	424.16	247.83						
Sum	104.83	231.54	426.86	250.53	253.44	80,200[m]	sej/J	2.03E+13	1.59[l]	402.97
Heating oil [MJ/1000 seedlings]										
Seed treatment	2.70	2.70	2.70	2.70						
Seedling production	381.57	433.54	1081.11	1299.56						
Sum	384.27	436.24	1083.81	1302.26	801.65	47,900[k]	sej/J	3.84E+13	1.10[l]	881.81
Petrol [MJ/1000 seedlings]										
Internal transport	3.43	3.39	6.28		3.28	47,900[k]	sej/J	1.57E+11	1.21[l]	3.96
Total amount of emergy and primary energy								8.15E+13		2059.25

Table A.J-1 *continued*

a) Data from Aldentun (2002).
b) The heating value for horticultural peat was assumed as equal to the heating value of milled peat and variant of sod peat, according to Burvall (2003). The LHV for milled peat and variant of sod peat = 0.8 MWh/m^3 = 0.8 x 10^6 x 3600 J/m^3 = 2.88 GJ/m^3. Density of peat = 300 kg/m^3 (Statistics Sweden, 2002). Thus, the LHV = 2880 / 300 MJ/kg = 9.6 MJ/kg. The solar transformity for peat = 1.9 x 10^4 sej/J (Odum, 1996). Thus, the solar transformity [sej/kg] = 1.9 x 10^4 x 9.6 x 10^6 sej/kg = 1.824 x 10^{11} sej/kg.
c) The HHV was used as primary energy conversion factor for peat. The moisture content of milled peat and variant of sod peat with the LHV being 9.6 MJ/kg (see footnote b) was assumed as 50%. Thus, the HHV = (9.6 / 0.50 + 1.32) MJ/kg_{dm} = 20.52 MJ/kg_{dm}.
d) Solar transformity for nitrogen in nitrogen fertilizer = 4.60 x 10^{12} sej/kg (Odum, 1996).
e) The nitrogen content in the forest fertilizer Skog-CAN = 27.2% (Skogens Gödslings AB, 2004). Thus, the amount of emergy in the fertilizers used = 2.03 x 0.272 x 4.60 x 10^{12} sej = 2.54 x 10^{12} sej.
f) The amount of embodied energy in nitrogen fertilizer = 48 MJ/kg (Börjesson, 1996).
g) The solar transformity for polymer materials was assumed equal to the solar transformity for refined fuels from crude oil, being 47,900 sej/J (Doherty, Nilsson & Odum, 2002).
h) The total amount of polymer materials = 4.97 kg/1000 seedlings. The LHV of polymer materials was assumed as equal to the LHV of propane and butane, being 46.1 MJ/kg (Swedish Energy Agency, 2004b). Thus, the amount of emergy in the polymer materials used = 4.97 x 4.61 x 10^7 x 4.79 x 10^4 sej/1000 seedlings = 1.10 x 10^{13} sej/1000 seedlings.
i) The amount of embodied energy in polymer materials, including transport to component manufacturing = 44.9 MJ/kg (see Table A.I-1 and A.I-4).
j) The total amount of polymer materials = 4.97 kg/1000 seedlings. Thus, the amount of embodied energy in the polymer materials used = 4.97 x 44.9 MJ/1000 seedlings = 223.21 MJ/1000 seedlings.
k) The solar transformity for refined fuels from crude oil = 47,900 sej/J (Doherty, Nilsson & Odum, 2002).
l) See Table 2-1.
m) Solar transformity for hydroelectric power generated in Sweden = 80,200 sej/J (Odum, 1996).

Table A.J-2. *Physical data for silviculture*

Item	Treated area[a] [ha/year]	Fuel use [MJ/ha]	Mass depreciation [kg/ha]	[kg]	Embodied energy [MJ/ha]	[MJ/ha of total forest land]
Cleaning	55,000	53.46[b]				
Scarification	195,624	886.94[c]	0.436[c]		26.72	
Planting and sawing	177,840	283.13[d]				
Precommercial thinning	222,300	53.46[e]				
Forest fertilization	20,000	363.49[f]	0.193[f]		29.26	
Ash recirculation	217,600	583.38[g]	0.193[g]		58.52	
Forest drainage[h]			3.55E-04	7758		2.20E-03
Forest roads[i]			2.45E-02	536,098		0.152

a) See Table 3-3.
b) The direct energy use at cleaning was assumed equal to the direct energy use at precommercial thinning, ***i.e.*** 53.46 MJ/ha (see footnote e).
c) See Table A.J-3.
d) The sum of diesel oil and engine oil required at manual planting is 5.00 l/ha in Northern Sweden and 10.78 l/ha in Southern Sweden (Berg & Lindholm, 2005). Thus, the average amount of diesel oil and engine oil required = (5.00 + 10.78) / 2 l/ha = 7.89 l/ha. $LHV_{diesel\ oil}$ = 35.9 MJ/l (Swedish Energy Agency, 2004b). The LHV of engine oil was assumed equal to the LHV of diesel oil. Thus, the corresponding energy amount = 7.89 x 35.9 MJ/ha = 283.13 MJ/ha.
e) The consumption of petrol is 1.23 kg/ha at precommercial thinning in Sweden (Berg & Karjalainen, 2003). ρ_{petrol} = 750 kg/m^3 (The Swedish Petroleum Institute, 9-Oct-2005 (URL)) and LHV_{petrol} = 32.6 MJ/l (Swedish Energy Agency, 2004b). Thus, the direct energy required at precommercial thinning = 1.23 x 32.6 / 0.75 MJ/ha = 53.46 MJ/ha.
f) See Table A.J-4.
g) See Table A.J-5.
h) See Table A.J-6.
i) See Table A.J-7.

Table A.J-3. *Data for soil scarification*

Item	Forwarder	Mounder	Total	Total costs in €
Investment [SEK]	1600,000[a]	1100,000[b]	2700,000	296,085
Remaining value[c] [%]	10%	10%		
Operating time[d] [h_u/year]	4368	4368		
Economic life time [year]	8	6		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	231,892	201,329		
Capital costs [SEK/h_u]	53.09	46.09		
Service & maintenance costs [SEK/year]	100,000[e]	183,333[f]		
Other costs [SEK/year]	64,800[g]			
Total service & maintenance costs [SEK/year]	164,800	183,333		
Total service & maintenance costs [SEK/h_u]	37.73	41.97		
Personnel costs [SEK/h_u]	170.00[h]			
Personnel costs [SEK/year]	1485,120[i]			
Actual operating time [h_u/year]	4368	4368		
Utilization factor[j] [%]	85%	85%		
Effective operating time [h_{G15}/year]	3713	3713		
Capital costs [SEK/year]	231,892	201,329	433,221	47,507
Total service & maintenance costs [SEK/year]	164,800	183,333	348,133	38,177
Personnel costs [SEK/year]	1485,120		1485,120	162,860
Fuel [l/h_{G15}]	21.0[k]			
Fuel [l/year]	77,969		77,969	
LHV_{fuel} [MJ/l]	35.9[l]			
Fuel required [MJ/year]	2799,080		2799,080	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	545,782		545,782	59,851
Total costs[n] [SEK/year]	2427,593	384,662	2812,256	308,395
Treated area [ha/h_{G15}]		0.85[o]		
Treated area [ha/year]		3156	3156	
Total costs per hectare [SEK/ha]			891.12	
Capital costs per hectare [SEK/ha]			137.27	
Weight [t]	16.0[p]	4.5[q]	20.5	
Technical life time[r] [years]	16	12		
Technical life time [hours]	69,888	52,416		
Wear per hour [kg/h_u]	0.229	0.086		
Wear per hectare [kg/ha]	0.317	0.119	0.436	
Solar transformity [sej/kg]	2.97E+12[s]	1.52E+12[s]	2.65E+12[t]	
Direct energy required per hectare [MJ/ha]	886.94		886.94	
Embodied energy[s] [GJ]	1133	162.7		
Embodied energy[u] [MJ/(ha x year)]	22.42	4.30	26.72	

a) Data from Gullberg (2003).

Table A.J-3 *continued*

b) The investment cost of the three-row mounder Bracke M36.a is 1100,000 SEK (Andersson, 2004).
c) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
d) The equipment is operated by almost three shifts and the number of working hours is 12 h_u per shift (Andersson, 2004). The equipment was assumed being used 26 weeks per year. Thus, the annual operating time = 24 x 7 x 26 h_u/year = 4368 h_u/year.
e) Assumed as equal to the quotient of half the investment cost and the economic life time.
f) Assumed as equal to the quotient of the investment cost and the economic life time.
g) Other costs were assumed equal to other costs received for bundling (see Table A.J-14). Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
h) Data from Bredberg (2004).
i) The number of personnel is 2 per shift (Andersson, 2004). Thus, the personnel costs = 170.00 x 2 x 4368 SEK/year = 1485,120 SEK/year.
j) Assumed value.
k) Data from Berg & Karjalainen (2003).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The sum of capital costs, service & maintenance costs, personnel costs and fuel costs.
o) Data from Andersson (2004).
p) The minimum weight of a John Deere forwarder 1110D 8W is 15,370 kg (John Deere International, 16-Aug-2005 (URL)). The weight of the forwarder including accessories was assumed to be 16.0 t.
q) The weight of the three-row mounder Bracke M36.a is 4,500 kg (Bracke Forest AB, 2005 (URL)).
r) The technical life time was assumed as twice as long as the economic life time.
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (16.0 x 2.97 x 10^{12} + 4.5 x 1.52 x 10^{12}) / 20.5 sej/kg = 2.65 x 10^{12} sej/kg.
u) The total embodied energy = (22.42 + 4.30) MJ/(ha x year) = 26.72 MJ/(ha x year).

Table A.J-4. *Data for forest fertilization*

Item	Truck	Tractor[a]	Spreader	Tractor[a]	Spreader	Total	Total costs in €
Investment [SEK]	2250,000[b]	1600,000[c]	200,000[d]	1600,000[c]	200,000[d]	5850,000	641,518
Remaining value [%]	10%[b]	10%[e]	5%[f]	10%[e]	5%[f]		
Operating time[d] [h_u /year]	3500	3500	3500	3500	3500		
Economic life time [year]	8[b]	8[e]	5[g]	8[e]	5[g]		
Interest rate [%]	6%	6%	6%	6%	6%		
Capital costs [SEK/year]	326,098	231,892	45,105	231,892	45,105	880,092	
Capital costs [SEK/h_u]	93.17	66.25	12.89	66.25	12.89		
Service & maintenance costs [SEK/year]	281,250[h]	200,000[h]	40,000[g]	200,000[h]	40,000[g]		
Other costs [SEK/year]	157,000[i]	64,800[j]		64,800[j]			
Total service & maintenance costs [SEK/year]	438,250	264,800	40,000	264,800	40,000		
Total service & maintenance costs [SEK/h_u]	125.21	75.66	11.43	75.66	11.43		
Personnel costs[k] [SEK/h_u]		170.00		170.00			
Personnel costs[l] [SEK/year]		595,000		595,000			
Actual operating time[d] [h_u /year]	3500	3500	3500	3500	3500		
Utilization factor[m] [%]	60.0%	68.6%	68.6%	68.6%	68.6%		
Effective operating time[d] [h_{G15} /year]	2100	2400	2400	2400	2400		
Capital costs [SEK/year]	326,098	231,892	45,105	231,892	45,105	880,092	96,512
Total service & maintenance costs [SEK/year]	438,250	264,800	40,000	264,800	40,000	1047,850	114,908
Personnel costs [SEK/year]		595,000		595,000		1190,000	130,497
Fuel [l/km]	0.6[d]						
Fuel [l/h_{G15}]	42.0[n]	12.0[o]		12.0[o]			
Fuel [l/year]	88,200	28,800		28,800		145,800	
LHV_{fuel}[p] [MJ/l]	35.9	35.9		35.9			
Fuel required [MJ/year]	3166,380	1033,920		1033,920		5234,220	
Specific fuel cost[q] [SEK/l]	7.00	7.00		7.00			
Fuel costs [SEK/year]	617,400	201,600		201,600		1020,600	111,920

Table A.J-4 *continued*

Item	Truck	Tractor	Spreader	Tractor	Spreader	Total	Total costs in €
Specific cost of fertilizer[r] [SEK/t]			2740		2740		
Cost of fertilizer [SEK/year]			10879,412		10879,412		
Total costs[s] [SEK/year]	1381,748	1293,292	10964,517	1293,292	10964,517	25897,365	2839,935
Treated area[d] [ha/h_{G15}]			3		3	6	
Treated area [ha/year]			7200		7200	14,400	
Spread amount of nitrogen[d] [kg_N/ha]			150		150	150	
Spread amount of fertilizer[t] [kg/ha]			551		551	551	
Spread amount of fertilizer [t/year]			3971		3971	7941	
Total cost per ha [SEK/ha]						1798	197
Capital cost per ha [SEK/ha]						61.12	
Cost per ha of fertilizer [SEK/ha]						1,511	166
Cost per ton of fertilizer [SEK/t]						3261	358
Weight [t]	20[b]	16[u]	2[v]	16[u]	2[v]	56	
Technical life time [years]	16[w]	16[w]	5[x]	16[w]	5[x]		
Technical life time [hours]	56,000	56,000	17,500	56,000	17,500		
Wear per hour [kg/h_u]	0.357	0.286	0.114	0.286	0.114		
Wear per ha [kg/ha]	0.060	0.048	0.019	0.048	0.019	0.193	
Solar transformity [sej/kg]	2.60E+12[y]	2.97E+12[y]	1.31E+12[y]	2.97E+12[y]	1.31E+12[y]	2.72E+12[z]	
Direct energy required per ha and year [MJ/(ha x year)]						363.5	
Embodied energy[y] [GJ]	1,238	1,133	62.3	1,133	62.3		
Embodied energy [MJ/(ha x year)]	6.14	9.83	1.73	9.83	1.73	29.26	

Table A.J-4 *continued*

a) Medium-large forwarders were used as tractors for the spreader equipments.
b) Data from Staland (2004).
c) The investment cost for a medium-large forwarder is 1600,000 SEK (Gullberg, 2003).
d) Data from Gunnarsson (2004).
e) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
f) The remaining value for the spreaders was assumed to correspond to the scrap value.
g) Data from Huss (2004).
h) Assumed as equal to the quotient of the investment cost and the economic life time.
i) Taxes = 40,000 SEK/year, insurances = 42,000 SEK/year and tyre costs = 75,000 SEK/year (Staland, 2004). Thus, the sum of other costs = (40,000 + 42,000 + 75,000) SEK/year = 157,000 SEK/year.
j) Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
k) Data from Bredberg (2004).
l) The number of personnel is 2 per shift (Gunnarsson, 2004).
m) Calculated as the ratio of the effective operating time and the actual operating time.
n) The average speed was assumed as 70 km/h. Thus, the fuel consumption = 70 x 0.6 l/h_{G15} = 42.0 l/h_{G15}.
o) The fuel consumption at fertilization = 12.0 l/h_{G15} (Gunnarsson, 2004).
p) Data from Swedish Energy Agency (2004b).
q) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
r) Data from Lundh (2005). Delivered in sacks with the weights being 1000 kg. A carriage corresponding to 80 SEK/t is included.
s) The sum of capital costs, service & maintenance costs, personnel costs and fuel costs.
t) The nitrogen content in the forest fertilizer Skog-CAN = 27.2% (Skogens Gödslings AB, 2004 (URL)). Thus, the spread amount of fertilizer = 150 / 0.272 kg/ha = 551 kg/ha.
u) The weight of a John Deere forwarder 1410D 6W is 15,200 kg as a minimum (Deere & Company, 27-Jun-2005 (URL)). The total weight of the forwarder was assumed as 16,000 kg.
v) The weight of a spreader with 1200 kg of loading weight is 625 kg (Sonesson, 1993). The loading weight of the spreaders used for ash recirculation is 6000 kg as a maximum (Gunnarsson, 2004). The weight of the spreaders was assumed as 2000 kg.
w) The technical life time was assumed as twice the economic life time.
x) The spreaders are scrapped after 5 years (Gunnarsson, 2004).
y) See Table A.I-7.
z) The total solar transformity = [the weighted value with regard to the weights of the equipment] = $(20 \times 2.60 \times 10^{12} + 16 \times 2.97 \times 10^{12} + 2.0 \times 1.31 \times 10^{12} + 16 \times 2.97 \times 10^{12} + 2.0 \times 1.31 \times 10^{12}) / 56$ sej/kg = 2.72×10^{12} sej/kg.

Table A.J-5. *Data for ash recirculation*

Item	Truck	Tractor[a]	Spreader	Tractor[a]	Spreader	Total	Total costs in €
Investment [SEK]	2250,000[b]	1600,000[c]	200,000[d]	1600,000[c]	200,000[d]	5850,000	641,518
Remaining value [%]	10%[b]	10%[e]	5%[f]	10%[e]	5%[f]		
Operating time[d] [h_u/year]	3500	3500	3500	3500	3500		
Economic life time [year]	8[b]	8[e]	5[g]	8[e]	5[g]		
Interest rate [%]	6%	6%	6%	6%	6%		
Capital costs [SEK/year]	326,098	231,892	45,105	231,892	45,105	880,092	
Capital costs [SEK/h_u]	93.17	66.25	12.89	66.25	12.89		
Service & maintenance costs [SEK/year]	281,250[h]	200,000[h]	40,000[g]	200,000[h]	40,000[g]		
Other costs [SEK/year]	157,000[i]	64,800[j]		64,800[j]			
Total service & maintenance costs [SEK/year]	438,250	264,800	40,000	264,800	40,000		
Total service & maintenance costs [SEK/h_u]	125.21	75.66	11.43	75.66	11.43		
Personnel costs[k] [SEK/h_u]		170.00		170.00			
Personnel costs[l] [SEK/year]		595,000		595,000			
Actual operating time[d] [h_u/year]	3500	3500	3500	3500	3500		
Utilization factor[m] [%]	60.0%	68.6%	68.6%	68.6%	68.6%		
Effective operating time[d] [h_{G15}/year]	2100	2400	2400	2400	2400		
Capital costs [SEK/year]	326,098	231,892	45,105	231,892	45,105	880,092	96,512
Total service & maintenance costs [SEK/year]	438,250	264,800	40,000	264,800	40,000	1047,850	114,908
Personnel costs [SEK/year]		595,000		595,000		1190,000	130,497
Fuel [l/km]	0.6[d]						
Fuel [l/h_{G15}]	42.0[n]	6.0[o]		6.0[o]			
Fuel [l/year]	88,200	14,400		14,400		117,000	
LHV_{fuel}[p] [MJ/l]	35.9	35.9		35.9			
Fuel required [MJ/year]	3166,380	516,960		516,960		4200,300	
Specific fuel cost[q] [SEK/l]	7.00	7.00		7.00			
Fuel costs [SEK/year]	617,400	100,800		100,800		819,000	89,812

Table A.J-5 *continued*

Item	Truck	Tractor	Spreader	Tractor	Spreader	Total	Total costs in €
Total costs[r] [SEK/year]	1381,748	1192,492	85,105	1192,492	85,105	3936,942	431,730
Treated area[d] [ha/h_{G15}]			1.5		1.5	3	
Treated area [ha/year]			3600		3600	7200	
Spread amount[d] [t_{ash}/ha]			3		3	3	
Spread amount [t_{ash}/h_{G15}]			4.5		4.5	9	
Spread amount [t_{ash}/year]			10,800		10,800	21,600	
Cost per ha [SEK/ha]						547	60
Capital cost per ha [SEK/ha]						122.23	13.40
Cost per ton ash [SEK/t_{ash}]						182	20
Weight [t]	20[b]	16[s]	2[t]	16[s]	2[t]	56	
Technical life time [years]	16[u]	16[u]	5[v]	16[u]	5[v]		
Technical life time [hours]	56,000	56,000	17,500	56,000	17,500		
Wear per hour [kg/h_u]	0.357	0.286	0.114	0.286	0.114		
Wear per ha [kg/ha]	0.060	0.048	0.019	0.048	0.019	0.193	
Solar transformity [sej/kg]	2.60E+12[w]	2.97E+12[w]	1.31E+12[w]	2.97E+12[w]	1.31E+12[w]	2.72E+12[x]	
Direct energy required per ha and year [MJ/(ha x year)]						583.4	
Embodied energy[w] [GJ]	1,238	1,133	62.3	1,133	62.3		
Embodied energy [MJ/(ha x year)]	12.29	19.66	3.46	19.66	3.46	58.52	

Table A.J-5 *continued*

a) Medium-large forwarders were used as tractors for the spreader equipments.
b) Data from Staland (2004).
c) The investment cost for a medium-large forwarder is 1600,000 SEK (Gullberg, 2003).
d) Data from Gunnarsson (2004).
e) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
f) The remaining value for the spreaders was assumed to correspond to the scrap value.
g) Data from Huss (2004).
h) Assumed as equal to the quotient of the investment cost and the economic life time.
i) Taxes = 40,000 SEK/year, insurances = 42,000 SEK/year and tyre costs = 75,000 SEK/year (Staland, 2004). Thus, the sum of other costs = (40,000 + 42,000 + 75,000) SEK/year = 157,000 SEK/year.
j) Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
k) Data from Bredberg (2004).
l) The number of personnel is 2 per shift (Gunnarsson, 2004).
m) Calculated as the ratio of the effective operating time and the actual operating time.
n) The average speed was assumed as 70 km/h. Thus, the fuel consumption = 70 x 0.6 l/h_{G15} = 42.0 l/h_{G15}.
o) The fuel consumption was assumed as half of the fuel consumption at fertilization. The fuel consumption at fertilization = 12.0 l/h_{G15} (Gunnarsson, 2004). Thus, the fuel consumption at ash recirculation = 12.0 / 2 l/h_{G15} = 6.0 l/h_{G15}.
p) Data from Swedish Energy Agency (2004b).
q) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
r) The sum of capital costs, service & maintenance costs, personnel costs and fuel costs.
s) The weight of a John Deere forwarder 1410D 6W is 15,200 kg as a minimum (Deere & Company, 28-Jun-2005 (URL)). The total weight of the forwarder was assumed as 16,000 kg.
t) The weight of a spreader with 1200 kg of loading weight is 625 kg (Sonesson, 1993). The loading weight of the spreaders used for ash recirculation is 6000 kg as a maximum (Gunnarsson, 2004). The weight of the spreaders was assumed as 2000 kg.
u) The technical life time was assumed as twice the economic life time.
v) The spreaders are scrapped after 5 years (Gunnarsson, 2004).
w) See Table A.I-7.
x) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (20 x 2.60 x 10^{12} + 16 x 2.97 x 10^{12} + 2.0 x 1.31 x 10^{12} + 16 x 2.97 x 10^{12} + 2.0 x 1.31 x 10^{12}) / 56 sej/kg = 2.72 x 10^{12} sej/kg.

Table A.J-6. *Data for construction and maintenance of forest drainage*

Item		Costs in €
Investments [SEK/year]	525,000[a]	
Maintenance costs [SEK/year]	10000,000[b]	
Total costs [SEK/year]	10525,000	1154,000
Capital costs [SEK/year]	2363,000[c]	259,200
Capital costs [SEK/ha]	0.108[d]	
Wear [kg/year]	7758[e]	
Wear [kg/ha]	3.55E-04[f]	
Weight of a compact wheel loader [t]	8.0[g]	
Technical life time [years]	10[h]	
Embodied energy of a compact wheel loader [GJ]	495.4[i]	
Embodied energy [MJ/(kg x year)]	6.19[j]	
Embodied energy [kJ/(ha x year)]	2.20[k]	

a) During 1995, 1998, 1999 and 2000, the average cost for construction of new ditches was 7.01 SEK/m, and in 2002, the length of new ditches was 75 km (National Board of Forestry, 2004). The annual cost for construction of new ditches was assumed as 75,000 x 7 SEK = 525,000 SEK.
b) During the years 1995, 1998, 1999 and 2000, the maintenance cost for forest drainage varied from 6.3 MSEK through to 17.2 MSEK (National Board of Forestry, 2004). In this work, the maintenance cost for forest drainage was assumed as 10.0 MSEK/year.
c) The capital cost at construction and maintenance of forest drainage was assumed as proportional to the capital cost and total costs of harvesting and forwarding of roundwood at final felling. The total costs of harvesting and forwarding at final felling = (14.60 + 45.00 + 9.48 + 38.15) SEK/t_{dm} = 107.24 SEK/t_{dm}, and the capital cost of harvesting and forwarding at final felling = (14.60 + 9.48) SEK/t_{dm} = 24.08 SEK/t_{dm} (see Tables A.J-8 and A.J-11). Thus, the capital cost at construction and maintenance of forest drainage = 10525,000 x 10^6 x 24.08 / 107.24 SEK/year = 2363,000 MSEK/year.
d) The capital cost at construction and maintenance of forest drainage per hectare of forest land = 2.363 x 10^6 / (21.84 x 10^6) SEK/ha = 0.108 SEK/ha.
e) The mass depreciation at construction and maintenance of forest drainage was assumed as proportional to the mass depreciation and total costs of harvesting and forwarding of roundwood at final felling. The total costs of harvesting and forwarding at final felling = (14.60 + 45.00 + 9.48 + 38.15) SEK/t_{dm} = 107.24 SEK/t_{dm}, and the mass depreciation of harvesting and forwarding at final felling = (0.042 + 0.037) kg/t_{dm} = 0.079 kg/t_{dm} (see Tables A.J-8 and A.J-11). Thus, the mass depreciation at construction and maintenance of forest drainage = 10.525 x 10^6 x 0.079 / 107.24 kg/year = 7758 kg/year.
f) The mass depreciation at construction and maintenance of forest drainage per hectare of forest land = 7758 / (21.84 x 10^6) kg/ha = 3.55 x 10^{-4} kg/ha.
g) The operating weight of a Volvo compact wheel loader L40B is 7,900 – 8,400 kg (Volvo Construction Equipment Corporation, 2005 (URL)).
h) The average technical life time for equipment used for construction and maintenance of forest drainage was assumed as 10 years.
i) See Table A.H-7.
j) Embodied energy [MJ/(kg x year)] = 495.4 / (8.0 x 10) MJ/(kg x year) = 6.19 MJ/(kg x year).
k) Embodied energy [MJ/(ha x year)] = (embodied energy (MJ/(kg x year))) x (wear (kg/ha)). Thus, the amount of embodied energy [MJ/(ha x year)] = 6.19 x 3.55 x 10^{-4} MJ/(ha x year) = 2.20 kJ/(ha x year).

Table A.J-7. *Data for construction and maintenance of forest roads*

Item		Costs in €
Investments [SEK/year]	122075,000[a]	
Maintenance costs [SEK/year]	605233,000[a]	
Total costs [SEK/year]	727308,000	79757,400
Capital costs [SEK/year]	163316,000[b]	17909,400
Capital costs [SEK/ha]	7.48[c]	
Wear [kg/year]	536,098[d]	
Wear [kg/ha]	2.45E-02[e]	
Weight of a compact wheel loader [t]	8.0[f]	
Technical life time [years]	10[g]	
Embodied energy of a compact wheel loader [GJ]	495.4[h]	
Embodied energy [MJ/(kg x year)]	6.19[i]	
Embodied energy [MJ/(ha x year)]	0.152[j]	

a) Data from National Board of Forestry (2004).

b) The capital cost at construction and maintenance of forest roads was assumed as proportional to the capital cost and total costs of harvesting and forwarding of roundwood at final felling. The total costs of harvesting and forwarding at final felling = (14.60 + 45.00 + 9.48 + 38.15) SEK/t_{dm} = 107.24 SEK/t_{dm}, and the capital cost of harvesting and forwarding at final felling = (14.60 + 9.48) SEK/t_{dm} = 24.08 SEK/t_{dm} (see Tables A.J-8 and A.J-11). Thus, the capital cost at construction and maintenance of forest roads = 727.308 x 10^6 x 24.08 / 107.24 SEK/year = 163.316 MSEK/year.

c) The capital cost at construction and maintenance of forest roads per hectare of forest land = 1.63316 x 10^8 / (21.84 x 10^6) SEK/ha = 7.48 SEK/ha.

d) The mass depreciation at construction and maintenance of forest roads was assumed as proportional to the mass depreciation and total costs of harvesting and forwarding of roundwood at final felling. The total costs of harvesting and forwarding at final felling = (14.60 + 45.00 + 9.48 + 38.15) SEK/t_{dm} = 107.24 SEK/t_{dm}, and the mass depreciation of harvesting and forwarding at final felling = (0.042 + 0.037) kg/t_{dm} = 0.079 kg/t_{dm} (see Tables A.J-8 and A.J-11). Thus, the mass depreciation at construction and maintenance of forest roads = 727.308 x 10^6 x 0.079 / 107.24 kg/year = 536,098 kg/year.

e) The mass depreciation at construction and maintenance of forest roads per hectare of forest land = 536,098 / (21.84 x 10^6) kg/ha = 2.45 x 10^{-2} kg/ha.

f) The operating weight of a Volvo compact wheel loader L40B is 7,900 – 8,400 kg (Volvo Construction Equipment Corporation, 2005 (URL)).

g) The average technical life time for equipment used for construction and maintenance of forest drainage was assumed as 10 years.

h) See Table A.H-7.

i) Embodied energy [MJ/(kg x year)] = 495.4 / (8.0 x 10) MJ/(kg x year) = 6.19 MJ/(kg x year).

j) Embodied energy [MJ/(ha x year)] = (embodied energy (MJ/(kg x year))) x (wear (kg/ha)). Thus, the amount of embodied energy [MJ/(ha x year)] = 6.19 x 2.45 x 10^{-2} MJ/(ha x year) = 0.152 MJ/(ha x year).

Table A.J-8. *Data for harvesters*

Item	Harvester for final felling	Costs in €	Harvester for thinning	Costs in €	Harvester for early thinning	Costs in €
Investment [SEK]	3200,000[a]	350,916	2600,000[a]	285,119	2300,000[a, b]	252,221
Remaining value[c] [%]	15%		15%		15%	
Operating time[d] [h_u/year]	3360		3360		3360	
Economic life time[e] [year]	8		8		8	
Interest rate[c] [%]	6%		6%		6%	
Capital costs [SEK/year]	438,018		355,889		314,825	
Capital costs [SEK/h_u]	130.36		105.92		93.70	
Service & maintenance costs[f] [SEK/year]	400,000		325,000		287,500	
Other costs[g] [SEK/year]	64,800		64,800		64,800	
Total service & maintenance costs [SEK/year]	464,800		389,800		352,300	
Total service & maintenance costs [SEK/h_u]	138.33		116.01		104.85	
Personnel costs[h] [SEK/h_u]	170.00		170.00		170.00	
Personnel costs [SEK/year]	571,200		571,200		571,200	
Actual operating time [h_u/year]	3360		3360		3360	
Utilization factor[a] [%]	81%		81%		81%	
Effective operating time [h_{G15}/year]	2722		2722		2722	
Capital costs [SEK/year]	438,018	48,034	355,889	39,027	314,825	34,524
Total service & maintenance costs [SEK/year]	464,800	50,971	389,800	42,746	352,300	38,634
Personnel costs [SEK/year]	571,200	62,638	571,200	62,638	571,200	62,638
Fuel [l/h_{G15}]	16.5[i]		13.3[c]		10.0[c]	
Fuel [l/year]	44,906		36,288		27,216	
Lower heating value[j] [MJ/l]	35.9		35.9		35.9	
Energy required [MJ/year]	1612,140		1302,739		977,054	
Specific fuel cost[k] [SEK/l]	7.00		7.00		7.00	
Fuel costs [SEK/year]	314,345	34,471	254,016	27,856	190,512	20,892

Table A.J-8 *continued*

Item	Harvester for final felling	Costs in €	Harvester for thinning	Costs in €	Harvester for early thinning	Costs in €
Total costs[l] [SEK/year]	1788,363	196,114	1570,905	172,267	1428,837	156,688
Performance						
Trees per effective hour [trees/h_{G15}]	75[m]		82[n]		200[o]	
Volume per tree [$m^3{}_f$ /tree]	0.35		0.22		0.10	
Production per effective hour, weight[p] [t_{dm}/h_{G15}]	11.0		7.6		8.2	
Production per effective hour, volume[q] [$m^3{}_f$ /h_{G15}]	26.25		18.0		19.6	
Production, dry matter weight [t_{dm}/year]	30,006		20,621		22,404	
Capital costs [SEK/t_{dm}]	14.60		17.26		14.05	
O & M costs [SEK/t_{dm}]	45.00		58.92		49.72	
Weight [t]	20[r]		14[s]		15[t]	
Technical life time[u] [years]	16		16		16	
Technical life time [hours]	53,760		53,760		53,760	
Wear per hour [kg/h_u]	0.372		0.260		0.279	
Wear per produced ton biomass [kg/t_{dm}]	0.042		0.042		0.042	
Solar transformity [sej/kg]	2.97E+12[v]		2.97E+12[v]		2.71E+12[w]	
Direct energy required per metric ton dry matter [MJ/t_{dm}]	53.73		63.18		43.61	
Embodied energy[v] [GJ]	1416		990.8		966.4[x]	
Embodied energy [MJ/t_{dm}]	2.95		3.00		2.70	

Table A.J-8 *continued*

a) Data from Gullberg (2003).
b) Additional investment cost of a CRL machine for trees from early thinning was assumed as 200,000 SEK.
c) Assumed value.
d) The work was assumed as being performed in two shifts of 210 days per year, 8 h_u per shift. Annual operating time = 2 x 210 x 8 h_u/year = 3360 h_u/year.
e) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
f) Assumed as equal to the quotient of the investment cost and the economic life time.
g) Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
h) Data from Bredberg (2004).
i) Data from Berg & Karjalainen (2003).
j) Data from Swedish Energy Agency (2004b).
k) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
l) The sum of capital costs, service & maintenance costs, personnel costs and fuel costs.
m) In the beginning of the 1990s, the performance at final felling was about 60 trees/h_{G15} at a tree volume of 0.35 m^3_{fpb} /tree (Brunberg, 1992). Today, the performance at final felling is assumed as 75 trees/h_{G15} at a tree volume of 0.35 m^3_{fpb}/tree.
n) The performance at thinning was assumed as 82 trees/h_{G15} at a tree volume of 0.22 m^3_{fpb} /tree, according to Brunberg (1997).
o) Data from Lönner *et al.* (1998).
p) The basic density was assumed as 420 kg_{dm}/m^3_f. The production per effective hour [t_{dm}/h_{G15}] = n_{trees} / h_{G15} x V_{tree} x ρ.
q) The production per effective hour [m^3_f/h_{G15}] = n_{trees} / h_{G15} x V_{tree}.
r) The weight of a John Deere 1470D harvester is 19.7 t (Deere & Company, 26-Jun-2005 (URL)).
s) The weight of a John Deere 1070D harvester is 14.1 t (Deere & Company, 27-Jun-2005 (URL)).
t) The weight of a harvester for early thinning is 12.0 t and the weight of a CRL machine for trees from early thinning is 3.0 t (see Table A.I-7). Thus, the total weight of the equipment = 15.0 t.
u) The technical life time was assumed as twice the economic life time.
v) See Table A.I-7.
w) The total solar transformity was weighted with regard to the weights of the equipment. The solar transformities for a harvester for early thinning was 2.97E+12 sej/kg and 1.64E+12 sej/kg for a CRL machine for trees from early thinning (see Table A.H-7). Thus, the total solar transformity = (12.0 x 2.97 x10^{12} + 3.0 x 1.64 x10^{12}) / 15.0 sej/kg = 2.71 x10^{12} sej/kg.
x) The amount of embodied energy for a harvester for early thinning was 849.2 GJ and 117.2 GJ for a CRL machine for trees from early thinning (see Table A.I-7). Thus, the total amount of embodied energy = (849.2 + 117.2) GJ = 966.4 GJ.

Table A.J-9. *Data for felling, delimbing and cutting with power saw*

Item	Felling-delimbing-cutting with power saw	Costs in €	Felling with power saw	Costs in €
Investment[a] [SEK]	6000	658	6000	658
Remaining value[b]	10%		10%	
Operating time [h_u/year]	100[c]		480[d]	
Utilization factor[b] [%]	80%		80%	
Life cycle[b] [year]	8		8	
Interest rate [%]	6%		6%	
Capital costs [SEK/year]	870	95	870	95
Service & maintenance costs[e] [SEK/year]	375		375	
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	375	41	375	41
Personnel costs[f] [SEK/h_u]	170.00		170.00	
Personnel costs [SEK/year]	17,000	1864	81,600	8948
Fuel [l/h_{G15}]	0.55[g]		0.55[h]	
Fuel [l/year]	44		211	
LHV_{fuel}[i] [MJ/l]	32.6		32.6	
LHV_{fuel} [MJ/year]]	1434		6885	
Fuel cost[j] [SEK/l]	7.00		7.00	
Fuel cost per year [SEK/year]	308	34	1478	162
Operating costs[k] [SEK/year]	17,683	1939	83,453	9152
Total annual costs[l] [SEK/year]	18,553	2034	84,323	9247
Production per effective operating hour [t_{dm}/h_{G15}]	0.8[m]		3.7[n]	
Annual production [t_{dm}/year]	61.2		1437.0	
Cost/unit [SEK/t_{dm}]	303.38		58.68	
Capital costs [SEK/t_{dm}]	14.22		0.61	
O & M costs [SEK/t_{dm}]	289.16		58.07	
Weight[o] [t]	0.006		0.006	
Technical life time[p] [years]	16		16	
Technical life time [hours]	1600		7680	
Wear per hour [kg/h_u]	0.004		0.001	
Wear per produced ton biomass [kg/t_{dm}]	0.006		0.0003	
Solar transformity[q] [sej/kg]	1.64E+12		1.64E+12	
Direct energy required per metric ton dry matter [MJ/t_{dm}]	23.46		4.79	
Embodied energy[q] [GJ]	0.23		0.23	
Embodied energy [MJ/t_{dm}]	0.240		0.010	

a) The investment costs of Husqvarna power saws for professional use range from 4800 to 8800 SEK (Husqvarna AB, 2005 (URL)). Thus, the investment cost of a power saw was assumed as 6000 SEK.
b) Assumed value.
c) Manual felling-delimbing-cutting was assumed being performed a short time per year by leisure fellers or owners of small forest properties or workers at ornamental parks *etc*.
d) The work was assumed being performed 3 months per year, 8 h_u per shift. Annual operating time = 3 x 20 x 8 h_u/year = 480 h_u/year.

Table A.J-9 *continued*

e) Assumed as equal to the quotient of half the investment cost and the economic life time.
f) Data from Bredberg (2004).
g) Assumed as equal to the fuel consumption at thinning and final felling by power saw, according to Berg & Karjalainen (2003).
h) Data from Berg & Karjalainen (2003).
i) Data from Swedish Energy Agency (2004b).
j) The cost of petrol was assumed as 7.00 SEK/litre.
k) The sum of service & maintenance total costs, personnel costs and fuel costs.
l) The sum of capital costs and operating costs.
m) The performance when the average diameter in breast height ranges from 10 to 30 cm is 1.20 through to 0.45 h_u/m^3_{sk} at normal conditions (Sennblad & Gustafson, 1975). Thus, the variation in production at the same variation in average diameter in breast height = 0.95 / (1.20 x 0.80) through 0.95 / (0.45 x 0.80) m^3_{fpb}/h_{G15} = 0.99 through to 2.64 m^3_{fpb}/h_{G15}. The average production = ((2.64 – 0.99) / 2 + 0.99) m^3_{fpb}/h_{G15} = 1.82 m^3_{fpb}/h_{G15}. The basic density was assumed as 420 kg_{dm}/m^3_{fpb}. Thus, the production = 1.82 x 0.42 t_{dm}/h_{G15} = 0.76 t_{dm}/h_{G15}.
n) The performance when the average diameter in breast height ranges from 15 cm to 30 cm is 0.20 through to 0.10 h_u/m^3_{sk} (Sennblad & Gustafson, 1975). Thus, the variation in production at the same variation in average diameter in breast height = 0.95 / (0.20 x 0.80) through 0.95 / (0.10 x 0.80) m^3_{fpb}/h_{G15} = 5.94 through 11.88 m^3_{fpb}/h_{G15}. The average production = ((11.88 – 5.94) / 2 + 5.94) m^3_{fpb}/h_{G15} = 8.91 m^3_{fpb}/h_{G15}. The basic density was assumed as 420 kg_{dm}/m^3_{fpb}. Thus, the production = 8.91 x 0.42 t_{dm}/h_{G15} = 3.74 t_{dm}/h_{G15}.
o) The weights of Husqvarna power saws for professional use range from 3.8 to 10.4 kg (Husqvarna AB, 2005 (URL)). Thus, the weight of a power saw was assumed as 6.0 kg.
p) The technical life time was assumed as twice the economic life time.
q) See Table A.I-7.

Table A.J-10. *Data for tractor and delimbing-cutting processor*

Item	Tractor	Processor	Total	Costs in €
Investment [SEK]	300,000[a]	180,000[b]	480,000	52,637
Remaining value [%]	15%[c, d]	25%[c, e]		
Operating time [h_u/year]	1000[f]	480[g]		
Economic life time [year]	11[h]	8[i]		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	32,332	21,740		
Capital costs [SEK/h_u]	32.33	45.29		
Service & maintenance costs[j] [SEK/year]	27,273	22,500		
Other costs [SEK/year]	5000[i]			
Total service & maintenance costs [SEK/year]	32,273	22,500		
Total service & maintenance costs [SEK/h_u]	32.27	46.88		
Personnel costs [SEK/h_u]	170.00[k]			
Personnel costs [SEK/year]	170,000			
Actual operating time[l] [h_u/year]	480	480		
Utilization factor[i] [%]	85%	85%		
Effective operating time [h_{G15}/year]	408	408		
Capital costs [SEK/year]	15,519	21,740	37,259	4086
Total service & maintenance costs [SEK/year]	15,491	22,500	37,991	4166
Personnel costs [SEK/year]	81,600		81,600	8948
Fuel [l/h_{G15}]	5.00[m]			
Fuel [l/year]	2040		2040	
LHV_{fuel} [MJ/l]	35.9[n]			
Energy required [MJ/year]	73,236		73,236	
Specific fuel cost	7.00[o]			
Fuel costs [SEK/year]	14,280		14,280	1566
Total costs [SEK/year]	126,890	44,240	171,130	18,766
Performance				
Trees per effective hour [trees/h_{G15}]		78[p]		
Volume per tree [m^3f /tree]		0.25		
Production per effective hour, weight[q] [t_{dm}/h_{G15}]		8.2		
Production per effective hour, volume[r] [m^3f /h_{G15}]		19.5		
Production, dry matter weight [t_{dm}/year]		3342		
Weight [t]	5.0[s]	1.5[i]	6.5	
Technical life time[t] [years]	22	16		
Technical life time [hours]	22,000	7680		
Wear per hour [kg/h_u]	0.227	0.195		
Wear per produced ton biomass [kg/t_{dm}]	0.033	0.028	0.061	
Solar transformity [sej/kg]	2.60E12[u]	1.64E12[u]	2.38E12[v]	
Direct energy required per metric ton dry matter [MJ/t_{dm}]	21.92		21.92	
Embodied energy[u] [GJ]	309.6	58.6		
Embodied energy [MJ/t_{dm}]	2.02	1.10	2.07[w]	

a) Data from Gullberg (2003).
b) Data from Eklund (2004).

Table A.J-10 *continued*

c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) The remaining value for tractors used in forestry was assumed as 15% after 11 years.
e) The remaining value was assumed as 25% after 8 years.
f) The annual operating time for tractors was assumed as 1000 h_u/year, according to Hadders, Jonsson, & Sundberg (1997).
g) The work was assumed being performed 3 months per year, 8 h_u per shift. Annual operating time = 3 x 20 x 8 h_u/year = 480 h_u/year.
h) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). It was assumed that the economic life time for tractors used in forestry was equal to the economic life time for tractors used in agriculture, ***i.e.*** 11 years.
i) Assumed value.
j) Assumed as equal to the quotient of the investment cost and the economic life time.
k) Data from Bredberg (2004).
l) See footnote g.
m) The fuel cost is 30 SEK/h_{G15} (Gullberg, 2003). The fuel cost = 7.00 SEK/litre (see footnote o). Thus, the amount of fuel required = 30 / 7.00 litre/h_{G15} = 5.00 litre/h_{G15}.
n) Data from Swedish Energy Agency (2004b).
o) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
p) The performance was assumed as 78 trees/h_{G15} at a tree volume of 0.25 m^3_{fpb} /tree, according to Gullberg (2004).
q) The basic density was assumed as 420 kg_{dm}/m^3_f. The production per effective hour [t_{dm}/h_{G15}] = n_{trees} / h_{G15} x V_{tree} x ρ.
r) The production per effective hour [m^3_f/h_{G15}] = n_{trees} / h_{G15} x V_{tree}.
s) The average shipping weight of a John Deere 6620SE is 5,020 kg (John Deere International, 27-Jun-2005 (URL)).
t) The technical life time was assumed as twice the economic life time.
u) See Table A.I-7.
v) The total solar transformity = the weighted value with regard to the weights of the equipment. Thus, the total solar transformity = (5.0 x 2.60 x 10^{12} + 1.5 x 1.64 x 10^{12}) / 6.5 sej/kg = 2.38 x 10^{12} sej/kg.
w) The total embodied energy = the sum of embodied energy with regard to the annual actual operating time. Thus, the total embodied energy = (480 / 1000 x 2.02 + 480 / 480 x 1.10) MJ/t_{dm} = 2.07 MJ/t_{dm}.

Table A.J-11. *Data for forwarders for final felling and for thinning*

Item	Forwarder for final felling	Costs in €	Forwarder for thinning	Costs in €
Investment [SEK]	1750,000[a]	191,907	1350,000[a]	148,043
Remaining value[b] [%]	10%		10%	
Operating time[c] [h_u/year]	3360		3360	
Economic life time[b] [year]	8		8	
Interest rate [%]	6%		6%	
Capital costs [SEK/year]	253,632		195,659	
Capital costs [SEK/h_u]	75.49		58.23	
Service & maintenance costs[d] [SEK/year]	109,375		84,375	
Other costs[e] [SEK/year]	64,800		64,800	
Total service & maintenance costs [SEK/year]	174,175		149,175	
Total service & maintenance costs [SEK/h_u]	51.84		44.40	
Personnel costs[f] [SEK/h_u]	170.00		170.00	
Personnel costs [SEK/year]	571,200		571,200	
Actual operating time [h_u/year]	3360		3360	
Utilization factor[a] [%]	90%		90%	
Effective operating time [h_{G15}/year]	3024		3024	
Capital costs [SEK/year]	253,632	27,814	195,659	21,456
Total service & maintenance costs [SEK/year]	174,175	19,100	149,175	16,359
Personnel costs [SEK/year]	571,200	62,638	571,200	62,638
Fuel [l/h_{G15}]	13.0[g]		10.0[h]	
Fuel [l/year]	39,312		30,240	
LHV_{fuel}[i] [MJ/l]	35.9		35.9	
Energy required [MJ/year]	1411,301		1085,616	
Specific fuel cost[j] [SEK/l]	7.00		7.00	
Fuel costs [SEK/year]	275,184	30,177	211,680	23,213

Table A.J-11 *continued*

Item	Forwarder for final felling		Costs in €	Forwarder for thinning		Costs in €
Total costs[k] [SEK/year]		1274,191	139,729		1127,714	123,666
	Roundwood	Bales		Roundwood	Bales	
Load space [m^3]	27.0[l]	31.3[m]		14.8[n]	14.8[n]	
Solid volume [%]	65[o]	40[p]		60[q]	40[p]	
Basic density [kg/m^3_f]	420[r]	410[s]		420[r]	410[s]	
Solid volume per load[t] [m^3_f/load]	17.55	12.50		8.88	5.92	
Dry matter per load[u] [t_{dm}/load]	7.37	5.13		3.73	2.43	
Speed[v] [km/h]	3.6	3.6		3.6	3.6	
Transport distance[w] [m]	450	450		450	450	
Travel distance[x] [m]	900	900		900	900	
Loading and unloading [min_{G15}/load]	35[y, z]	30[aa]		45[y, bb]	30[cc]	
Time per turn[dd] [min]	50	45		60	45	
Performance						
Production per effective hour, weight[ee] [t_{dm}/h_{G15}]	8.85	6.83		3.73	3.24	
Production per effective hour, volume[ff] [m^3f/h_{G15}]	21.1	16.7		8.9	7.9	
Production, dry matter weight [t_{dm}/year]	26,748	20,664		11,278	9786	
Capital costs [SEK/t_{dm}]	9.48	12.27		17.35	19.99	
O & M costs [SEK/t_{dm}]	38.15	49.39		82.64	95.24	
Weight [t]	18[gg]	18[gg]		11[hh]	11[hh]	
Technical life time[ii] [years]	16	16		16	16	
Technical life time [hours]	53,760	53,760		53,760	53,760	
Wear per hour [kg/h_u]	0.298	0.298		0.298	0.298	
Wear per produced ton biomass [kg/t_{dm}]	0.037	0.048		0.089	0.102	
Solar transformity[jj] [sej/kg]	2.97E+12	2.97E+12		2.97E+12	2.97E+12	
Direct energy required per metric ton dry matter [MJ/t_{dm}]	52.76	68.30		96.26	110.93	

Table A.J-11 *continued*

Item	Forwarder for final felling		Costs in €	Forwarder for thinning		Costs in €
	Roundwood	Bales		Roundwood	Bales	
Embodied energy[jj] [GJ]	1,274	1,274		778.4	778.4	
Embodied energy [MJ/t_{dm}]	2.976	3.853		4.314	4.971	

Table A.J-11 *continued*

a) Data from Gullberg (2003).
b) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
c) The work was assumed being performed in two shifts 210 days per year, 8 h_u per shift. Annual operating time = 2 x 210 x 8 h_u/year = 3360 h_u/year.
d) Assumed as equal to the quotient of half the investment cost and the economic life time.
e) Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
f) Data from Bredberg (2004).
g) Gullberg (2003) estimates the fuel cost to be 78 SEK/h_{G15}, when the fuel cost is 6.00 SEK/litre. Thus, the amount of fuel required = 78 / 6.00 litre/h_{G15} = 13.0 litre/h_{G15}.
h) Gullberg (2003) estimates the fuel cost to be 60 SEK/h_{G15}, when the fuel cost is 6.00 SEK/litre. Thus, the amount of fuel required = 60 / 6.00 litre/h_{G15} = 10.0 litre/h_{G15}.
i) Data from Swedish Energy Agency (2004b).
j) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
k) The sum of capital costs, service & maintanenance costs, personnel costs and fuel costs.
l) The cross sectional area was assumed as 5.4 m^2, according to the minimum cross sectional area of a John Deere forwarder 1710D VLS (Deere & Company, 27-Jun-2005 (URL)). The load height was assumed as 5.0 m. Thus, the load space = 5.4 x 5.0 m^3 = 27.0 m^3.
m) The cross sectional area was assumed as 2.5 x 2.5 m^2 = 6.25 m^2, according to a medium cross sectional area of a John Deere forwarder 1710D VLS (Deere & Company, 27-Jun-2005 (URL)). The load height was assumed as 5.0 m. Thus, the load space = 6.25 x 5.0 m^3 = 31.25 m^3.
n) The cross sectional area of a John Deere forwarder 810D = 3.3 – 3.9 m^2 (John Deere International, 16-Aug-2005 (URL)). Thus, the cross sectional area was assumed as 3.7 m^2 and the load height was assumed as 4.0 m. Thus, the load space = 4.0 x 3.7 m^3 = 14.8 m^3.
o) The percentage of solid volume for pulp wood of pine = 65 – 72%. The corresponding percentage of solid volume for pulp wood of spruce and birch = 65 – 73% and 50 – 68% respectively (Nylinder, 1979). The average percentage of solid volume of roundwood was assumed as 65%.
p) The percentage of solid volume for undensified logging residues is 10 – 20% (Nylinder, 1979). The average percentage of solid volume for baled logging residues was assumed as 40%.
q) The percentage of solid volume for broad-leaf trees and coniferous trees with the average diameter being 10 cm is 56 – 59% and 64 – 67% (Nylinder, 1972). The average percentage of solid volume for trees received at thinning was assumed as 60%.
r) The basic density of wood = 420 $kg_{dm}/m^3{}_f$ (see Table A.B-2).
s) The basic density of logging residues from pine and spruce is 395 $kg_{dm}/m^3{}_f$ and 425 $kg_{dm}/m^3{}_f$ respectively (Hakkila, 1978). Thus, the average value of the basic density of logging residues from pine and spruce = (395 + 425) / 2 $kg_{dm}/m^3{}_f$ = 410 $kg_{dm}/m^3{}_f$.
t) V_{solid} per load = (load space) x (percentage of solid volume)
u) Dry matter per load = ρ_{wood} x V_{solid} / load
v) The average speed was assumed as 3.6 kg/h, according to Andersson & Nordén (2000).
w) The transport distance was assumed as 450 m.
x) Travel distance = 2 x (transport distance)
y) Edin & Forsman (2002) estimate the average time for loading and unloading to be 72.5% of the total time used for forwarding.
z) The time for loading and unloading of roundwood at final felling was assumed as 70.0% of the total time used for forwarding.

Table A.J-11 *continued*

aa) The time for loading and unloading at forwarding of bales received at final felling was assumed as somewhat shorter than the time required for loading and unloading of roundwood at final felling.
bb) The time for loading and unloading of roundwood at thinning was assumed as 75.0% of the total time used for forwarding.
cc) The time for loading and unloading at forwarding of bales received at thinning was assumed as equal to the time required for loading and unloading of bales received at final felling.
dd) Time per turn = (time for loading and unloading) + (travel distance) / (speed)
ee) Production per effective hour [t_{dm}/h_{G15}] = (dry matter per load) / ((time for loading and unloading) + (travel distance) / (speed))
ff) Production per effective hour [m^3_f/h_{G15}] = (production per effective hour) / ρ_{wood}
gg) The weight of a John Deere forwarder 1710D 6W = 18,100 kg (Deere & Company, 28-Jun-2005 (URL)).
hh) The minimum weight of a John Deere forwarder 810D = 10,970 kg (John Deere International, 16-Aug-2005 (URL)).
ii) The technical life time was assumed as twice the economic life time.
jj) See Table A.I-7.

Table A.J-12. *Data for tractor and trailer with grapple loader for forwarding*

Item	Tractor	Trailer	Total	Total costs in €
Investment [SEK]	300,000[a]	90,000[a]	390,000	42,768
Remaining value [%]	15%[b, c]	25%[b, d]		
Operating time [h_u/year]	1000[e]	480[f]		
Economic life time[g] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	32,332	8559		
Capital costs [SEK/h_u]	32.33	17.83		
Service & maintenance costs[h] [SEK/year]	27,273	8182		
Other costs [SEK/year]	64,800[i]			
Total service & maintenance costs [SEK/year]	92,073	8182		
Total service & maintenance costs [SEK/h_u]	92.07	17.05		
Personnel costs [SEK/h_u]	170.00[j]			
Personnel costs [SEK/year]	170,000			
Actual operating time[k] [h_u/year]	480	480		
Utilization factor[l] [%]	85%	85%		
Effective operating time [h_{G15}/year]	408	408		
Capital costs [SEK/year]	15,519	8559	24,078	2640
Total service & maintenance costs [SEK/year]	44,195	8182	52,377	5744
Personnel costs [SEK/year]	81,600		81,600	8948
Fuel [l/h_{G15}]	5.00[m]			
Fuel [l/year]	2040		2040	
LHV_{fuel} [MJ/l]	35.9[n]			
Energy required [MJ/year]	73,236		73,236	
Specific fuel cost [SEK/l]	7.00[o]			
Fuel costs [SEK/year]	14,280		14,280	1566
Total costs [SEK/year]	155,594	16,740	172,335	18,898
Load space [m^3]			10.0[p]	
Solid volume [%]			65[q]	
Density [kg_{dm}/m^3f]			420[r]	
Solid volume per load[s] [$m^3{}_f$/load]			6.50	
Dry matter per load[t] [t_{dm} /load]			2.73	
Speed [km/h]			3.6[u]	
Transport distance [m]			450[v]	
Travel distance[w] [m]			900	
Loading and unloading [min_{G15}/load]			45[x]	
Time per turn[y] [min]			30	
Performance				
Production per effective hour, weight[z] [t_{dm}/h_{G15}]			3.64	
Production per effective hour, volume[aa] [m^3f /h_{G15}]			8.7	
Production, dry matter weight [t_{dm}/year]			1485	
Capital costs [SEK/t_{dm}]			16.21	
O & M costs [SEK/t_{dm}]			99.83	

Table A.J-12 *continued*

Item	Tractor	Trailer	Total
Weight [t]	5.0[bb]	3.5[cc]	8.5
Technical life time[dd] [years]	22	22	
Technical life time [hours]	22,000	10,560	
Wear per hour [kg/h_u]	1.000	2.083	
Wear per produced ton biomass [kg/t_{dm}]	0.323	0.673	0.997
Solar transformity [sej/kg]	2.60E12[ee]	1.54E12[ee]	2.16E12[ff]
Direct energy required per metric ton dry matter [MJ/t_{dm}]	49.31		49.31
Embodied energy[ee] [GJ]	309.6	128.2	
Embodied energy [MJ/t_{dm}]	4.55	3.92	6.11[gg]

a) Data from Gullberg (2003).
b) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for tractors used in forestry was assumed as 15% after 11 years.
d) The remaining value was assumed as 25% after 8 years.
e) The annual operating time for tractors was assumed as 1000 h_u/year, according to Hadders, Jonsson, & Sundberg (1997).
f) The work was assumed being performed in 3 months per year, 8 h_u per shift. Annual operating time = 3 x 20 x 8 h_u/year = 480 h_u/year.
g) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The economic life time for tractors used in forestry was assumed equal to the economic life time for tractors used in agriculture, *i.e.* 11 years.
h) Assumed as equal to the quotient of the investment cost and the economic life time.
i) Other costs were assumed as equal to other costs for forwarder for final felling and forwarder for thinning, *i.e.* 64,800 SEK/year (see Table A.D-4, footnote e).
j) Data from Bredberg (2004).
k) See footnote f.
l) Assumed value.
m) The fuel cost is 30 SEK/h_{G15} (Gullberg, 2003). The fuel cost = 7.00 SEK/litre (see footnote o). Thus, the amount of fuel required = 30 / 7.00 litre/h_{G15} = 5.00 litre/h_{G15}.
n) Data from Swedish Energy Agency (2004b).
o) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
p) The cross sectional areas for trailers produced by Moheda System AB range from 1.9 to 3.0 m^2 (Moheda System AB, 2005 (URL)). Thus, the average cross sectional area for these trailers is about 2.5 m^2. The load height was assumed as 4.0 m. Thus, the load space = 2.5 x 4.0 m^3 = 10.0 m^3.
q) The percentage of solid volume for pulp wood of pine = 65 – 72%. The corresponding percentage of solid volume for pulp wood of spruce and birch = 65 – 73% and 50 – 68% respectively (Nylinder, 1979). The average percentage of solid volume of roundwood was assumed as 65%.
r) The basic density of wood = 420 $kg_{dm}/m^3{}_f$ (see Table A.B-2).
s) V_{solid} per load = (load space) x (percentage of solid volume)
t) Dry matter per load = ρ_{wood} x V_{solid} / load
u) The average speed was assumed as 3.6 kg/h, according to Andersson & Nordén (2000).
v) The transport distance was assumed as 450 m.
w) Travel distance = 2 x (transport distance)

Table A.J-12 *continued*

x) The effective operating time for loading and unloading was assumed as equal to the effective operating time for loading and unloading at forwarding of roundwood at thinning, *i.e.* 45 min_{G15}/load.
y) Time per turn = (time for loading and unloading) + (travel distance) / (speed)
z) Production per effective hour [t_{dm}/h_{G15}] = (dry matter per load) / ((time for loading and unloading) + (travel distance) / (speed))
aa) Production per effective hour [m^3_f/h_{G15}] = (production per effective hour) / ρ_{wood}
bb) The average shipping weight of a John Deere 6620SE is 5020 kg (John Deere International, 27-Jun-2005 (URL)).
cc) The weight of a Kronos trailer 120 4WD = 1950 kg (Wikar Oy Ab, 7-Sep-2005 (URL)). The weight of a Kronos loader 5000 XXL with grapple and rotator = 1250 kg (Wikar Oy Ab, 8-Sep-2005 (URL)). The total weight of the trailer, grapple and loader was assumed as 3500 kg.
dd) The technical life time was assumed as twice the economic life time.
ee) See Table A.I-7.
ff) The total solar transformity = [the weighted value with regard to the weights of the equipment] = ($5.0 \times 2.60 \times 10^{12} + 3.5 \times 1.54 \times 10^{12}$) / 8.5 sej/kg = 2.16×10^{12} sej/kg.
gg) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time] = (480 / 1000 x 4.55 + 480 / 480 x 3.92) MJ/t_{dm} = 6.11 MJ/t_{dm}.

Table A.J-13. *Data for tractor and hanger with grapple loader for forwarding*

Item	Tractor	Hanger	Total	Total costs in €
Investment [SEK]	150,000[a]	40,000[b]	190,000	20,836
Remaining value [%]	15%[c, d]	25%[c, e]		
Operating time [h_u/year]	1000[f]	160[g]		
Economic life time[h] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	16,166	3804		
Capital costs [SEK/h_u]	16.17	23.77		
Service & maintenance costs[i] [SEK/year]	13,636	3636		
Total service & maintenance costs [SEK/h_u]	13.64	22.73		
Personnel costs [SEK/h_u]	170.00[j]			
Personnel costs [SEK/year]	170,000			
Actual operating time[k] [h_u/year]	160	160		
Utilization factor[l] [%]	85%	85%		
Effective operating time [h_{G15}/year]	136	136		
Capital costs [SEK/year]	2587	3804	6390	701
Total service & maintenance costs [SEK/year]	2182	3636	5818	638
Personnel costs [SEK/year]	27,200		27,200	2983
Fuel [l/h_{G15}]	0.70[l]			
Fuel [l/year]	95.2		95.2	
LHV_{fuel} [MJ/l]	35.9[m]			
Energy required [MJ/year]	3418		3418	
Specific fuel cost [SEK/l]	7.00[n]			
Fuel costs [SEK/year]	666		666	73
Total costs [SEK/year]	32,635	7440	40,075	4395
Density [kg_{dm}/m^3f]			420[o]	
Performance				
Production per effective hour, weight [t_{dm}/h_{G15}]			0.5[p]	
Production per effective hour, volume[q] [m^3f /h_{G15}]			1.2	
Production, dry matter weight [t_{dm}/year]			68.0	
Weight [t]	2.0[r]	1.0[s]	3.0	
Technical life time[t] [years]	22	22		
Technical life time [hours]	22,000	3520		
Wear per hour [kg/h_u]	1.000	6.250		
Wear per produced ton biomass [kg/t_{dm}]	2.353	14.706	17.059	
Solar transformity [sej/kg]	2.60E12[u]	1.54E12[u]	2.25E12[v]	
Direct energy required per metric ton dry matter [MJ/t_{dm}]	50.26		50.26	
Embodied energy[u] [GJ]	123.8	36.6		
Embodied energy [MJ/t_{dm}]	13.2	24.5	26.6[w]	

a) The investment cost for a small tractor was assumed as 150,000 SEK.
b) The investment cost for a hanger was assumed as 40,000 SEK.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) The remaining value for tractors used in forestry was assumed as 15% after 11 years.
e) The remaining value was assumed as 25% after 8 years.

Table A.J-13 *continued*

f) The annual operating time for tractors was assumed as 1000 h_u/year, according to Hadders, Jonsson, & Sundberg (1997).
g) The work was assumed being performed 1 month per year, 8 h_u per shift. Annual operating time = 20 x 8 h_u/year = 160 h_u/year.
h) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The economic life time for tractors used in forestry was assumed as equal to the economic life time for tractors used in agriculture, ***i.e.*** 11 years.
i) Assumed as equal to the quotient of the investment cost and the economic life time.
j) Data from Bredberg (2004).
k) See footnote g.
l) Assumed value.
m) Data from Swedish Energy Agency (2004b).
n) The cost of diesel oil was assumed equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
o) The basic density of wood = 420 kg_{dm}/m^3_f (see Table A.B-2).
p) The production per effective hour was assumed as 0.5 t_{dm}/h_{G15}.
q) Production per effective hour [m^3_f /h_{G15}] = (production per effective hour) / ρ_{wood}
r) The weight of a small tractor was assumed as 2000 kg.
s) The weight of a hanger was assumed as 1000 kg.
t) The technical life time was assumed as twice the economic life time.
u) See Table A.I-7.
v) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (2.0 x 2.60 x 10^{12} + 1.0 x 1.54 x 10^{12}) / 3.0 sej/kg = 2.25 x 10^{12} sej/kg.
w) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time] = (160 / 1000 x 13.2 + 160 / 160 x 24.5) MJ/t_{dm} = 26.6 MJ/t_{dm}.

Table A.J-14. *Data for bundling*

Item	Forwarder	Bundler	Total	Total costs in €
Investment [SEK]	1350,000[a]	1458,000[b]	2808,000	307,929
Remaining value[c] [%]	10%	10%		
Operating time [h_u/year]	3360[d]	1680[e]		
Economic life time[c] [year]	8	6		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	195,659	266,852		
Capital costs [SEK/h_u]	58.23	158.84		
Service & maintenance costs [SEK/year]	84,375[f]	243,000[g]		
Other costs [SEK/year]		64,800[h]		
Total service & maintenance costs [SEK/year]	84,375	307,800		
Total service & maintenance costs [SEK/h_u]	25.11	183.21		
Personnel costs [SEK/h_u]		170.00[i]		
Personnel costs [SEK/year]		285,600		
Actual operating time [h_u/year]	1680	1680		
Utilization factor[j] [%]	85%	85%		
Effective operating time [h_{G15}/year]	1428	1428		
Capital costs [SEK/year]	97,829	266,852	364,682	39,991
Total service & maintenance costs [SEK/year]	42,188	307,800	349,988	38,380
Personnel costs [SEK/year]		285,600	285,600	31,319
Fuel [l/h_{G15}]		12.5[k]		
Fuel [l/year]		17,850	17,850	
LHV_{fuel} [MJ/l]		35.9[l]		
Fuel required [MJ/year]		640,815	640,815	
Specific fuel cost [SEK/l]		7.00[m]		
Fuel costs [SEK/year]		124,950	124,950	13,702
Total costs[n] [SEK/year]	140,017	985,202	1125,219	123,393
Density [kg_{dm}/m^3f]		410[o]		
Bales per hour [bales/h_{G15}]		23.4[p]/15.0[q]		
Dry matter per bale [t_{dm}/bale]		0.269[r]		
Production per effective hour, weight[s] [t_{dm}/h_{G15}]		6.28/4.03		
Production, dry matter weight[t] [t_{dm}/year]		8972/5751		
Capital costs [SEK/t_{dm}]			40.65	
O & M costs [SEK/t_{dm}]			84.77	
Weight [t]				
Technical life time[w] [years]	11.0[u]	6.5[v]	17.5	
Technical life time [hours]	16	12		
Wear per hour [kg/h_u]	53,760	20,160		
Wear per produced ton biomass	0.205	0.322		
[kg/t_{dm}]	0.060	0.094	0.154	
Solar transformity [sej/kg]	2.97E+12[x]	1.64E+12[x]	2.48E+12[y]	
Direct energy required per t_{dm}[z] [MJ/t_{dm}]		71.42/111.42	71.42/111.42	

Table A.J-14 *continued*

Item	Forwarder	Bundler	Total	Total costs in €
Embodied energy[x] [GJ]	778.4	253.9		
Embodied energy[z] [MJ/t_{dm}]	2.71/4.23	2.36/3.68	3.71[aa]/5.79[bb]	

a) Data from Gullberg (2003).
b) The investment cost of bundler Fiberpac 370 was 1375,000 SEK in year 2000 (Andersson & Nordén, 2000). The change in consumer price index for January 2000-June 2002 = 6.0% (Statistics Sweden, 19-Jul-2004 (URL)). Thus, the investment cost in June 2002 = 1375,000 x 1.06 SEK = 1458,000 SEK.
c) According to cost calculations of forestry equipment performed by Andersson & Nordén (2000).
d) The forwarder was assumed being used in two shifts 210 days per year, 8 h_u per shift. Annual operating time = 2 x 210 x 8 h_u/year = 3360 h_u/year.
e) The bundler was assumed being used in two shifts 105 days per year, 8 h_u per shift. Annual operating time = 2 x 105 x 8 h_u/year = 1680 h_u/year.
f) Assumed as equal to the quotient of half the investment cost and the economic life time.
g) Assumed as equal to the quotient of the investment cost and the economic life time.
h) Travelling costs = 50,400 SEK/year, insurances = 8400 SEK/year and tyre costs = 6000 SEK/year (Andersson & Nordén, 2000). Thus, the sum of other costs = (50,400 + 8400 + 6000) SEK/year = 64,800 SEK/year.
i) Data from Bredberg (2004).
j) Assumed value.
k) Data from Andersson & Nordén (2000).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The sum of capital costs, service & maintenance costs, personnel costs and fuel costs.
o) The average value of the basic density of logging residues from pine and spruce = 410 kg_{dm}/m^3_f (see Table A.J-11, footnote s).
p) The number of bundled bales per hour at final felling = 23.4 bales/h_{G15} (Andersson & Nordén, 2000).
q) The number of bundled bales per hour at thinning was assumed as 15.0 bales/h_{G15}.
r) Data from Andersson & Nordén (2000). The dry matter weight per bale was assumed equal at final felling and thinning.
s) The production (dry matter weight) per effective hour = (the number of bales per hour) x (dry matter weight per bale). The value to the left of the slash is for final felling, whereas the value to the right of the slash is for thinning.
t) The annual production (dry matter weight) = (the production (dry matter weight) per effective hour) x (annual effective operating time). The value to the left of the slash is for final felling, whereas the value to the right of the slash is for thinning.
u) The minimum weight of a John Deere forwarder 810D = 10,970 kg (John Deere International, 16-Aug-2005 (URL)).
v) Data from Andersson & Nordén (2000).
w) The technical life time was assumed as twice the economic life time.
x) See Table A.I-7.
y) The total solar transformity = [the weighted value with regard to the weights of the equipment] = $(11.0 \times 2.97 \times 10^{12} + 6.5 \times 1.64 \times 10^{12}) / 17.5$ sej/kg = 2.48×10^{12} sej/kg.
z) The value to the left of the slash is for final felling, whereas the value to the right of the slash is for thinning.

Table A.J-14 *continued*

aa) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time] = (1680 / 3360 x 2.71 + 1680 / 1680 x 2.36) MJ/t_{dm} = 3.71 MJ/t_{dm}.

bb) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time] = (1680 / 3360 x 4.23 + 1680 / 1680 x 3.68) MJ/t_{dm} = 5.79 MJ/t_{dm}.

Table A.J-15. *Data for agriculture at willow farming (compiled from Tables A.J-18 through to A.J-22, A.J-24 through to A.J-27 and A.J-34)*

Item	Direct energy use [MJ/(ha x yr)]	Mass depreciation [kg/(ha x yr)]	Weight of equipment [t]	Solar transformity [sej/kg]	Embodied energy [MJ/t_{dm}]	Specific capital costs [SEK/(ha x yr)]	O & M costs [SEK/(ha x yr)]	Expendables [SEK/(ha x yr)]
Harrowing	7.20	0.008	9.40	2.33E+12	0.03	1.21	5.02	
Mechanical weed control	9.77	0.020	7.90	2.48E+12	0.08	3.94	13.87	
Clearing of stones	13.05	0.049	8.00	2.60E+12	0.11	5.76	13.99	
Rolling	4.73	0.012	10.50	2.25E+12	0.05	1.52	5.29	
Planting	16.32	0.028	8.10	2.48E+12	0.14	12.91	38.42	255.82
Trimming	78.99	0.074	8.80	2.38E+12	0.29	16.30	61.23	
Herbicides	52.22	0.066	7.70	2.53E+12	0.46	13.77	56.33	68.82
Fertilization of low plant stands	157.63	0.523	15.70	2.54E+12	3.78	42.14	159.57	428.86
Fertilization of high plant stands	31.53	0.102	15.40	2.57E+12	0.75	9.07	31.51	316.45
Soil milling	190.92	0.257	8.40	2.42E+12	1.52	40.18	130.13	
Total	562.36	1.139		2.46E+12[a]	7.21	146.80	515.35	1 069.95

a) The total solar transformity for machinery equipment was calculated by weighting the solar transformities of each operation by the weight of equipment used in the operation.

Table A.J-16a. *Data for agriculture at reed canary grass farming (compiled from Tables A.J-18, A.J-21, A.J-23, A.J-26, A.J-35 and A.J-36)*

Item	Direct energy use [MJ/(ha x yr)]	Mass depreciation [kg/(ha x yr)]	Weight of equipment [t]	Solar transformity [sej/kg]	Embodied energy [MJ/t_{dm}]	Specific capital costs [SEK/(ha x yr)]	O & M costs [SEK/(ha x yr)]	Expendables [SEK/(ha x yr)]
Harrowing	28.79	0.030	9.4	2.17E+12	0.16	4.84	20.09	
Sowing	24.44	0.039	8.5	2.44E+12	0.35	6.31	23.30	146.18
Rolling	18.93	0.050	10.5	2.25E+12	0.27	6.09	21.15	
Fertilization	225.19	0.747	15.7	2.54E+12	7.32	60.19	227.96	547.75
Disc harrow ploughing	117.49	0.135	9.0	2.34E+12	1.14	21.77	88.65	
Ploughing	102.80	0.125	10.3	2.38E+12	2.19	19.98	78.42	
Total	517.64	1.126		2.37E+12[a]	11.44	119.19	459.56	693.94

Table A.J-16b. *Data for baling, field transport and storage at reed canary grass farming (compiled from Tables A.J-31 through A.J-33)*

Item	Direct energy use [MJ/(ha x yr)]	Mass depreciation [kg/(ha x yr)]	Weight of equipment [t]	Solar transformity [sej/kg]	Embodied energy [MJ/t_{dm}]	Specific capital costs [SEK/(ha x yr)]	O & M costs [SEK/(ha x yr)]
Baling	568.36	1.493	14.0	2.12E+12	11.36	353.87	838.38
Field transport	98.64	0.400	11.2	2.21E+12	3.24	58.94	157.80
Storage						454.39	2.27
Total	667.01	1.893		2.16E+12[a]	14.60	867.20	998.45

a) The total solar transformity for machinery equipment was calculated by weighting the solar transformities of each operation by the weight of equipment used in the operation.

Table A.J-17. *Data for baling, field transport and storage of straw at wheat farming (compiled from Tables A.J-31 through to A.J-33)*

Item	Direct energy use [MJ/(ha x yr)]	Mass depreciation [kg/(ha x yr)]	Weight of equipment [t]	Solar transformity [sej/kg]	Embodied energy [MJ/t_{dm}]	Specific capital costs [SEK/(ha x yr)]	O & M costs [SEK/(ha x yr)]
Baling	694.67	1.824	14.0	2.12E+12	46.84	432.50	1024.69
Field transport	120.56	0.489	11.2	2.21E+12	13.37	72.04	192.86
Storage						208.26	1.04
Total	815.23	2.313		2.16E+12[a]	60.21	712.81	1 218.59

a) The total solar transformity for machinery equipment was calculated by weighting the solar transformities of each operation by the weight of equipment used in the operation.

Table A.J-18. *Data for harrowing*

Item	Tractor	Harrow	Total	Costs in €
Investment [SEK]	620,000[a]	140,000[b]	760,000	83,342
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	13,313		
Capital costs [SEK/h_u]	58.96	26.63		
Service & maintenance costs [SEK/year]	62,000[f]	49,000[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	49,000		
Total service & maintenance costs [SEK/h_u]	62.00	98.00		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	13,313	42,793	4693
Total service & maintenance costs [SEK/year]	20,925	33,075	54,000	5922
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	21.00[k]			
Fuel [l/year]	7088		7088	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	254,441		254,441	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	49,613		49,613	5441
Total costs [SEK/year]	173,952	46,388	220,340	24,163
Treated area [ha/h_{G15}]		4.76[n]		
Treated area [ha/year]		1607	1607	
Cost per ha [SEK/ha]			137	
Specific capital costs[o] [SEK/(ha x year)]			1.21/4.84	
Specific O & M costs[o] [SEK/(ha x year)]			5.02/20.09	
Weight [t]	7.0[p]	2.4[q]	9.4	
Technical life time[r] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.218		
Wear per ha [kg/ha]	0.099	0.068	0.167	
Mass depreciation [kg/(ha x year)]			0.008[s]/0.030[t]	
Solar transformity [sej/kg]	2.60E12[u]	1.54E12[u]	2.33E12[v]	
Direct energy required per ha [MJ/ha]	158.32		158.32	
Direct energy required per ha and year [MJ/(ha x year)]	7.20[w]/28.79[x]		7.20/28.79	
Embodied energy[t] [GJ]	433.4	87.7		

Table A.J-18 *continued*

Item	Tractor	Harrow	Total
Embodied energy [MJ/(ha x year)]	6.13	2.48	0.25[y]/1.01[z]
Embodied energy [MJ/t_{dm}]			0.03[aa]/0.16[bb]

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Towed harrow. Width = 7 m.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for cultivation equipment = 0.70 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.70 x 140,000 / 1000 x 500 SEK/year = 49,000 SEK/year.
h) Data from Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the harrow.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Assumed value for a tractor with 110 kW power output, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed equal to the cost during 2002 in Sweden, being approximately 7 SEK/l (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The effective operating time per ha with a harrow with the width being 7.8 m = 0.21 h_{G15}/ha (Landbrugets rådgivningscenter, 2002). The treated area = 1 / 0.21 ha/h_{G15} = 4.76 ha/h_{G15}.
o) The value to the left of the slash is for willow farming, whereas the value to the right of the slash is for reed canary grass farming.
p) Data from Sonesson (1993).
q) The weight of a harrow with a width being 9 m = 3.1 t (Sonesson, 1993). Thus, the weight of a harrow with a width being 7 m was assumed as 7 / 9 x 3.1 t = 2.4 t.
r) The technical life time was assumed as twice the economic life time.
s) The mass depreciation at willow farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.167 x 1 / 22 kg/(ha x year) = 0.008 kg/(ha x year).
t) The mass depreciation at reed canary grass farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.167 x 2 / 11 kg/(ha x year) = 0.030 kg/(ha x year).
u) See Table A.I-7.
v) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 2.4 x 1.54 x 10^{12}) / 9.4 sej/kg = 2.33 x 10^{12} sej/kg.

Table A.J-18 *continued*

w) Direct energy required per hectare and year for willow farming = (direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period). Thus, direct energy required per hectare and year = 158.32 x 1 / 22 MJ/(ha x year) = 7.20 MJ/(ha x year).

x) Direct energy required per hectare and year for reed canary grass farming = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 158.32 x 2 / 11 MJ/t_{dm} = 28.79 MJ/(ha x year).

y) The total embodied energy for willow farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 6.13 + 500 / 500 x 2.48) / 22 MJ/(ha x year) = 0.25 MJ/(ha x year).

z) The total embodied energy for reed canary grass farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 6.13 + 500 / 500 x 2.48) x 2 / 11 MJ/(ha x year) = 1.01 MJ/(ha x year).

aa) Embodied energy for willow farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 0.25 x 22 / 183 MJ/t_{dm} = 0.03 MJ/t_{dm}.

bb) Embodied energy for reed canary grass farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 1.01 x 11 / 67.5 MJ/t_{dm} = 0.16 MJ/t_{dm}.

Table A.J-19. *Data for mechanical weed control at willow farming*

Item	Tractor	Harrow	Total	Costs in €
Investment [SEK]	620,000[a]	100,000[b]	720,000	78,956
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	9509		
Capital costs [SEK/h_u]	58.96	19.02		
Service & maintenance costs [SEK/year]	62,000[f]	35,000[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	35,000		
Total service & maintenance costs [SEK/h_u]	62.00	70.00		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338	38,989	4,276
Capital costs [SEK/year]	29,479	9509	44,550	4885
Total service & maintenance costs [SEK/year]	20,925	23,625	73,935	8108
Personnel costs [SEK/year]	73,935			
Fuel [l/h_{G15}]	7.98[k]			
Fuel [l/year]	2693		2693	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	96,688		96,688	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	18,853		18,853	2067
Total costs [SEK/year]	143,192	33,134	176,327	19,336
Treated area [ha/h_{G15}]		4.0[n]		
Treated area [ha/year]		1,350	1,350	
Cost per ha [SEK/ha]			131	
Specific capital costs [SEK/(ha x year)]			3.94	
Specific O & M costs [SEK/(ha x year)]			13.87	
Weight [t]	7.0[o]	0.9[o]	7.9	
Technical life time[p] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.082		
Wear per ha [kg/ha]	0.118	0.030	0.148	
Mass depreciation [kg/(ha x year)]			0.020[q]	
Solar transformity [sej/kg]	2.60E12[r]	1.54E12[r]	2.48E12[s]	
Direct energy required per ha [MJ/ha]	71.62		71.62	
Direct energy required per ha and year[t] [MJ/(ha x year)]	9.77		9.77	
Embodied energy[r] [GJ]	433.4	32.9		
Embodied energy [MJ/(ha x year)]	7.30	1.11	0.65[u]	
Embodied energy [MJ/t_{dm}]			0.08[v]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-19 *continued*

b) Assumed value, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for cultivation equipment = 0.70 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.70 x 100,000 / 1000 x 500 SEK/year = 35,000 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the harrow.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) The fuel consumption at mechanical weed control is 38% of the fuel consumption at ordinary harrowing (Sonesson, 1993). The fuel consumption at ordinary harrowing = 21.00 litre/h_{G15} (see Table A.D-15). Thus, the fuel consumption at mechanical weed control = 0.38 x 21.00 litre/h_{G15} = 7.98 litre/h_{G15}.
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) Data from Sonesson (1993). The working width = 6.2 m and the working speed = 9 km/h.
o) Data from Sonesson (1993).
p) The technical life time was assumed as twice the economic life time.
q) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.148 x 3 / 22 kg/(ha x year) = 0.020 kg/(ha x year).
r) See Table A.I-7.
s) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 0.9 x 1.54 x 10^{12}) / 7.9 sej/kg = 2.48 x 10^{12} sej/kg.
t) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 71.62 x 3 / 22 MJ/(ha x year) = 9.77 MJ/(ha x year).
u) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 7.30 + 500 / 500 x 1.11) x 3 / 22 MJ/t_{dm} = 0.65 MJ/t_{dm}.
v) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 0.65 x 22 / 183 MJ/t_{dm} = 0.08 MJ/t_{dm}.

Table A.J-20. *Data for clearing of stones at willow farming*

Item	Loader	Costs in €
Investment [SEK]	450,000[a]	49,348
Remaining value [%]	25%[b]	
Operating time [h_u/year]	500[c]	
Economic life time [year]	11[d]	
Interest rate [%]	6%	
Capital costs [SEK/year]	42,793	
Capital costs [SEK/h_u]	85.59	
Service & maintenance costs [SEK/year]	16,313[e]	
Other costs [SEK/year]		
Total service & maintenance costs [SEK/year]	16,313	
Total service & maintenance costs [SEK/h_u]	32.63	
Personnel costs [SEK/h_u]	147.87[f]	
Personnel costs [SEK/year]	73,935	
Actual operating time [h_u/year]	150[g]	
Utilization factor [%]	67.5%[h]	
Effective operating time [h_{G15}/year]	101	
Capital costs [SEK/year]	12,838	1408
Total service & maintenance costs [SEK/year]	3303	362
Personnel costs [SEK/year]	22,181	2432
Fuel [l/h_{G15}]	8.00[i]	
Fuel [l/year]	810	
Lower heating value [MJ/l]	35.9[j]	
Energy required [MJ/year]	29,079	
Specific fuel cost [SEK/l]	7.00[k]	
Fuel costs [SEK/year]	5670	622
Total costs [SEK/year]	43,992	4824
Treated area [ha/h_{G15}]	1.00[l]	
Treated area [ha/year]	101	
Cost per ha [SEK/ha]	434	
Specific capital costs [SEK/(ha x year)]	5.76	
Specific O & M costs [SEK/(ha x year)]	13.99	
Weight [t]	8.0[m]	
Technical life time [years]	22[n]	
Technical life time [hours]	11,000	
Wear per hour [kg/h_u]	0.727	
Wear per ha [kg/ha]	1.077	
Mass depreciation [kg/(ha x year)]	0.049[o]	
Solar transformity [sej/kg]	2.60E+12[p]	
Direct energy required per ha [MJ/ha]	287.20	
Direct energy required per ha and year [MJ/(ha x year)]	13.05[q]	
Embodied energy [GJ]	495.4[p]	
Embodied energy [MJ/(ha x year)]	0.91[r]	
Embodied energy [MJ/t_{dm}]	0.11[s]	

a) A two wheel-drive loader with accessories (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) Data from Hadders, Jonsson, & Sundberg (1997).

Table A.J-20 *continued*

d) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
e) The service & maintenance cost = 0.0725 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.0725 x 450,000 / 1000 x 500 SEK/year = 16,313 SEK/year.
f) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
g) Assumed value.
h) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
i) Assumed value based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
j) Data from Swedish Energy Agency (2004b).
k) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
l) Data from Rosenqvist (1997).
m) The operating weight of a Volvo compact wheel loader L40B is 7,900 – 8,400 kg (Volvo Construction Equipment Corporation, 2005 (URL)).
n) The technical life time was assumed as twice the economic life time.
o) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1.077 x 1 / 22 kg/(ha x year) = 0.049 kg/(ha x year).
p) See Table A.I-7.
q) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 287.20 x 1 / 22 MJ/(ha x year) = 13.05 MJ/(ha x year).
r) The total embodied energy = 495.4 / (22 x 1.00 x 500 x 0.675) MJ/(ha x year) = 66.72 MJ/(ha x year). The embodied energy at willow farming = [the total embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (150 / 500 x 66.72) / 22 MJ/t_{dm} = 0.91 MJ/t_{dm}.
s) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 0.91 x 22 / 183 MJ/t_{dm} = 0.11 MJ/t_{dm}.

Table A.J-21. *Data for rolling*

Item	Tractor	Roller	Total	Costs in €
Investment [SEK]	620,000[a]	100,000[b]	720,000	78,956
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	9509		
Capital costs [SEK/h_u]	58.96	19.02		
Service & maintenance costs [SEK/year]	62,000[f]	25,000[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	25,000		
Total service & maintenance costs [SEK/h_u]	62.00	50.00		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	9509	38,989	4276
Total service & maintenance costs [SEK/year]	20,925	16,875	37,800	4145
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	10.00[k]			
Fuel [l/year]	3375		3375	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	121,163		121,163	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	23,625		23,625	2591
Total costs [SEK/year]	147,964	26,384	174,349	19,119
Treated area [ha/h_{G15}]		3.45[n]		
Treated area [ha/year]		1164	1164	
Cost per ha [SEK/ha]			150	
Specific capital costs[o] [SEK/(ha x year)]			1.52/6.09	
Specific O & M costs[o] [SEK/(ha x year)]			5.29/21.15	
Weight [t]	7.0[p]	3.5[q]		
Technical life time[r] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.318		
Wear per ha [kg/ha]	0.137	0.137	0.273	
Mass depreciation [kg/(ha x year)]			0.012[s]/0.050[t]	
Solar transformity [sej/kg]	2.60E12[u]	1.54E12[u]	2.25E12[v]	
Direct energy required per ha [MJ/ha]	104.11		104.11	
Direct energy required per ha and year [MJ/(ha x year)]	4.73[w]/18.93[x]		4.73/18.93	
Embodied energy[u] [GJ]	433.4	127.9		

Table A.J-21 *continued*

Item	Tractor	Roller	Total	Costs in €
Embodied energy [MJ/(ha x year)]	8.46	5.00	0.42[y]/1.68[z]	
Embodied energy [MJ/t_{dm}]			0.05[aa]/0.27[bb]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Carried by wheels. Width = 9 m.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The service & maintenance costs for cultivation equipment range from 50% to 90% of [(investment cost) / 1000 x (operating time)] (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The service & maintenance costs for rollers were assumed as equal to 50% of [(investment cost) / 1000 x (operating time)]. Thus, the service & maintenance costs = 0.50 x 100,000 / 1000 x 500 SEK/year = 25,000 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the roller.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The effective operating time per ha with a roller with the operation width being 8.7 m = 0.29 h_{G15}/ha (Elinder & Falk, 1983). The treated area = 1 / 0.29 ha/h_{G15} = 3.45 ha/h_{G15}.
o) The value to the left of the slash is for willow farming, whereas the value to the right of the slash is for reed canary grass farming.
p) Data from Sonesson (1993).
q) Assumed as equal to the weight of a Väderstad Rollex roller RX 940, operation width = 9,4 m (Sonesson, 1993).
r) The technical life time was assumed as twice the economic life time.
s) The mass depreciation at willow farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.273 x 1 / 22 kg/(ha x year) = 0.012 kg/(ha x year).
t) The mass depreciation at reed canary grass farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.273 x 2 / 11 kg/(ha x year) = 0.050 kg/(ha x year).
u) See Table A.I-7.
v) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 3.5 x 1.54 x 10^{12}) / 10.5 sej/kg = 2.25 x 10^{12} sej/kg.

Table A.J-21 *continued*

w) Direct energy required per hectare and year at willow farming = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 104.11 x 1 / 22 MJ/(ha x year) = 4.73 MJ/(ha x year).
x) Direct energy required per hectare and year at reed canary grass farming = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 104.11 x 2 / 11 MJ/(ha x year) = 18.93 MJ/(ha x year).
y) The total embodied energy at willow farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 8.46 + 500 / 500 x 5.00) / 22 MJ/(ha x year) = 0.42 MJ/(ha x year).
z) The total embodied energy at reed canary grass farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 8.46 + 500 / 500 x 5.00) x 2 / 11 MJ/(ha x year) = 1.68 MJ/(ha x year).
aa) Embodied energy at willow farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 0.42 x 22 / 183 MJ/t_{dm} = 0.05 MJ/t_{dm}.
bb) Embodied energy at reed canary grass farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 1.68 x 11 / 67.5 MJ/t_{dm} = 0.27 MJ/t_{dm}.

Table A.J-22. *Data for planting of willow*

Item	Tractor	Planter	Total	Costs in €
Investment [SEK]	620,000[a]	550,000[b]	1170,000	128,304
Remaining value [%]	25%[c]	0%[d]		
Operating time [h_u/year]	1000[e]	667[d]		
Economic life time [year]	11[f]	8[d]		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	88,570		
Capital costs [SEK/h_u]	58.96	132.79		
Service & maintenance costs [SEK/year]	62,000[g]	183,425[h]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	183,425		
Total service & maintenance costs [SEK/h_u]	62.00	275.00		
Personnel costs [SEK/h_u]	147.87[i]			
Personnel costs [SEK/year]	147,870			
Actual operating time[j] [h_u/year]	667	667		
Utilization factor[k] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	450	450		
Capital costs [SEK/year]	39,325	88,570	127,895	14,025
Total service & maintenance costs [SEK/year]	27,914	123,812	151,726	16,638
Personnel costs[l] [SEK/year]	197,259		197,259	21,632
Fuel [l/h_{G15}]	10.0[d]			
Fuel [l/year]	4502		4502	
Lower heating value [MJ/l]	35.9[m]			
Energy required [MJ/year]	161,631		161,631	
Specific fuel cost [SEK/l]	7.00[n]			
Fuel costs [SEK/year]	31,516		31,516	3456
Expendables [SEK/year]		2533,866[o]	2533,866	277,867
Total costs [SEK/year]	296,014	2746,248	3042,262	333,618
Treated area [ha/h_{G15}]		1.00[d]		
Treated area [ha/year]		450	450	
Cost per ha [SEK/ha]			6757	
Specific capital costs [SEK/(ha x year)]			12.91	
Specific O & M costs [SEK/(ha x year)]			38.42	
Specific costs for expendables [SEK/(ha x year)]			255.82	
Weight[p] [t]	7.0	1.1	8.1	
Technical life time[q] [years]	22	16		
Technical life time [hours]	22,000	10,672		
Wear per hour [kg/h_u]	0.318	0.103		
Wear per ha [kg/ha]	0.471	0.153	0.624	
Mass depreciation [kg/(ha x year)]			0.028[r]	
Solar transformity [sej/kg]	2.60E12[s]	1.69E12[s]	2.48E12[t]	
Direct energy required per ha [MJ/ha]	359.00		359.00	
Direct energy required per ha and year[u] [MJ/(ha x year)]	16.32		16.32	
Embodied energy[s] [GJ]	433.4	44.2		

Table A.J-22 *continued*

Item	Tractor	Planter	Total	Costs in €
Embodied energy [MJ/(ha x year)]	29.19	6.13	1.16[v]	
Embodied energy [MJ/t_{dm}]			0.14[w]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) The investment cost of the planter model "Step" (Sjöström, 2004).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data from Sjöström (2004).
e) Data from Hadders, Jonsson, & Sundberg (1997).
f) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
g) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
h) The service & maintenance costs for the planter were assumed equal to the service & maintenance costs for a sowing machine, being 50% of [(investment cost) / 1000 x (operating time)] (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs for the planter = 0.50 x 550,000 / 1000 x 667 SEK/year = 183,425 SEK/year.
i) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
j) Equal to the operating time for the planter.
k) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
l) 2 to 3 persons are required for planting, including the driver of the tractor (Rosenqvist, 1997). Here, 2 persons including the driver of the tractor were assumed being required for planting. Thus, the personnel costs = 2 x 147.87 x 667 SEK/year = 197,259 SEK/year.
m) Data from Swedish Energy Agency (2004b).
n) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
o) The number of cuttings planted = 14,000 ha^{-1} (Sjöström, 2004). The cost per cutting is estimated by the Swedish Energy Agency (2003c) as 0.402 SEK at planting of large areas. Treated area = 450 ha/year. Thus, the cost of cuttings per year of planting = 0.402 x 14,000 x 450 SEK/year = 2533,866 SEK/ha.
p) Data from Sonesson (1993).
q) The technical life time was assumed as twice the economic life time.
r) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.624 x 1 / 22 kg/(ha x year) = 0.028 kg/(ha x year).
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 1.1 x 1.69 x 10^{12}) / 8.1 sej/kg = 2.48 x 10^{12} sej/kg.
u) Direct energy required per t_{dm} = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 359.00 x 1 / 22 MJ/(ha x year) = 16.32 MJ/(ha x year).

Table A.J-22 *continued*

v) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (667 / 1000 x 29.19 + 667 / 667 x 6.13) / 22 MJ/t_{dm} = 1.16 MJ/t_{dm}.
w) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 1.16 x 22 / 183 MJ/t_{dm} = 0.14 MJ/t_{dm}.

Table A.J-23. *Data for sowing at reed canary grass farming*

Item	Tractor	Sowing machine	Total	Costs in €
Investment [SEK]	620,000[a]	75,000[b]	695,000	76,214
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	7,132		
Capital costs [SEK/h_u]	58.96	14.26		
Service & maintenance costs [SEK/year]	62,000[f]	18,750[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	18,750		
Total service & maintenance costs [SEK/h_u]	62.00	37.50		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	7132	36,611	4015
Total service & maintenance costs [SEK/year]	20,925	12,656	33,581	3683
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	11.70[k]			
Fuel [l/year]	3949		3949	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	141,760		141,760	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	27,641		27,641	3031
Expendables [SEK/year]		847,969[n]	847,969	14,822
Total costs [SEK/year]	151,981	867,757	1019,738	111,826
Treated area [ha/h_{G15}]			1.56[o]	
Treated area [ha/year]			527	
Cost per ha [SEK/ha]			1934	
Specific capital costs [SEK/(ha x year)]			6.31	
Specific O & M costs [SEK/(ha x year)]			23.30	
Specific costs for expendables [SEK/(ha x year)]			146.18	
Weight[p] [t]	7.0	1.5	8.5	
Technical life time[q] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.136		
Wear per ha [kg/ha]	0.302	0.129	0.431	
Mass depreciation [kg/(ha x year)]			0.039[r]	
Solar transformity [sej/kg]	2.60E12[s]	1.69E12[s]	2.44E12[t]	
Direct energy required per ha [MJ/ha]	268.82		268.82	
Direct energy required per ha and year [MJ/(ha x year)]	24.44[u]		24.44	
Embodied energy[r] [GJ]	433.4	60.2		
Embodied energy [MJ/(ha x year)]	37.4	5.19	2.17[v]	
Embodied energy [MJ/t_{dm}]			0.35[w]	

Table A.J-23 *continued*

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Carried sowing machine with an operational width being 4 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The service & maintenance costs for sowing machines = 0.50 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.50 x 75,000 / 1000 x 500 SEK/year = 18,750 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the sowing machine.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The amount of seeds required = 15 kg/ha, and the cost of seeds was 100 SEK/kg in 1997 (Olsson *et al.*, 2001). Change in consumer price index for July 1997 – June 2002 = 7.2% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the cost of seeds in June 2002 = 100 x 1.072 SEK/kg = 107.20 SEK/kg, and the cost of seeds per hectare = 107.20 x 15 SEK/ha = 1608 SEK/ha. The total cost of seeds per year of sowing = [(the cost of seeds per hectare) x (treated area per year)] = 1608 x 527 SEK/year = 847,969 SEK/year.
o) The effective operating time per ha with a sowing machine with the operational width being 4.0 m and the speed being 7 km/h = 0.64 h_{G15}/ha (Elinder & Falk, 1983). The treated area = 1 / 0.64 ha/h_{G15} = 1.56 ha/h_{G15}.
p) Data from Sonesson (1993).
q) The technical life time was assumed as twice the economic life time.
r) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.431 x 1 / 11 kg/(ha x year) = 0.039 kg/(ha x year).
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 1.5 x 1.69 x 10^{12}) / 8.5 sej/kg = 2.44 x 10^{12} sej/kg.
u) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 268.82 x 1 / 11 MJ/(ha x year) = 24.44 MJ/(ha x year).
v) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 37.4 + 500 / 500 x 5.19) / 11 MJ/(ha x year) = 2.17 MJ/(ha x year).
w) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 2.17 x 11 / 67.5 MJ/t_{dm} = 0.35 MJ/t_{dm}.

Table A.J-24. *Data for trimming at willow farming*

Item	Tractor	Field chopper	Total	Costs in €
Investment [SEK]	620,000[a]	250,000[b]	870,000	95,405
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	23,774		
Capital costs [SEK/h_u]	58.96	47.55		
Service & maintenance costs [SEK/year]	62,000[f]	81,250[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	81,250		
Total service & maintenance costs [SEK/h_u]	62.00	162.50		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	23,774	53,253	5840
Total service & maintenance costs [SEK/year]	20,925	54,844	75,769	8309
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	21.30[k]			
Fuel [l/year]	7189		7189	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	258,076		258,076	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	50,321		50,321	5518
Total costs [SEK/year]	174,661	78,617	253,278	27,775
Treated area [ha/h_{G15}]		0.44[k]		
Treated area [ha/year]		149	149	
Cost per ha [SEK/ha]			1706	
Specific capital costs [SEK/(ha x year)]			16.30	
Specific O & M costs [SEK/(ha x year)]			61.23	
Weight [t]	7.0[n]	1.8[o]	8.8	
Technical life time[p] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.164		
Wear per ha [kg/ha]	1.071	0.551	1.622	
Mass depreciation [kg/(ha x year)]			0.074[q]	
Solar transformity [sej/kg]	2.60E12[r]	1.54E12[r]	2.38E12[s]	
Direct energy required per ha [MJ/ha]	1737.89		1737.89	
Direct energy required per ha and year[t] [MJ/(ha x year)]	78.99		78.99	
Embodied energy[r] [GJ]	433.4	65.9		
Embodied energy [MJ/(ha x year)]	66.3	20.2	2.42[u]	
Embodied energy [MJ/t_{dm}]			0.29[v]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-24 *continued*

b) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Medium size, acid pump is included.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for field choppers with an acid pump = 0.65 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.65 x 250,000 / 1000 x 500 SEK/year = 81,250 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the field chopper.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) Data from Sonesson (1993).
o) The weights for different precision choppers range from 1300 to 2300 kg (Statens Maskinprovningar, 1986). Thus, the weight of a chopper of medium size is about 1800 kg.
p) The technical life time was assumed as twice the economic life time.
q) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1.622 x 1 / 22 kg/(ha x year) = 0.074 kg/(ha x year).
r) See Table A.I-7.
s) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 1.8 x 1.4 x 10^{12}) / 8.8 sej/kg = 2.38 x 10^{12} sej/kg.
t) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1737.89 x 1 / 22 MJ//ha x year) = 78.99 MJ/(ha x year).
u) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 66.3 + 500 / 500 x 20.2) / 22 MJ/t_{dm} = 2.42 MJ/t_{dm}.
v) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 2.42 x 22 / 183 MJ/t_{dm} = 0.29 MJ/t_{dm}.

Table A.J-25. *Data for spraying of herbicides at willow farming*

Item	Tractor	Sprayer	Total	Costs in €
Investment [SEK]	620,000[a]	110,000[b]	730,000	80,053
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	10,460		
Capital costs [SEK/h_u]	58.96	20.92		
Service & maintenance costs [SEK/year]	62,000[f]	57,750[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	57,750		
Total service & maintenance costs [SEK/h_u]	62.00	115.50		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	10,460	39,940	4380
Total service & maintenance costs [SEK/year]	20,925	38,981	59,906	6569
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	12.50[k]			
Fuel [l/year]	4219		4219	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	151,453		151,453	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	29,531		29,531	3238
Cost of Cougar [SEK/year]		594,844[n]	594,844	65,231
Cost of Roundup Bio [SEK/year]		143,136[o]	143,136	15,696
Total costs at spraying of Cougar [SEK/year]	153,871	644,285	798,156	87,527
Total costs at spraying of Roundup Bio [SEK/year]	153,871	192,578	346,448	37,992
Treated area [ha/h_{G15}]			3.125[p]	
Treated area [ha/year]			1055	
Cost per hectare at spraying of Cougar [SEK/ha]			757	
Cost per hectare at spraying of Roundup Bio [SEK/ha]			328	
Specific capital costs [SEK/(ha x year)]			13.77	
Specific O & M costs [SEK/(ha x year)]			56.33	
Specific costs for expendables [SEK/(ha x year)]			68.82	
Weight [t]	7.0[q]	0.7[r]	7.7	
Technical life time[s] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.064		
Wear per ha [kg/ha]	0.151	0.030	0.181	
Mass depreciation [kg/(ha x year)]			0.066[t]	

Table A.J-25 *continued*

Item	Tractor	Sprayer	Total	Costs in €
Solar transformity [sej/kg]	2.60E12[u]	1.79E12[u]	2.53E12[v]	
Direct energy required per ha [MJ/ha]	143.60		143.60	
Direct energy required per ha and year [MJ/(ha x year)]	52.22[w]		52.22	
Embodied energy[u] [GJ]	433.4	29.8		
Embodied energy [MJ/(ha x year)]	18.7	1.28	3.86[x]	
Embodied energy [MJ/t_{dm}]			0.46[y]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Carried sprayer, volume = 1000 litre, operation width = 12 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The service & maintenance costs for sprayers range from 60% to 150% of [(investment cost) / 1000 x (operating time)] (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The service & maintenance costs for the sprayer were assumed as equal to 105% of [(investment cost) / 1000 x (operating time)]. Thus, the service & maintenance costs = 1.05 x 110,000 / 1000 x 500 SEK/year = 57,750 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the sprayer.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The dosage of Cougar at one occasion per rotation is 2.0 litre/ha, and the cost is 282 SEK/litre (Jansson, 2004a). The treated area = 1055 ha/year. Thus, the cost of Cougar per year = 282 x 2.0 x 1055 SEK/year = 594,844 SEK/year.
o) The dosage of Roundup Bio per rotation is 19.0 litre/ha and the number of occasions of spraying per rotation is seven (see Chapter 3). The cost of Roundup Bio is 50 SEK/litre (Jansson, 2004a). The treated area = 1055 ha/year. Thus, the average cost of Roundup Bio per year of occasion = 50 x 19.0 x 1055 / 7 SEK/year = 143,136 SEK/year.
p) The effective operating time per ha with a sprayer with the operation width being 12 m and the tank volume being 800 litre = 0.32 h_{G15}/ha (Landbrugets rådgivningscenter, 2002). The treated area = 1 / 0.32 ha/h_{G15} = 3.125 ha/h_{G15}.
q) Data from Sonesson (1993).

Table A.J-25 *continued*

r) The weight of a sprayer with the operation width being 12 m and loading capacity being 1500 litre = 800 kg (Sonesson, 1993). The weight of a sprayer with the operation width being 12 m and loading capacity being 1000 litre was assumed as 700 kg.
s) The technical life time was assumed as twice the economic life time.
t) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.181 x 8 / 22 kg/(ha x year) = 0.066 kg/(ha x year).
u) See Table A.I-7.
v) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 0.7 x 1.79 x 10^{12}) / 7.7 sej/kg = 2.53 x 10^{12} sej/kg.
w) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (dry matter yield per rotation period)] = 143.60 x 8 / 22 MJ/(ha x year) = 52.22 MJ/(ha x year).
x) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 18.7 + 500 / 500 x 1.28) x 7 / 22 MJ/t_{dm} = 3.86 MJ/t_{dm}.
y) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 3.86 x 22 / 183 MJ/t_{dm} = 0.46 MJ/t_{dm}.

Table A.J-26. *Data for fertilization of low stands*

Item	Tractor	Loader	Fertilizer spreader	Total	Total costs in €
Investment [SEK]	620,000[a]	450,000[b]	70,000[c]	1140,000	125,014
Remaining value[d] [%]	25%	25%	25%		
Operating time[e] [h_u/year]	1000	500	500		
Economic life time[f] [year]	11	11	11		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	58,959	42,793	6657		
Capital costs [SEK/h_u]	58.96	85.59	13.31		
Service & maintenance costs [SEK/year]	62,000[g]	16,313[h]	36,750[i]		
Other costs [SEK/year]					
Total service & maintenance costs [SEK/year]	62,000	16,313	36,750		
Total service & maintenance costs [SEK/h_u]	62.00	32.63	73.50		
Personnel costs[j] [SEK/h_u]	147.87	147.87			
Personnel costs [SEK/year]	147,870	73,935			
Actual operating time [h_u/year]	500[k]	100[l]	500[k]		
Utilization factor[m] [%]	67.5%	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	68	338		
Capital costs [SEK/year]	29,479	8559	6657	44,695	4901
Total service & maintenance costs [SEK/year]	20,925	2202	24,806	47,933	5256
Personnel costs [SEK/year]	73,935	14,787		88,722	9729
Fuel[n] [l/h_{G15}]	12.50	6.5			
Fuel [l/year]	4219	439		4658	
LHV_{fuel}[o] [MJ/l]	35.9	35.9			
Fuel required [MJ/year]	151,453	15,751		167,204	
Specific fuel cost[p] [SEK/l]	7.00	7.00			
Fuel cost [SEK/year]	29,531	3071		32,603	3575

Table A.J-26 *continued*

Item	Tractor	Loader	Fertilizer spreader	Total	Total costs in €
Cost of N fertilizer at willow farming [SEK/year]			447,552[q]	447,552	49,079
Cost of PK fertilizer at willow farming [SEK/year]			462,240[r]	462,240	50,690
Cost of NPK fertilizer at RCG farming [SEK/year]			406,708[s]	406,708	44,600
Total costs at N fertilization at willow farming [SEK/year]	153,871	28,619	479,015	661,504	72,541
Total costs at PK fertilization at willow farming [SEK/year]	153,871	28,619	493,703	676,192	74,152
Total costs at NPK fertilization at RCG farming [SEK/year]	153,871	28,619	438,171	620,660	68,062
Treated area [ha/h_{G15}]			2.00[t]		
Treated area [ha/year]			675		
Cost per ha at N fertilization at willow farming [SEK/ha]				980	
Cost per ha at PK fertilization at willow farming [SEK/ha]				1002	
Cost per ha at NPK fertilization at RCG farming [SEK/ha]				919	
Specific capital costs[u] [SEK/(ha x year)]				42.14/60.19	
Specific O & M costs[u] [SEK/(ha x year)]				159.57/227.96	
Specific costs for expendables[u] [SEK/(ha x year)]				428.86/547.75	
Weight [t]	7.0[v]	8.0[w]	0.7[x]	15.7	
Technical life time[y] [years]	22	22	22		
Technical life time [hours]	22,000	11,000	11,000		
Wear per hour [kg/h_u]	0.318	0.727	0.064		
Wear per ha [kg/ha]	0.236	0.539	0.047	0.822	
Mass depreciation [kg/(ha x year)]				0.523[z]/0.747[aa]	
Solar transformity [sej/kg]	2.60E+12[bb]	2.60E+12[bb]	1.31E+12[bb]	2.54E+12[cc]	
Direct energy required per ha [MJ/ha]				247.71	
Direct energy required per ha and year [MJ/(ha x year)]				157.63[dd]/225.19[ee]	
Embodied energy[bb] [GJ]	433.4	495.4	21.8		

Table A.J-26 *continued*

Item	Tractor	Loader	Fertilizer spreader	Total	Total costs in €
Embodied energy [MJ/(ha x year)]	29.19	166.8	1.47	31.4[ff]/44.9[gg]	
Embodied energy [MJ/t_{dm}]				3.78[hh]/7.32[ii]	

Table A.J-26 *continued*

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) A two wheel-drive loader with accessories (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) Carried spreader, maximum volume = 2.5 m^3 and the operation width = 24 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
e) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
f) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
g) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
h) The service & maintenance cost = 0.0725 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.0725 x 450,000 / 1000 x 500 SEK/year = 16,313 SEK/year.
i) The service & maintenance costs for fertilizer spreaders range from 60% to 150% of [(investment cost) / 1000 x (operating time)] (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The service & maintenance costs for the fertilizer spreader were assumed as equal to 105% of [(investment cost) / 1000 x (operating time)]. Thus, the service & maintenance costs = 1.05 x 70,000 / 1000 x 500 SEK/year = 36,750 SEK/year.
j) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
k) Equal to the operating time for the fertilizer spreader.
l) Assumed value.
m) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
n) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
o) Data from Swedish Energy Agency (2004b).
p) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
q) The cost of N 27 is 2.24 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)), and the dosage per occasion is 296 kg/ha (see Chapter 3). The treated area = 675 ha/year. Thus, the cost of N 27 per occasion of fertilization at willow farming = 2.24 x 296 x 675 SEK/year = 447,552 SEK/year.
r) The cost of PK 7-25 is 2.14 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)), and the dosage per occasion is 320 kg/ha (see Chapter 3). The treated area = 675 ha/year. Thus, the cost of PK 7-25 per occasion of fertilization at willow farming = 2.14 x 320 x 675 SEK/year = 462,240 SEK/year.
s) The cost of urea (N 46) with the nitrogen content being 46.0% is 3.50 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the cost of the nitrogen in urea = 3.50 / 0.46 SEK/kg = 7.61 SEK/kg. The cost of superphosphate (P 20) with the phosphorus content being 20.0% is 2.40 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the cost of the phosphorus in superphosphate = 2.54 / 0.20 SEK/kg = 12.00 SEK/kg. The cost of potassium chloride (K 50) with the potassium content being 49.8% is 3.50 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the cost of the potassium in potassium chloride = 3.50 / 0.498 SEK/kg = 3.71 SEK/kg. The average dosages per occasion at fertilization of nitrogen, phosphorus and potassium are 54.0 kg/ha, 7.0 kg/ha and 29

Table A.J-26 *continued*

kg/ha respectively (see Chapter 3). The treated area = 675 ha/year. Thus, the average cost of NPK fertilization per occasion of fertilization at reed canary grass farming = (7.61 x 54.0 + 12.00 x 7.0 + 3.71 x 29.0) x 675 SEK/year = 406,708 SEK/year.

t) The effective operating time per ha at delivery of fertilizers in big bags = 0.50 h_{G15}/ha (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The treated area = 1 / 0.50 ha/h_{G15} = 2.00 ha/h_{G15}.
u) The value to the left of the slash is for willow farming, whereas the value to the right of the slash is for reed canary grass farming.
v) Data from Sonesson (1993).
w) The operating weight of a Volvo compact wheel loader L40B is 7900 – 8400 kg (Volvo Construction Equipment Corporation, 2005 (URL)).
x) The weight of a Bogballe SST 1200 with the loading weight being 1200 kg is 625 kg (Sonesson, 1993). The weight of a fertilizer spreader with the loading weight being 2500 litre was assumed as 700 kg.
y) The technical life time was assumed as twice the economic life time.
z) The mass depreciation at willow farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.822 x 14 / 22 kg/(ha x year) = 0.523 kg/(ha x year).
aa) The mass depreciation at reed canary grass farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.822 x 10 / 11 kg/(ha x year) = 0.747 kg/(ha x year).
bb) See Table A.I-7.
cc) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 8.0 x 2.60 x 10^{12} + 0.7 x 1.31 x 10^{12}) / 15.7 sej/kg = 2.54 x 10^{12} sej/kg.
dd) Direct energy required per hectare and year at willow farming = (direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period). Thus, direct energy required per hectare and year = 247.71 x 14 / 22 MJ/(ha x year) = 157.63 MJ/(ha x year).
ee) Direct energy required per hectare and year at reed canary grass farming = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 247.71 x 10 / 11 MJ/(ha x year) = 225.19 MJ/(ha x year).
ff) The total embodied energy at willow farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 29.19 + 100 / 500 x 166.8 + 500 / 500 x 1.47) x 14 / 22 MJ/(ha x year) = 31.4 MJ/(ha x year).
gg) The total embodied energy at reed canary grass farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 29.19 + 100 / 500 x 166.8) x 10 / 11 MJ/(ha x year) = 44.9 MJ/(ha x year).
hh) Embodied energy at willow farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 31.4 x 22 / 183 MJ/t_{dm} = 3.78 MJ/t_{dm}.
ii) Embodied energy at reed canary grass farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 44.9 x 11 / 67.5 MJ/t_{dm} = 7.32 MJ/t_{dm}.

Table A.J-27. *Data for fertilization of high stands at willow farming*

Item	Tractor	Loader	Fertilizer spreader	Total	Total costs in €
Investment [SEK]	620,000[a]	450,000[b]	105,750[c]	1175,750	128,934
Remaining value[d] [%]	25%	25%	25%		
Operating time[e] [h_u/year]	1000	500	500		
Economic life time[f] [year]	11	11	11		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	58,959	42,793	10,056		
Capital costs [SEK/h_u]	58.96	85.59	20.11		
Service & maintenance costs [SEK/year]	62,000[g]	16,313[h]	55,519[i]		
Other costs [SEK/year]					
Total service & maintenance costs [SEK/year]	62,000	16,313	55,519		
Total service & maintenance costs [SEK/h_u]	62.00	32.63	111.04		
Personnel costs [SEK/h_u]	147.87[j]				
Personnel costs [SEK/year]	147,870				
Actual operating time [h_u/year]	500[k]	100[l]	500[k]		
Utilization factor[m] [%]	67.5%	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	68	338		
Capital costs [SEK/year]	29,479	8559	10,056	48,094	5274
Total service & maintenance costs [SEK/year]	20,925	2202	37,475	60,602	6646
Personnel costs [SEK/year]	73,935			73,935	8108
Fuel[n] [l/h_{G15}]	12.50	6.5			
Fuel [l/year]	4219	439		4658	
LHV_{fuel}[o] [MJ/l]	35.9	35.9			
Fuel required [MJ/year]	151,453	15,751		167,204	
Specific fuel cost[p] [SEK/l]	7.00	7.00			
Fuel cost [SEK/year]	29,531	3071		32,603	3575

Table A.J-27 *continued*

Item	Tractor	Loader	Fertilizer spreader	Total	Total costs in €
Cost of N fertilizer [SEK/year]			1678,320[q]	1678,320	184,046
Total costs [SEK/year]	153,871	13,832	1725,851	1893,554	207,649
Treated area [ha/h_{G15}]				5.0[r]	
Treated area [ha/year]				1688	
Cost per ha [SEK/ha]				1122	
Specific capital costs [SEK/(ha x year)]				9.07	
Specific O & M costs [SEK/(ha x year)]				31.51	
Specific costs for expendables [SEK/(ha x year)]				316.45	
Weight [t]	7.0[s]	8.0[t]	0.4[s]	15.4	
Technical life time[u] [years]	22	22	22		
Technical life time [hours]	22,000	11,000	11,000		
Wear per hour [kg/h_u]	0.318	0.727	0.036		
Wear per ha [kg/ha]	0.094	0.215	0.011	0.321	
Mass depreciation [kg/(ha x year)]				0.102[v]	
Solar transformity [sej/kg]	2.60E+12[w]	2.60E+12[w]	1.31E+12[w]	2.57E+12[x]	
Direct energy required per ha [MJ/ha]				99.08	
Direct energy required per ha and year [MJ/(ha x year)]				31.53[y]	
Embodied energy[w] [GJ]	433.4	495.4	12.5		
Embodied energy [MJ/(ha x year)]	11.7	66.7	0.34	6.21[z]	
Embodied energy [MJ/t_{dm}]				0.75[aa]	

Table A.J-27 *continued*

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) A two wheel-drive loader with accessories (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The operation width = 38 m. The investment cost of the fertilizer spreader was 90,000 SEK in 1993 (Rosenqvist, 1997). Change in consumer price index for January 1993 – June 2002 = 17.5% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the investment cost in June 2002 = 90,000 x 1.175 SEK = 105,750 SEK.
d) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
e) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
f) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
g) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
h) The service & maintenance cost = 0.0725 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.0725 x 450,000 / 1000 x 500 SEK/year = 16,313 SEK/year.
i) The service & maintenance costs for fertilizer spreaders range from 60% to 150% of [(investment cost) / 1,000 x (operating time)] (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The service & maintenance costs for the fertilizer spreader were assumed as equal to 105% of [(investment cost) / 1000 x (operating time)]. Thus, the service & maintenance costs = 1.05 x 105,750 / 1000 x 500 SEK/year = 55,519 SEK/year.
j) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
k) Equal to the operating time for the fertilizer spreader.
l) Assumed value.
m) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
n) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
o) Data from Swedish Energy Agency (2004b).
p) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
q) The cost of N 27 is 2.24 SEK/kg (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)), and the dosage per occasion is 444 kg/ha (see Chapter 3). The treated area = 1688 ha/year. Thus, the cost of N 27 per occasion at fertilization of high stands at willow farming = 2.24 x 444 x 1688 SEK/year = 1678,320 SEK/year.
r) Data from Rosenqvist (1997).
s) Data from Sonesson (1993).
t) The operating weight of a Volvo compact wheel loader L40B is 7900 – 8400 kg (Volvo Construction Equipment Corporation, 2005 (URL)).
u) The technical life time was assumed as twice the economic life time.
v) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.321 x 7 / 22 kg/(ha x year) = 0.102 kg/(ha x year).
w) See Table A.I-7.
x) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 8.0 x 2.60 x 10^{12} + 0.4 x 1.31 x 10^{12}) / 15.4 sej/kg = 2.57 x 10^{12} sej/kg.

Table A.J-27 *continued*

y) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 99.08 x 7 / 22 MJ/(ha x year) = 31.53 MJ/(ha x year).
z) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 11.7 + 100 / 500 x 66.7 + 500 / 500 x 0.34) x 7 / 22 MJ/(ha x year) = 6.21 MJ/(ha x year).
aa) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 6.21 x 22 / 183 MJ/t_{dm} = 0.75 MJ/t_{dm}.

Table A.J-28. *Data for harvesting and field transport of willow*

Item	Tractor	Tipper	Harvester	Total	Total costs in €
Investment [SEK]	620,000[a]	175,000[b]	1332,000[c]	2127,000	233,249
Remaining value [%]	25%[d]	25%[d]	5%[e]		
Operating time[f] [h_u/year]	1000	500	500		
Economic life time[g] [year]	11	11	11		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	58,959	16,642	160,444		
Capital costs [SEK/h_u]	58.96	33.28	320.89		
Service & maintenance costs [SEK/year]	62,000[h]	35,000[i]	83,250[j]		
Other costs [SEK/year]					
Total service & maintenance costs [SEK/year]	62,000	35,000	83,250		
Total service & maintenance costs [SEK/h_u]	62.00	70.00	166.50		
Personnel costs [SEK/h_u]	147.87[k]				
Personnel costs [SEK/year]	147,870				
Actual operating time[l] [h_u/year]	500	500	500		
Utilization factor[m] [%]	67.5%	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338	338		
Capital costs [SEK/year]	29,479	16,642	160,444	206,565	22,652
Total service & maintenance costs [SEK/year]	20,925	23,625	56,194	100,744	11,048
Personnel costs [SEK/year]	73,935			73,935	8108
Fuel [l/h_{G15}]	10.0[n]		30.0[e]		
Fuel [l/year]	3,375		10,125	13,500	
LHV_{fuel}[o] [MJ/l]	35.9		35.9		
Fuel required [MJ/year]	121,163		363,488	484,650	
Specific fuel cost[p] [SEK/l]	7.00		7.00		
Fuel cost [SEK/year]	23,625		70,875	94,500	10,363

Table A.J-28 *continued*

Item	Tractor	Tipper	Harvester	Total	Total costs in €
Total costs [SEK/year]	147,964	40,267	287,513	475,743	52,171
Treated area [ha/h_{G15}]				1.10[q]	
Treated area [ha/year]				371	
Cost per ha [SEK/ha]				1281	
Specific capital costs [SEK/(ha x year)]				177.04	
Specific O & M costs [SEK/(ha x year)]				230.70	
Weight [t]	7.0[r]	3.4[r]	12.2[e]	22.6	
Technical life time[s] [years]	22	22	22		
Technical life time [hours]	22,000	11,000	11,000		
Wear per hour [kg/h_u]	0.318	0.309	1.109		
Wear per ha [kg/ha]	0.429	0.416	1.494	2.339	
Mass depreciation [kg/(ha x year)]				0.744[t]	
Solar transformity [sej/kg]	2.60E+12[u]	1.54E+12[u]	1.81E+12[u]	2.01E+12[v]	
Direct energy required per ha [MJ/ha]				1305.45	
Direct energy required per ha and year [MJ/(ha x year)]				415.37[w]	
Embodied energy[u] [GJ]	433.4	124.5	525.7		
Embodied energy [MJ/(ha x year)]	53.1	15.2	64.4	33.8[x]	
Embodied energy [MJ/t_{dm}]				4.06[y]	

Table A.J-28 *continued*

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Loading capacity = 15 t (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The investment cost of a willow harvester, model Empire 2000, was 1.200 MSEK in 1995 (Danfors & Nordén, 1995). Change in consumer price index for January 1995 – June 2002 = 11.0% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the investment cost in June 2002 = 1.2 x 1.11 MSEK = 1.332 MSEK.
d) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
e) Data from Danfors & Nordén (1995).
f) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
g) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
h) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
i) The service & maintenance costs = 0.40 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.40 x 175,000 / 1000 x 500 SEK/year = 35,000 SEK/year.
j) The service & maintenance costs of a willow harvester, model Empire 2000, was 75,000 SEK in 1995 (Danfors & Nordén, 1995). Change in consumer price index for January 1995 – June 2002 = 11.0% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the service & maintenance costs in June 2002 = 75,000 x 1.11 SEK = 83,250 SEK.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
l) Equal to the operating time for the harvester.
m) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
n) Assumed value, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
o) Data from Swedish Energy Agency (2004b).
p) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
q) The treated area per effective operating time = 1.10 ha/h_{G15} when the biomass yield per harvest is 50 t/ha (Danfors & Nordén, 1995).
r) Data from Sonesson (1993).
s) The technical life time was assumed as twice the economic life time.
t) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 2.339 x 7 / 22 kg/(ha x year) = 0.744 kg/(ha x year).
u) See Table A.I-7.
v) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 3.4 x 1.54 x 10^{12} + 12.2 x 1.81 x 10^{12}) / 22.6 sej/kg = 2.01 x 10^{12} sej/kg.
w) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1305.45 x 7 / 22 MJ/(ha x year) = 415.37 MJ/(ha x year).
x) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 53.1 + 500 / 500 x 15.2 + 500 / 500 x 64.4) x 7 / 22 MJ/(ha x year) = 33.8 MJ/(ha x year).

Table A.J-28 *continued*

y) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 33.8 x 22 / 183 MJ/t_{dm} = 4.06 MJ/t_{dm}.

Table A.J-29. *Data for harvesting of reed canary grass*

Item	Tractor	Mower	Total	Costs in €
Investment [SEK]	620,000[a]	180,000[b]	800,000	87,729
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	17,117		
Capital costs [SEK/h_u]	58.96	34.23		
Service & maintenance costs [SEK/year]	62,000[f]	63,000[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	63,000		
Total service & maintenance costs [SEK/h_u]	62.00	126.00		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	17,117	46,596	5110
Total service & maintenance costs [SEK/year]	20,925	42,525	63,450	6958
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	15.0[k]			
Fuel [l/year]	5063		5063	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	181,744		181,744	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	35,438		35,438	3886
Total costs [SEK/year]	159,777	59,642	219,419	24,062
Treated area [ha/h_{G15}]			2.60[n]	
Treated area [ha/year]			878	
Cost per ha [SEK/ha]			250	
Specific capital costs [SEK/(ha x year)]			43.45	
Specific O & M costs [SEK/(ha x year)]			161.14	
Annual average harvest [t_{dm}/year]			5385	
Weight [t]	7.0[o]	1.7[p]	8.7	
Technical life time[q] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.155		
Wear per ha [kg/ha]	0.181	0.088	0.269	
Mass depreciation [kg/(ha x year)]			0.220[r]	
Solar transformity [sej/kg]	2.60E12[s]	2.75E12[s]	2.63E12[t]	
Direct energy required per ha [MJ/ha]	207.12		207.12	
Direct energy required per ha and year [MJ/(ha x year)]	169.46[u]		169.46	
Embodied energy[s] [GJ]	433.4	111.2		
Embodied energy [MJ/(ha x year)]	22.5	5.76	13.9[v]	
Embodied energy [MJ/t_{dm}]			2.26[w]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-29 *continued*

b) Towed mower with an operational width being 3.2 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for mowers = 0.75 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.75 x 180,000 / 1000 x 500 SEK/year = 63,000 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the mower.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Assumed value, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The treated area per effective operating time with a mower with the operational width being 2.0 m and the speed being 9.8 km/h = 1.6 ha/h_{G15} (Lindgren *et al.*, 2002). The treated area per effective operating time was assumed as proportional to the operational width of the mower. Thus, the treated area per effective operating time with a mower with the operational width being 3.2 m = 3.2 / 2.0 x 1.6 ha/h_{G15} = 2.6 ha/h_{G15}.
o) Data from Sonesson (1993).
p) Weight of the mower Taarup 4032C/4032R (Kverneland Group Sverige AB, 8-Oct-2004 (URL)).
q) The technical life time was assumed as twice the economic life time.
r) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.269 x 9 / 11 kg/(ha x year) = 0.220 kg/(ha x year).
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 1.7 x 2.75 x 10^{12}) / 8.7 sej/kg = 2.63 x 10^{12} sej/kg.
u) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 207.12 x 9 / 11 MJ/(ha x year) = 169.46 MJ/(ha x year).
v) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 22.5 + 500 / 500 x 5.76) x 9 / 11 MJ/(ha x year) = 13.9 MJ/(ha x year).
w) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 13.9 x 11 / 67.5 MJ/t_{dm} = 2.26 MJ/t_{dm}.

Table A.J-30. *Data for harvesting of wheat*

Item	Combine	Costs in €
Investment [SEK]	1200,000[a]	131,593
Remaining value [%]	5%[b]	
Operating time [h_u/year]	500[c]	
Economic life time [year]	11[d]	
Interest rate [%]	6%	
Capital costs [SEK/year]	144,544	
Capital costs [SEK/h_u]	289.09	
Service & maintenance costs [SEK/year]	83,250[e]	9129
Other costs [SEK/year]		
Total service & maintenance costs [SEK/year]	83,250	9129
Total service & maintenance costs [SEK/h_u]	166.50	
Personnel costs [SEK/h_u]	147.87[f]	
Personnel costs [SEK/year]	73,935	8108
Actual operating time [h_u/year]	500[g]	
Utilization factor [%]	67.5%[h]	
Effective operating time [h_{G15}/year]	338	
Capital costs [SEK/year]	144,544	15,851
Total service & maintenance costs [SEK/year]	56,194	6162
Personnel costs [SEK/year]	73,935	8108
Fuel [l/h_{G15}]	34.2[i]	
Fuel [l/year]	11,543	
Lower heating value [MJ/l]	35.9[j]	
Energy required [MJ/year]	414,376	
Specific fuel cost [SEK/l]	7.00[k]	
Fuel costs [SEK/year]	80,798	8860
Total costs [SEK/year]	355,470	38,981
Treated area [ha/h_{G15}]	2.10[i]	
Treated area [ha/year]	709	
Cost per ha [SEK/ha]	502	
Specific capital costs [SEK/(ha x year)]	203.94	
Specific O & M costs [SEK/(ha x year)]	297.60	
Weight [t]	11.5[l]	
Technical life time [years]	22[m]	
Technical life time [hours]	11,000	
Wear per hour [kg/h_u]	1.045	
Wear per ha [kg/ha]	0.738	
Solar transformity [sej/kg]	1.81E+12[n]	
Direct energy required per ha and year [MJ/(ha x year)]	584.66[o]	
Embodied energy [GJ]	495.4[n]	
Embodied energy [MJ/(ha x year)]	31.8[p]	
Embodied energy [MJ/t_{dm}]	5.89[q]	

a) A combine with 140 kW power output and operation width being 5.4 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) Data from Danfors & Nordén (1995).
c) Data from Hadders, Jonsson, & Sundberg (1997).
d) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-30 *continued*

e) The service & maintenance cost was assumed as equal to the service & maintenance cost of the harvester Empire 2000. The service & maintenance cost of Empire 2000 was 75,000 SEK in 1995 (Danfors & Nordén, 1995). Change in consumer price index for January 1995 – June 2002 = 11.0% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the service & maintenance cost in June 2002 = 75,000 x 1.11 SEK = 83,250 SEK.
f) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
g) Assumed value.
h) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
i) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
j) Data from Swedish Energy Agency (2004b).
k) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
l) The weight of the combine Fendt 5220 E (P_{output} = 162 kW) without cutting table is 10.1 t (AGCO GmbH, 5-Oct-2005 (URL)). The weight of a standard cutting table is about 1.6 t (AGCO AB, 4-Oct-2005). Thus, the weight of a combine with 140 kW power output with cutting table was assumed as 11.5 t.
m) The technical life time was assumed as twice the economic life time.
n) See Table A.I-7.
o) Direct energy required per hectare and year = [(direct energy required) / (treated area per year)] = 414,376 / 708.8 MJ/(ha x year) = 584.66 MJ/(ha x year).
p) The embodied energy per hectare and year = 495.4 / (22 x 2.10 x 500 x 0.675) MJ/(ha x year) = 31.8 MJ/(ha x year).
q) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period). The yield per hectare for autumn wheat in Sweden was 6.351 t/ha in 2002, and the moisture content was assumed as 15% (see footnote o). Thus, the embodied energy [MJ/t_{dm}] = 31.8 / (0.85 x 6.351) MJ/t_{dm} = 5.89 MJ/t_{dm}.

Table A.J-31. *Data for baling of reed canary grass and straw*

Item	Tractor	Baler	Total	Costs in €
Investment [SEK]	620,000[a]	742,300[b]	1362,300	149,391
Remaining value [%]	25%[c]	30%[d]		
Operating time[e] [h_u/year]	1000	500		
Economic life time[f] [year]	11	8		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	83,676		
Capital costs [SEK/h_u]	58.96	167.35		
Service & maintenance costs [SEK/year]	62,000[g]	204,133[h]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	204,133		
Total service & maintenance costs [SEK/h_u]	62.00	408.27		
Personnel costs [SEK/h_u]	147.87[i]			
Personnel costs [SEK/year]	147,870			
Actual operating time[j] [h_u/year]	500	500		
Utilization factor[k] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	83,676	113,155	12,409
Total service & maintenance costs [SEK/year]	20,925	137,789	158,714	17,405
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	15.0[l]			
Fuel [l/year]	5063		5063	
Lower heating value [MJ/l]	35.9[m]			
Energy required [MJ/year]	181,744		181,744	
Specific fuel cost [SEK/l]	7.00[n]			
Fuel costs [SEK/year]	35,438		35,438	3886
Total costs [SEK/year]	159,777	221,465	381,242	41,807
Treated area [ha/h_{G15}]			0.78[o]	
Treated area [ha/year]			262	
Cost per ha [SEK/ha]			1457	
Specific capital costs[p] [SEK/(ha x year)]			353.87/432.50	
Specific O & M costs[p] [SEK/(ha x year)]			838.38/1024.69	
Weight [t]	7.0[q]	7.0[r]	14.0	
Technical life time[s] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.636		
Wear per ha [kg/ha]	0.608	1.216	1.824	
Mass depreciation [kg/(ha x year)]			1.493[t]/1.824[u]	
Solar transformity [sej/kg]	2.60E12[v]	1.64E12[v]	2.12E12[w]	
Direct energy required per ha [MJ/ha]	694.67		694.67	

Table A.J-31 *continued*

Item	Tractor	Baler	Total
Direct energy required per ha and year [MJ/(ha x year)]	568.36[x]/694.67[y]		568.36/694.67
Embodied energy[v] [GJ]	433.4	273.5	
Embodied energy [MJ/(ha x year)]	75.3	47.5	69.7[z]/85.2[aa]
Embodied energy [MJ/t_{dm}]			11.4[bb]/46.8[cc]

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) The investment cost of the baler Hesston 4800/4900 in June 1993 was 650,000 SEK (Flodén, 1994). Change in consumer price index for June 1993 – June 2002 = 14.2% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the investment cost in June 2002 = 650,000 x 1.142 SEK = 742,300 SEK.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data from Hadders, Jonsson, & Sundberg (1997).
e) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
f) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
g) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
h) The average service & maintenance costs for balers = 0.55 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.55 x 742,300 / 1000 x 500 SEK/year = 204,133 SEK/year.
i) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
j) Equal to the operating time for the baler.
k) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
l) Data from Börjesson (1996).
m) Data from Swedish Energy Agency (2004b).
n) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
o) The effective operating time per ha with 4.3 balers = 18 / 60 h_{G15}/ha (Hadders, Jonsson & Sundberg, 1997). The treated area for one baler = 1 / (18 x 4.3 / 60) ha/h_{G15} = 0.78 ha/h_{G15}.
p) The value to the left of the slash is for baling of reed canary grass, whereas the value to the right of the slash is for baling of straw.
q) Data from Sonesson (1993).
r) The weight of the baler Claas Quadrant 1200 is 5500 kg (Sonesson, 1993). As the weight of the bales made by the baler Hesston 4800/4900 is almost twice the weight of the bales made by the baler Claas Quadrant 1200 (Hadders, Jonsson & Sundberg, 1997), the weight of the baler Hesston 4800/4900 was assumed as 7000 kg.
s) The technical life time was assumed as twice the economic life time.

Table A.J-31 *continued*

t) The mass depreciation at reed canary grass farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1.824 x 9 / 11 kg/(ha x year) = 1.493 kg/(ha x year).
u) The mass depreciation at baling of straw = the wear per ha = 1.824 kg/(ha x year).
v) See Table A.I-7.
w) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 7.0 x 1.64 x 10^{12}) / 14.0 sej/kg = 2.12 x 10^{12} sej/kg.
x) Direct energy required per hectare and year at baling of reed canary grass = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 694.67 x 9 / 11 MJ/(ha x year) = 568.36 MJ/(ha x year).
y) Direct energy required per hectare and year at baling of straw = [(direct energy required) / (treated area per year)] = 181,744 / 261.6 MJ/(ha x year) = 694.67 MJ/(ha x year).
z) The total embodied energy at baling of reed canary grass = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 75.3 + 500 / 500 x 47.5) x 9 / 11 MJ/(ha x year) = 69.7 MJ/(ha x year).
aa) The total embodied energy at baling of straw = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 75.3 + 500 / 500 x 47.5) MJ/(ha x year) = 85.2 MJ/(ha x year).
bb) Embodied energy] at baling of reed canary grass [MJ/t_{dm} = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 69.7 x 11 / 67.5 MJ/t_{dm} = 11.4 MJ/t_{dm}.
cc) Embodied energy at baling of straw [MJ/t_{dm} = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 85.2 / 1.818 MJ/t_{dm} = 46.8 MJ/t_{dm}.

Table A.J-32. *Data for loading and field transport of reed canary grass and straw*

Item	Tractor	Wagon for big bales	Front-loader	Total	Total costs in €
Investment [SEK]	620,000[a]	105,000[b]	65,000[c]	790,000	86,632
Remaining value [%]	25%[d]	10%[e]	25%[d]		
Operating time[f] [h_u/year]	1000	500	500		
Economic life time [year]	11[g]	15[e]	8[e]		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	58,959	9730	7851		
Capital costs [SEK/h_u]	58.96	19.46	15.70		
Service & maintenance costs [SEK/year]	62,000[h]	21,000[i]	2356[j]		
Other costs [SEK/year]					
Total service & maintenance costs [SEK/year]	62,000	21,000	2356		
Total service & maintenance costs [SEK/h_u]	62.00	42.00	4.71		
Personnel costs [SEK/h_u]	147.87[k]				
Personnel costs [SEK/year]	147,870				
Actual operating time[l] [h_u/year]	500	500	500		
Utilization factor[m] [%]	67.5%	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338	338		
Capital costs [SEK/year]	29,479	9730	7851	47,060	5161
Total service & maintenance costs [SEK/year]	20,925	14,175	1590	36,690	4024
Personnel costs [SEK/year]	73,935			73,935	8108
Fuel [l/h_{G15}]	6.5[n]				
Fuel [l/year]	2194			2194	
LHV_{fuel} [MJ/l]	35.9[o]				
Fuel required [MJ/year]	78,756			78,756	
Specific fuel cost [SEK/l]	7.00[p]				
Fuel cost [SEK/year]	15,356			15,356	1684

Table A.J-32 *continued*

Item	Tractor	Wagon for big bales	Front-loader	Total	Total costs in €
Total costs [SEK/year]	139,696	23,905	9441	173,042	18,976
Treated area [ha/h_{G15}]				1.94[q]	
Treated area [ha/year]			653	653	
Cost per ha [SEK/ha]				265	
Specific capital costs[r] [SEK/(ha x year)]				58.94/72.04	
Specific O & M costs[r] [SEK/(ha x year)]				157.80/192.86	
Weight [t]	7.0[s]	3.5[t]	0.7[u]	11.2	
Technical life time[v] [years]	22	30	16		
Technical life time [hours]	22,000	15,000	8000		
Wear per hour [kg/h_u]	0.318	0.233	0.088		
Wear per hectare [kg/ha]	0.244	0.179	0.067	0.489	
Mass depreciation [kg/(ha x year)]				0.400[w]/0.489[x]	
Solar transformity [sej/kg]	2.60E+12[y]	1.54E+12[y]	1.69E+12[y]	2.21E+12[z]	
Direct energy required per ha [MJ/ha]	120.56			120.56	
Direct energy required per ha and year [MJ/(ha x year)]	98.64[aa]/120.56[bb]			98.64/120.56	
Embodied energy[y] [GJ]	433.4	128.2	28.1		
Embodied energy [MJ/(ha x year)]	30.2	6.54	2.69	19.9[cc]/24.3[dd]	
Embodied energy [MJ/t_{dm}]				3.24[ee]/13.4[ff]	

Table A.J-32 *continued*

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) The investment cost of the wagon LRMA 12000 designed for big bales (Rasmusson, 2004).
c) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
d) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
e) Data from Hadders, Jonsson, & Sundberg (1997).
f) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
g) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
h) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
i) The service & maintenance cost for wagons = 0.40 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.40 x 105,000 / 1000 x 500 SEK/year = 21,000 SEK/year.
j) The service & maintenance cost = 0.0725 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.0725 x 65,000 / 1000 x 500 SEK/year = 2356 SEK/year.
k) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
l) Equal to the operating time for the wagon and the front-loader.
m) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
n) The fuel consumption at field transport with the load weight being 11 t is 8 litre/h_{G15} and the fuel consumption at loading with front-loader = 5 litre/h_{G15} (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). The average fuel consumption at loading and field transport of baled reed canary grass and straw was assumed as (8 + 5) / 2 litre/h_{G15}, *i.e.* 6.5 litre/h_{G15}.
o) Data from Swedish Energy Agency (2004b).
p) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
q) The effective operating time per ha at loading of baled reed canary grass or straw on the field is 7 / 60 h_{G15}/ha. The corresponding effective operating times per ha at transport on the field, transport to storage and loading to storage are 4 / 60 h_{G15}/ha, 14 / 60 h_{G15}/ha and 6 / 60 h_{G15}/ha respectively (Hadders, Jonsson & Sundberg, 1997). Thus the treated area for loading and field transport = 1 / ((7 + 4 + 14 + 6) / 60) ha/h_{G15} = 1.94 ha/h_{G15}.
r) The value to the left of the slash is for field transport of reed canary grass, whereas the value to the right of the slash is for field transport of straw.
s) Data from Sonesson (1993).
t) The weight of the wagon LRMA 12000 designed for big bales (Rasmusson, 2004).
u) The weight of a front-loader designed for tractors with 32 – 57 kW power output range is 560 kg (Sonesson, 1993). Thus, the weight of a front-loader designed for a tractor with 110 kW power output was assumed as 700 kg.
v) The technical life time was assumed as twice the economic life time.
w) The mass depreciation at reed canary grass farming = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.489 x 9 / 11 kg/(ha x year) = 0.400 kg/(ha x year).

Table A.J-32 *continued*

x) The mass depreciation at baling of straw = the wear per ha = 0.489 kg/(ha x year).
y) See Table A.I-7.
z) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 3.5 x 1.54 x 10^{12} + 0.7 x 1.69 x 10^{12}) / 11.2 sej/kg = 2.21 x 10^{12} sej/kg.
aa) Direct energy required per hectare and year at reed canary grass farming = (direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period). Thus, direct energy required per hectare and year = 120.56 x 9 / 11 MJ/(ha x year) = 98.64 MJ/t_{dm}.
bb) Direct energy required per hectare and year at handling of straw = [(direct energy required) / (treated area per year)] = 78,756 / 653.2 MJ/(ha x year) = 120.56 MJ/(ha x year).
cc) The total embodied energy at reed canary grass farming = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 30.2 + 500 / 500 x 6.54 + 500 / 500 x 2.69) x 9 / 11 MJ/(ha x year) = 19.9 MJ/(ha x year).
dd) The total embodied energy at handling of straw = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 30.2 + 500 / 500 x 6.54 + 500 / 500 x 2.69) MJ/(ha x year) = 24.3 MJ/(ha x year).
ee) Embodied energy at reed canary grass farming [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 19.9 x 11 / 67.5 MJ/t_{dm} = 3.24 MJ/t_{dm}.
ff) Embodied energy at handling of straw [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 24.3 / 1.818 MJ/t_{dm} = 13.4 MJ/t_{dm}.

Table A.J-33. *Data for storage of reed canary grass (RCG) and straw in a barn*

Item	Barn for RCG	Costs in €	Barn for straw	Costs in €
Investment [SEK]	2000,000[a]	219,322	750,000[b]	82,246
Remaining value[c]	0%		0%	
Economic life time[d] [year]	30		30	
Interest rate [%]	6%		6%	
Capital costs [SEK/year]	145,298	15,934	54,487	5975
Service & maintenance costs[e] [SEK/year]	726		272	
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	726		272	
Operating costs [SEK/year]	726	80	272	30
Total annual costs [SEK/year]	146,024	16,013	54,759	6005

a) The treated area for baling of reed canary grass is 262 ha/year (see Table A.D-28). The annual baled quantity of reed canary grass = 262 x 7.5 t_{dm}/year = 1962 t_{dm}/year. The moisture content was assumed as 15% and the density of rectangular bales of reed canary grass is 165 kg/m^3 (Flodén, 1994). Thus, the total volume of baled reed canary grass = 1962 / (0.85 x 0.165) m^3 = 13,991 m^3. The floor area required for the barn if the height of the barn is 10 m = 13,991 / 10 m^2 = 1399 m^2. The investment cost for a barn with that size was assumed as 2.000 MSEK.

b) The treated area for baling of straw is 262 ha/year (see Table A.D-28). The annual baled quantity of straw = 262 x 1.818 t_{dm}/year = 475.7 t_{dm}/year. The moisture content was assumed as 15%, and the density of rectangular bales of straw is 150 kg/m^3, according to Flodén (1994). Thus, the total volume of baled straw = 475.7 / (0.85 x 0.150) m^3 = 3731 m^3. The floor area required for the barn if the height of the barn is 10 m = 3731 / 10 m^2 = 373 m^2. The investment cost for a barn with that size was assumed as 750,000 SEK.

c) The remaining value was assumed as zero after 30 years.

d) The economic life time was assumed being 30 years.

e) Assumed as 0.5% of the investment cost.

Table A.J-34. *Data for rotary cultivation at willow farming*

Item	Tractor	Rotary cultivator	Total	Costs in €
Investment [SEK]	620,000[a]	85,125[b]	705,125	77,325
Remaining value[c] [%]	25%	25%		
Operating time [h_u/year]	1000[d]	200[e]		
Economic life time[f] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	7132		
Capital costs [SEK/h_u]	58.96	35.66		
Service & maintenance costs [SEK/year]	62,000[g]	11,918[h]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	11,918		
Total service & maintenance costs [SEK/h_u]	62.00	59.59		
Personnel costs [SEK/h_u]	147.87[i]			
Personnel costs [SEK/year]	147,870			
Actual operating time[j] [h_u/year]	200	200		
Utilization factor[k] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	135	135		
Capital costs [SEK/year]	11,792	8095	19,887	2181
Total service & maintenance costs [SEK/year]	8370	8044	16,414	1800
Personnel costs [SEK/year]	29,574		29,574	3243
Fuel [l/h_{G15}]	19.5[l]			
Fuel [l/year]	2633		2633	
Lower heating value [MJ/l]	35.9[m]			
Energy required [MJ/year]	94,507		94,507	
Specific fuel cost [SEK/l]	7.00[n]			
Fuel costs [SEK/year]	18,428		18,428	2021
Total costs [SEK/year]	68,163	16,139	84,302	9245
Treated area [ha/h_{G15}]			0.17[o]	
Treated area [ha/year]			23	
Cost per ha [SEK/ha]			3747	
Specific capital costs [SEK/(ha x year)]			40.18	
Specific O & M costs [SEK/(ha x year)]			130.13	
Weight [t]	7.0[p]	1.4[q]	8.4	
Technical life time[r] [years]	22	22		
Technical life time [hours]	22,000	4400		
Wear per hour [kg/h_u]	0.318	0.318		
Wear per ha [kg/ha]	2.828	2.828	5.657	
Mass depreciation [kg/(ha x year)]			0.257[s]	
Solar transformity [sej/kg]	2.60E12[t]	1.52E12[t]	2.42E12[u]	
Direct energy required per ha [MJ/ha]	4200.30		4200.30	
Direct energy required per ha and year [MJ/(ha x year)]	190.92[v]		190.92	
Embodied energy[t] [GJ]	433.4	50.6		
Embodied energy [MJ/(ha x year)]	875.7	102.3	12.6[w]	
Embodied energy [MJ/t_{dm}]			1.52[x]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-34 *continued*

b) The investment cost of a rotary cultivator with the operation width being 2.4 m was 75,000 SEK in 1994 (Rosenqvist, 1997). Change in consumer price index for January 1994 – June 2002 = 13.5% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, the investment cost in June 2002 = 75,000 x 1.135 MSEK = 85,125 SEK.
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) Assumed value.
f) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
g) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
h) The average service & maintenance costs for cultivation equipment = 0.70 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.70 x 85,125 / 1000 x 200 SEK/year = 11,918 SEK/year.
i) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
j) Equal to the operating time for the rotary cultivator.
k) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
l) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
m) Data from Swedish Energy Agency (2004b).
n) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
o) The effective operating time per ha with a rotary cultivator with the operation width being 2.4 m = 6.0 h_{G15}/ha (Rosenqvist, 1997). The treated area = 1 / 6.0 ha/h_{G15} = 0.17 ha/h_{G15}.
p) Data from Sonesson (1993).
q) The weight of a Meri rotary cultivator with the operational width being 2.5 m = 1.36 t (Rovaniemi, 2004).
r) The technical life time was assumed as twice the economic life time.
s) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 5.657 x 1 / 22 kg/(ha x year) = 0.257 kg/(ha x year).
t) See Table A.I-7.
u) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 1.4 x 1.52 x 10^{12}) / 8.4 sej/kg = 2.42 x 10^{12} sej/kg.
v) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 4200.30 x 1 / 22 MJ/(ha x year) = 190.92 MJ/(ha x year).
w) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (200 / 1000 x 875.7 + 200 / 200 x 102.3) / 22 MJ/(ha x year) = 12.6 MJ/(ha x year).
x) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 12.6 x 22 / 183 MJ/t_{dm} = 1.52 MJ/t_{dm}.

Table A.J-35. *Data for disc harrow ploughing at reed canary grass farming*

Item	Tractor	Disc harrow	Total	Costs in €
Investment [SEK]	620,000[a]	115,000[b]	735,000	80,601
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	10,936		
Capital costs [SEK/h_u]	58.96	21.87		
Service & maintenance costs [SEK/year]	62,000[f]	40,250[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	40,250		
Total service & maintenance costs [SEK/h_u]	62.00	80.50		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	10,936	40,415	4432
Total service & maintenance costs [SEK/year]	20,925	27,169	48,094	5274
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	18.00[k]			
Fuel [l/year]	6075		6075	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	218,093		218,093	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	42,525		42,525	4663
Total costs [SEK/year]	166,864	38,105	204,969	22,477
Treated area [ha/h_{G15}]			1.00[n]	
Treated area [ha/year]			338	
Cost per ha [SEK/ha]			607	
Specific capital costs [SEK/(ha x year)]			21.77	
Specific O & M costs [SEK/(ha x year)]			88.65	
Weight [t]	7.0[o]	2.0[p]	9.0	
Technical life time[q] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.182		
Wear per ha [kg/ha]	0.471	0.269	0.741	
Mass depreciation [kg/(ha x year)]			0.135[r]	
Solar transformity [sej/kg]	2.60E12[s]	1.44E12[s]	2.34E12[t]	
Direct energy required per ha [MJ/ha]	646.20		646.20	
Direct energy required per ha and year [MJ/(ha x year)]	117.49[u]		117.49	
Embodied energy[s] [GJ]	433.4	68.5		
Embodied energy [MJ/(ha x year)]	58.4	9.23	6.98[v]	
Embodied energy [MJ/t_{dm}]			1.14[w]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-35 *continued*

b) The operational width = 3.6 m (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for cultivation equipment = 0.70 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.70 x 115,000 / 1000 x 500 SEK/year = 40,250 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the disc harrow.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Assumed value for a tractor with 110 kW power output, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The effective operating time per ha at ploughing with the operational width being 2.13 m and the speed being 6 km/h = 1.5 h_{G15}/ha (Elinder & Falk, 1983). The efficiency was assumed as 50% greater at disc harrow ploughing. Thus, the treated area = 1 / 1.5 x 1.5 ha/h_{G15} = 1.00 ha/h_{G15}.
o) Data from Sonesson (1993).
p) Assumed value.
q) The technical life time was assumed as twice the economic life time.
r) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 0.741 x 2 / 11 kg/(ha x year) = 0.135 kg/(ha x year).
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 2.0 x 1.44 x 10^{12}) / 9.0 sej/kg = 2.34 x 10^{12} sej/kg.
u) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 646.20 x 2 / 11 MJ/(ha x year) = 117.49 MJ/(ha x year).
v) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 58.4 + 500 / 500 x 9.23) / 11 MJ/(ha x year) = 6.98 MJ/(ha x year).
w) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 6.98 x 11 / 67.5 MJ/t_{dm} = 1.14 MJ/t_{dm}.

Table A.J-36. *Data for ploughing at reed canary grass farming*

Item	Tractor	Plough	Total	Costs in €
Investment [SEK]	620,000[a]	210,000[b]	830,000	91,019
Remaining value[c] [%]	25%	25%		
Operating time[d] [h_u/year]	1000	500		
Economic life time[e] [year]	11	11		
Interest rate [%]	6%	6%		
Capital costs [SEK/year]	58,959	19,970		
Capital costs [SEK/h_u]	58.96	39.94		
Service & maintenance costs [SEK/year]	62,000[f]	73,500[g]		
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	62,000	73,500		
Total service & maintenance costs [SEK/h_u]	62.00	147.00		
Personnel costs [SEK/h_u]	147.87[h]			
Personnel costs [SEK/year]	147,870			
Actual operating time[i] [h_u/year]	500	500		
Utilization factor[j] [%]	67.5%	67.5%		
Effective operating time [h_{G15}/year]	338	338		
Capital costs [SEK/year]	29,479	19,970	49,449	5423
Total service & maintenance costs [SEK/year]	20,925	49,613	70,538	7735
Personnel costs [SEK/year]	73,935		73,935	8108
Fuel [l/h_{G15}]	21.00[k]			
Fuel [l/year]	7088		7088	
Lower heating value [MJ/l]	35.9[l]			
Energy required [MJ/year]	254,441		254,441	
Specific fuel cost [SEK/l]	7.00[m]			
Fuel costs [SEK/year]	49,613		49,613	5441
Total costs [SEK/year]	173,952	69,582	243,534	26,706
Treated area [ha/h_{G15}]			0.67[n]	
Treated area [ha/year]			225	
Cost per ha [SEK/ha]			1082	
Specific capital costs [SEK/(ha x year)]			19.98	
Specific O & M costs [SEK/(ha x year)]			78.42	
Weight [t]	7.0[o]	3.3[p]	10.3	
Technical life time[q] [years]	22	22		
Technical life time [hours]	22,000	11,000		
Wear per hour [kg/h_u]	0.318	0.300		
Wear per ha [kg/ha]	0.707	0.667	1.374	
Mass depreciation [kg/(ha x year)]			0.125[r]	
Solar transformity [sej/kg]	2.60E12[s]	1.91E12[s]	2.38E12[t]	
Direct energy required per ha [MJ/ha]	1130.85		1130.85	
Direct energy required per ha and year [MJ/(ha x year)]	102.80[u]		102.80	
Embodied energy[s] [GJ]	433.4	149.6		
Embodied energy [MJ/(ha x year)]	87.6	30.2	13.5[v]	
Embodied energy [MJ/t_{dm}]			2.19[w]	

a) A four wheel-drive tractor with a power output being 110 kW (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).

Table A.J-36 *continued*

b) The investment cost of a partly carried shifter plough with 6 cutters (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
d) Data for the annual operating time for machinery from Hadders, Jonsson, & Sundberg (1997).
e) The economic life time for equipment in agriculture is 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
f) The average service & maintenance costs = 0.10 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.10 x 620,000 / 1000 x 1000 SEK/year = 62,000 SEK/year.
g) The average service & maintenance costs for cultivation equipment = 0.70 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance costs = 0.70 x 210,000 / 1000 x 500 SEK/year = 73,500 SEK/year.
h) Data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)). Basic salary, overtime pay, holiday pay, costs for sickness benefit, payroll tax and insurances are included.
i) Equal to the operating time for the plough.
j) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
k) Assumed value for a tractor with 110 kW power output, based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
l) Data from Swedish Energy Agency (2004b).
m) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
n) The effective operating time per ha at ploughing with the operational width being 2.13 m and the speed being 6 km/h = 1.5 h_{G15}/ha (Elinder & Falk, 1983). Thus, the treated area = 1 / 1.5 ha/h_{G15} = 0.67 ha/h_{G15}.
o) Data from Sonesson (1993).
p) Equal to the weight of the plough Kverneland PB/RB (Kverneland Group Sverige AB, 9-Oct-2004 (URL)).
q) The technical life time was assumed as twice the economic life time.
r) The mass depreciation = (wear per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1.374 x 1 / 11 kg/(ha x year) = 0.125 kg/(ha x year).
s) See Table A.I-7.
t) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (7.0 x 2.60 x 10^{12} + 3.3 x 1.91 x 10^{12}) / 10.3 sej/kg = 2.38 x 10^{12} sej/kg.
u) Direct energy required per hectare and year = [(direct energy required per ha) x (number of occasions per rotation period) / (length of rotation period)] = 1130.85 x 1 / 11 MJ/(ha x year) = 102.80 MJ/(ha x year).
v) The total embodied energy = [the sum of embodied energy with regard to the annual actual operating time and number of occasions per rotation period] = (500 / 1000 x 87.6 + 500 / 500 x 30.2) / 11 MJ/(ha x year) = 13.5 MJ/(ha x year).
w) Embodied energy [MJ/t_{dm}] = Embodied energy [MJ/(ha x year)] x (years per rotation period) / (dry matter yield per rotation period) = 13.5 x 11 / 67.5 MJ/t_{dm} = 2.19 MJ/t_{dm}.

Table A.J-37. *Data for collecting of recovered wood at recycling station*

Item	Loader	Costs in €
Investment [SEK]	450,000[a]	49,348
Remaining value [%]	25%[b]	
Operating time [h_u/year]	3500[c]	
Economic life time [year]	5[c]	
Interest rate [%]	6%	
Capital costs [SEK/year]	80,121	
Capital costs [SEK/h_u]	22.89	
Service & maintenance costs [SEK/year]	114,188[d]	
Other costs [SEK/year]		
Total service & maintenance costs [SEK/year]	114,188	
Total service & maintenance costs [SEK/h_u]	32.63	
Personnel costs [SEK/h_u]	170.00[e]	
Personnel costs [SEK/year]	595,000	
Actual operating time [h_u/year]	3500[c]	
Utilization factor [%]	67.5%[f]	
Effective operating time [h_{G15}/year]	2363	
Capital costs [SEK/year]	80,121	8786
Total service & maintenance costs [SEK/year]	77,077	8452
Personnel costs [SEK/year]	595,000	65,248
Fuel [l/h_{G15}]	6.5[g]	
Fuel [l/year]	15,356	
Lower heating value [MJ/l]	35.9[h]	
Direct energy required [MJ/year]	551,289	
Specific fuel cost [SEK/l]	7.00[i]	
Fuel costs [SEK/year]	107,494	11,788
Total costs [SEK/year]	859,692	94,275
Capacity [m^3/h_{G15}]	240[j]	
Capacity [t_{dm}/h_{G15}]	78.8[k]	
Capacity [t_{dm}/year]	186,260	
Specific capital cost [SEK/t_{dm}]	0.43	
Specific variable costs [SEK/t_{dm}]	4.19	
Weight [t]	8.0[l]	
Technical life time [years]	10[m]	
Technical life time [hours]	35,000	
Wear per hour [kg/h_u]	0.229	
Wear per ton dry matter [kg/t_{dm}]	0.004	
Solar transformity [sej/kg]	2.60E+12[n]	
Direct energy required per t_{dm} [MJ/t_{dm}]	2.96[o]	
Embodied energy [GJ]	495.4[n]	
Embodied energy [MJ/t_{dm}]	0.27[p]	

a) A two wheel-drive loader with accessories (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
b) The remaining value for equipment in agriculture is 25 – 30% after 10 – 12 years (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)).
c) Assumed value.
d) The service & maintenance cost = 0.0725 x (investment cost) / 1000 x (operating time) (Swedish University of Agricultural Sciences, 8-Sep-2004 (URL)). Thus, the service & maintenance cost = 0.0725 x 450,000 / 1000 x 3500 SEK/year = 114,188 SEK/year.
e) Data from Bredberg (2004).

Table A.J-37 *continued*

f) Time for interruption = 10 – 20% and adjusting time = 15 – 20% (Elinder & Falk, 1983). Average additive time = (15 + 17.5)% = 32.5%. Thus, the effective operating time = (100 – 32.5)% = 67.5%.
g) Assumed value based on data from the Swedish University of Agricultural Sciences (8-Sep-2004 (URL)).
h) Data from Swedish Energy Agency (2004b).
i) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
j) The capacity at loading of straw balers with a front loader is estimated by Hadders, Jonsson & Sundberg (1997) to be 2.5 minutes/t. Thus, the capacity [t/h_{G15}] = 1 / 2.5 x 60 t/h_{G15} = 24 t/h_{G15}. $\rho_{straw\ balers}$ = 150 kg/m^3 (Flodén, 1994). Thus, the capacity [m^3/h_{G15}] = 24 / 0.150 m^3/h_{G15} = 160 m^3/h_{G15}. The capacity [m^3/h_{G15}] at collecting of recovered wood at a recycling station with a compact wheel loader (Volvo L40B) was assumed as 50% greater than the capacity [m^3/h_{G15}] at loading of straw balers with a front loader. Thus, the capacity [m^3/h_{G15}] at collecting of recovered wood at a recycling station = 160 x 1.50 m^3/h_{G15} = 240 m^3/h_{G15}.
k) $\rho_{recovered\ wood,\ average}$ = 365 kg/m^3 (Olsson, 2005). The moisture content of recovered wood was assumed as 10%. Thus, the basic density of recovered wood = 365 x (1 – 0.10) kg_{dm}/m^3 = 328.5 kg_{dm}/m^3. The capacity [t_{dm}/h_{G15}] = 240 x 0.3285 t_{dm}/h_{G15} = 78.8 t_{dm}/h_{G15}.
l) The operating weight of a Volvo compact wheel loader L40B is 7900 – 8400 kg (Volvo Construction Equipment Corporation, 12-Sep-2005 (URL)).
m) The technical life time was assumed as twice the economic life time.
n) See Table A.H-7.
o) Direct energy required per t_{dm} = [(direct energy required per year) / (capacity per year (t_{dm}/year))] = 551,289 / 186,260 MJ/t_{dm} = 2.96 MJ/t_{dm}.
p) The amount of embodied energy per ton dry matter = 495.4 / (10 x 78.8 x 2363) MJ/t_{dm} = 0.27 MJ/t_{dm}.

Table A.J-38a. *Data for trucks for timber and bundles haulage and wood chips, bark and sawdust*

Item	Truck for roundwood, bundles and biomass from agriculture	Costs in €	Truck for wood chips, bark, sawdust and recovered wood	Costs in €
Investment [SEK]	2250,000[a]	246,738	2489,614[b]	273,014
Remaining value [%]	10%[a]		10%[b]	
Operating time [h_u/year]	3360[c]		3520[d]	
Economic life time [year]	8[a]		8[b]	
Interest rate [%]	6%		6%	
Capital costs [SEK/year]	326,098		360,826	
Capital costs [SEK/h_u]	97.05		102.51	
Service & maintenance costs[e] [SEK/year]	281,250		311,202	
Other costs [SEK/year]	157,000[f]		157,000[g]	
Total service & maintenance costs [SEK/year]	438,250		468,202	
Total service & maintenance costs [SEK/h_u]	130.43		133.01	
Personnel costs[a] [SEK/h_u]	210.00		210.00	
Personnel costs [SEK/year]	705,600		739,200	
Actual operating time [h_u/year]	3360		3520	
Effective operating time [%]	90%[a]		90%[h]	
Effective operating time [h_{G15}/year]	3024		3168	
Capital costs [SEK/year]	326,098	35,760	360,826	35,760
Total service & maintenance costs [SEK/year]	438,250	48,059	468,202	48,059
Personnel costs [SEK/year]	705,600	77,377	739,200	77,377
LHV_{fuel}[i] [MJ/l]	35.9		35.9	
Weight [t]	20[a]		21[b]	
Technical life time[j] [years]	16		16	
Solar transformity[k] [sej/kg]	2.60E+12		2.60E+12	
Embodied energy[k] [GJ]	1238		1300	

a) Data from Staland (2004).
b) Data from Löthstam (2004).
c) The truck was used for two shifts 210 days per year, 8 h_u per shift (Staland, 2004). Annual operating time = 2 x 210 x 8 h_u/year = 3360 h_u/year.
d) The truck was used for two shifts 220 days per year, 8 h_u per shift (Löthstam, 2004). Annual operating time = 2 x 220 x 8 h_u/year = 3520 h_u/year.
e) Assumed as equal to the quotient of the investment cost and economic life time.
f) Taxes = 40,000 SEK/year, insurances = 42,000 SEK/year and tyre costs = 75,000 SEK/year (Staland, 2004). Thus, the sum of other costs = (40,000 + 42,000 + 75,000) SEK/year = 157,000 SEK/year.
g) Assumed as equal to the sum of other costs for a truck for timber and bundles.
h) Assumed as equal to the effective operating time for trucks for timber and bundles.
i) Data from Swedish Energy Agency (2004b).
j) The technical life time was assumed as twice the economic life time.
k) See Table A.H-7.

Table A.J-38b. *Transport data for truck used for roundwood, bundled logging residues and biomass assortments from agriculture*

Item	Roundwood	Bundled logging residues	Willow	Reed canary grass	Straw
Load space[a] $[m^3]$	93.8	93.8	93.8	93.8	93.8
V_{solid}[b] [%]	65%	40%	50%		
ρ_{basic} $[kg_{dm}/m^3_f]$	420[c]	420[d]	400[e]		
ρ $[kg/m^3]$				165[f]	150[f]
Moisture content [%]	50[b]	50[b]	50[b]	15[g]	15[h]
V_{solid}[i] $[m^3_f]$	60.9	37.5	46.9		
Weight of dry matter per load $[t_{dm}$ /load]	25.6[j]	15.8[j]	18.8[j]	13.1[k]	12.0[k]
Average speed[b] [km/h]	70	70	70	70	70
Transport distance[b] [km]	75	75	75	75	75
Transport distance per turn [km]	150	150	150	150	150
Fuel consumption[a] [l/km]	0.51	0.51	0.51	0.51	0.51
Loading and unloading $[min_{G15}$/load]	45[a]	40[l]	80[m]	40[n]	40[n]
Effective time per turn[o] $[h_{G15}$/turn]	2.89	2.81	3.48	2.81	2.81
Production per hour[p] $[t_{dm}/h_{G15}]$	8.85	5.61	5.39	4.68	4.25
Production per year[q] $[t_{dm}$/year]	26,754	16,952	16,311	14,152	12,866
Wear per t_{dm} of biomass[r] $[kg/t_{dm}]$	0.0467	0.0737	0.0766	0.0883	0.0972
Fuel consumption [l/turn]	76.5	76.5	76.5	76.5	76.5
Fuel consumption [l/year]	79,968	82,340	66,549	82,340	82,340
Fuel consumption [MJ/year]	2870,851	2956,004	2389,099	2956,004	2956,004
Direct energy required per t_{dm} $[MJ/t_{dm}]$	107.31	174.37	146.47	208.87	229.76
Fuel costs [SEK/year]	559,776	576,380	465,841	576,380	576,380
Total variable costs[t] [SEK/year]	1703,626	1720,230	1609,691	1720,230	1720,230
Specific capital cost $[SEK/t_{dm}]$	12.19	19.24	19.99	23.04	25.35
Variable costs $[SEK/t_{dm}]$	63.68	101.47	98.69	121.55	133.71
Embodied energy $[MJ/t_{dm}]$	2.89	4.57	4.75	5.47	6.02

Table A.J-38b *continued*

a) Data from Staland (2004).
b) Assumed values.
c) See Table A.B-2.
d) Assumed as equal to the basic density of roundwood.
e) Data from Edén (2000).
f) Data from Flodén (1994).
g) The moisture content of reed canary grass harvested in springtime of the next year after sowing is 10 through 15% (Bondesson, Kraft & Larsson, 1993; Burvall & Segerud, 1993). Thus, the moisture content of reed canary grass was assumed as 15%.
h) Assumed as equal to the moisture content of reed canary grass, *i.e.* 15.0%.
i) V_{solid} = (load space) x (percentage of solid volume)
j) Weight of dry matter per load = V_{solid} x ρ_{basic}
k) Weight of dry matter per load = (load space) x ρ x (percentage of dry matter)
l) The time for loading and unloading of bundled logging residues was assumed as somewhat shorter compared to the time for loading and unloading of roundwood.
m) The time for loading and unloading of willow was assumed as twice as long as the time for loading and unloading of bundled logging residues.
n) The time for loading and unloading was assumed as equal to the time for loading and unloading of bundled logging residues.
o) Time per turn = (time for loading and unloading) + (travel distance per turn) / (average speed)
p) Production per hour = (weight of dry matter per load) / (time per load)
q) Production per year = (production per effective hour) x (effective operating time per year)
r) Wear per t_{dm} of biomass = m_{truck} / ((technical life time (years)) x (production per year))
s) Fuel consumption per year = (fuel consumption per turn) x (effective operating time per year) / (effective time per turn)
t) The sum of service & maintenance costs, personnel costs and fuel costs.

Table A.J-38c. *Transport data for truck used for wood chips, bark, saw dust and recovered wood*

Item	Wood chips	Sawdust	Bark	Recovered wood
Load space[a] [m^3]	96.9	96.9	96.9	96.9
V_{solid}[b] [%]	40%	40%	40%	40%
ρ_{basic} [kg_{dm}/m^3_f]	420[c]	420[c]	413[d]	756[e]
V_{solid}[f] [m^3_f]	38.8	38.8	38.8	38.8
Weight of dry matter per load[g] [t_{dm} /load]	16.3	16.3	16.0	29.3
Average speed[b] [km/h]	70	70	70	70
Transport distance[b] [km]	75	75	75	75
Transport distance per turn [km]	150	150	150	150
Fuel consumption[a] [l/km]	0.45	0.45	0.45	0.45
Loading and unloading[h] [min_{G15}/load]	40	40	40	40
Effective time per turn[i] [h_{G15}/turn]	2.81	2.81	2.81	2.81
Production per hour[j] [t_{dm}/h_{G15}]	5.79	5.79	5.70	10.43
Production per year[k] [t_{dm}/year]	18,352	18,352	18,057	33,033
Wear per t_{dm} of biomass[l] [kg/t_{dm}]	0.0715	0.0715	0.0727	0.0397
Fuel consumption [l/turn]	67.5	67.5	67.5	67.5
Fuel consumption[m] [l/year]	76,113	76,113	76,113	76,113
Fuel consumption [MJ/year]	2732,440	2732,440	2732,440	2732,440
Direct energy required per t_{dm} [MJ/t_{dm}]	148.89	148.89	151.32	82.72
Fuel costs [SEK/year]	532,788	532,788	532,788	532,788
Total variable costs[n] [SEK/year]	1740,190	1740,190	1740,190	1740,190
Specific capital cost [SEK/t_{dm}]	19.66	19.66	19.98	10.92
Variable costs [SEK/t_{dm}]	94.83	94.83	96.37	52.68
Embodied energy [MJ/t_{dm}]	4.43	4.43	4.50	2.46

a) Data from Löthstam (2004).

Table A.J-38c *continued*

b) Assumed values.
c) See Table A.B-2.
d) Data from Björklund (2005).
e) The moisture content was assumed as 50.0% for wood chips and sawdust and 10% for recovered wood. The basic density for recovered wood was assumed as equal to the basic density for wood chips and sawdust. Thus, the basic density for recovered wood at the moisture content of 10% = 420 / 0.50 x (1 - 0.10) $kg_{dm}/m^3{}_f$ = 756 $kg_{dm}/m^3{}_f$.
f) V_{solid} = (load space) x (percentage of solid volume)
g) Weight of dry matter per load = V_{solid} x ρ_{basic}
h) The time for loading and unloading was assumed as equal to the time for loading and unloading of bundled logging residues, reed canary grass and straw (see Table A.J-38b)
i) Time per turn = (time for loading and unloading) + (travel distance per turn) / (average speed)
j) Production per hour = (weight of dry matter per load) / (time per load)
k) Production per year = (production per effective hour) x (effective operating time per year)
l) Wear per t_{dm} of biomass = m_{truck} / ((technical life time (years)) x (production per year))
m) Fuel consumption per year = (fuel consumption per turn) x (effective operating time per year) / (effective time per turn)
n) The sum of service & maintenance costs, personnel costs and fuel costs.

Table A.J-39. *Data for comminution by a drum chipper*

Item	Dumper	Crane	Drum chipper	Total	Total costs in €
Investment[a] [SEK]	636,000[b]	424,000[c]	1908,000[d]	2968,000	325,474
Remaining value[e] [%]	20%	0%	20%		
Operating time[f] [h_u/year]	3500	3500	3500		
Economic life time[e] [year]	6	6	6		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	103,471	86,226	189,697		
Capital costs [SEK/h_u]	29.56	24.64	54.20		
Service & maintenance costs[a] [SEK/year]	106,000[g]	35,330[h]	159,000[i]		
Other costs[a] [SEK/year]	131,408[j]		264,067[k]		
Total service & maintenance costs [SEK/year]	237,408	35,330	423,067		
Total service & maintenance costs [SEK/h_u]	67.83	10.09	120.88		
Personnel costs [SEK/h_u]			170.00[l]		
Personnel costs [SEK/year]			595,000		
Actual operating time [h_u/year]	3500	3500	3500		
Effektive operating time[f] [%]	85,0%	85,0%	85%		
Effektive operating time [h_{G15}/year]	2975	2975	2975		
Capital costs [SEK/year]	103,471	86,226	189,697	379,393	41,605
Total service & maintenance costs [SEK/year]	237,408	35,330	423,067	695,805	76,303
Personnel costs [SEK/year]			595,000	595,000	65,248
Fuel [l/h_{G15}]				50,5[e]	
Fuel [l/year]				150,238	
LHV_{fuel} [MJ/l]				35,9[m]	
Fuel required [MJ/year]				5393,526	
Specific fuel cost [SEK/l]				7,00[n]	
Fuel cost [SEK/year]				1051,663	115,327
Total costs [SEK/year]				2721,861	298,482

Table A.J-39 *continued*

Item	Dumper	Crane	Drum chipper	Total	Total costs in €
Basic density [kg_{dm}/m^3_f]				410[o]	
Bales per hour [bales/h_u]				145[e]	
Dry matter per bale [t_{dm}/bale]				0.268[e]	
Performance					
Production per effective hour, weight [t_{dm}/h_{G15}]				33.1[p]	
Production per effective hour, volume [m^3f/h_{G15}]				80.7[q]	
Production, dry matter weight [t_{dm}/year]				98,451	
Capital costs [SEK/t_{dm}]				3.85	
O & M costs [SEK/t_{dm}]				23.79	
Weight [t]	12.0[r]	2.0[f]	4.0[f]	18.0	
Technical life time[s] [years]	12	12	12		
Technical life time [hours]	42,000	42,000	42,000		
Wear per hour [kg/hu]	0.286	0.048	0.095		
Wear per produced ton biomass [kg/t_{dm}]	0.010	0.002	0.003	0.015	
Solar transformity [sej/kg]	2.60E+12[t]	1.52E+12[t]	1.52E+12[t]	2.24E+12[u]	
Direct energy required per metric ton dry matter [MJ/t_{dm}]				54.78	

Table A.J-39 *continued*

a) The costs were recalculated by the consumer price index from January 2000 through to June 2002. Change in consumer price index for that period = 6.0% (Statistics Sweden, 14-Dec-2004 (URL)).
b) The investment cost of a used dumper was 600,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the investment cost in June 2002 = 600,000 x 1.06 SEK = 636,000 SEK.
c) The investment cost of a crane was 400,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the investment cost in June 2002 = 400,000 x 1.06 SEK = 424,000 SEK.
d) The investment cost of a drum chipper was 1800,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the investment cost in June 2002 = 1800,000 x 1.06 SEK = 1908,000 SEK.
e) Data from Andersson & Nordén (2000).
f) Assumed value.
g) The service & maintenance costs of the dumper were 100,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 100,000 x 1.06 SEK = 106,000 SEK.
h) The service & maintenance costs of the crane were 33,330 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 33,330 x 1.06 SEK = 35,330 SEK.
i) The service & maintenance costs of the drum chipper were 150,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 150,000 x 1.06 SEK = 159,000 SEK.
j) Other costs including tyre costs and travelling costs for the dumper were 123,970 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 123,970 x 1.06 SEK = 131,408 SEK.
k) Other costs including taxes and insurances for the drum chipper were 249,120 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 249,120 x 1.06 SEK = 264,067 SEK.
l) Data from Bredberg (2004).
m) Data from Swedish Energy Agency (2004b).
n) The cost of diesel oil was assumed as equal to the cost during 2002 in Sweden, being approximately 7 SEK/litre (The Swedish Petroleum Institute, 12-May-2004 (URL)).
o) $\rho_{logging\ residues}$ = 410 $kg_{dm}/m^3{}_f$ (see Table A.J-11, footnote s).
p) The production (dry matter weight) per effective hour = [(the number of bales per effective hour) x (dry matter weight per bale)] = 145 x 0.85 x 0.268 t_{dm}/h_{G15} = 33.09 t_{dm}/h_{G15}.
q) The production per effective hour [$m^3{}_f/h_{G15}$] = m_{dm} / h_{G15} / ρ.
r) The weight of the dumper was assumed as equal to the weight of a small harvester.
s) The technical life time was assumed as twice the economic life time.
t) See Table A.I-7.
u) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (12.0 x 2.60 x 10^{12} + 2.0 x 1.52 x 10^{12} + 4.0 x 1.52 x 10^{12}) / 18.0 sej/kg = 2.24 x 10^{12} sej/kg.

Table A.J-40. *Data for comminution by a scraper*

Item	Dumper	Crane	Scraper	Total	Total costs in €
Investment [SEK]	636,000[a, b]	424,000[a, c]	700,000[d]	1760,000	193,004
Remaining value [%]	20%[e]	0%[e]	20%[f]		
Operating time[g] [h_u/year]	3500	3500	3500		
Economic life time [year]	6[e]	6[e]	6[h]		
Interest rate [%]	6%	6%	6%		
Capital costs [SEK/year]	103,471	86,226	113,883		
Capital costs [SEK/h_u]	29.56	24.64	54.20		
Service & maintenance costs [SEK/year]	106,000[a, i]	35,330[a, j]	58,333[k, l]		
Other costs [SEK/year]	131,408[a, m]		96,880[k, n]		
Total service & maintenance costs [SEK/year]	237,408	35,330	155,213		
Total service & maintenance costs [SEK/h_u]	67.83	10.09	44.35		
Personnel costs [SEK/h_u]			170.00[o]		
Personnel costs [SEK/year]			595,000		
Actual operating time [h_u/year]	3500	3500	3500		
Effective operating time[g] [%]	85,0%	85,0%	85%		
Effective operating time [h_{G15}/year]	2975	2975	2975		
Capital costs [SEK/year]	103,471	86,226	113,883	286,335	31,400
Total service & maintenance costs [SEK/year]	237,408	35,330	155,213	432,783	47,460
Personnel costs [SEK/year]			595,000	595,000	65,248
Electric power [kW]				200[p]	
Electric power [GJ/year]				2142	
Cost of electricity [SEK/kWh]				0.30[g]	
Cost of electricity [SEK/year]				178,500	19,575
Total costs [SEK/year]				1492,618	163,682

Table A.J-40 *continued*

Item	Dumper	Crane	Scraper	Total	Total costs in €
Performance					
Production per effective hour, weight [t_{dm}/h_{G15}]				6.80[q]	
Production, dry matter weight [t_{dm}/year]				20,230	
Weight [t]	12.0[r]	2.0[g]	3.5[p]	17.5	
Technical life time[s] [years]	12	12	12		
Technical life time [hours]	42,000	42,000	42,000		
Wear per hour [kg/h_u]	0.286	0.048	0.083		
Wear per produced ton biomass [kg/t_{dm}]	0.049	0.008	0.014	0.072	
Solar transformity [sej/kg]	2.60E+12[t]	1.52E+12[t]	1.52E+12[t]	2.26E+12[u]	
Direct energy required per metric ton dry matter [MJ/t_{dm}]				105.88	

Table A.J-40 *continued*

a) The costs were recalculated by the consumer price index from January 2000 through June 2002. Change in consumer price index for that period = 6.0% (Statistics Sweden, 14-Dec-2004 (URL)).
b) The investment cost of a used dumper was 600,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the investment cost in June 2002 = 600,000 x 1.06 SEK = 636,000 SEK.
c) The investment cost of a crane was 400,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the investment cost in June 2002 = 400,000 x 1.06 SEK = 424,000 SEK.
d) The investment cost of a scraper is 700,000 SEK (Rockler, 2004).
e) Data from Andersson & Nordén (2000).
f) Assumed as equal to the remaining value of the drum chipper (see Table A.J-39).
g) Assumed value.
h) Assumed as equal to the economic life time of the drum chipper (see Table A.J-39).
i) The service & maintenance costs of the dumper were 100,000 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 100,000 x 1.06 SEK = 106,000 SEK.
j) The service & maintenance costs of the crane were 33,330 SEK in 2000 (Andersson & Nordén, 2000). Thus, the service & maintenance costs in June 2002 = 33,330 x 1.06 SEK = 35,330 SEK.
k) The variable costs of the scraper were assumed proportional to the variable costs of the drum chipper and the investment costs of the equipments. The investment cost of the drum chipper was 1908,000 SEK (see Table A.J-39).
l) The service & maintenance costs of the drum chipper were 159,000 SEK (see Table A.J-39). Thus, the service & maintenance costs of the scraper = 159,000 x 700,000 / 1908,000 SEK = 58,333 SEK.
m) Other costs including tyre costs and travelling costs for the dumper were 123,970 SEK in 2000 (Andersson & Nordén, 2000). Thus, the other costs in June 2002 = 123,970 x 1.06 SEK = 131,408 SEK.
n) Other costs including taxes and insurances for the drum chipper were 264,067 SEK (see Table A.D-11). Thus, the other costs for the scraper = (241,920 + 3000 + 4200) x 700,000 / 1800,000 SEK = 96,880 SEK.
o) Data from Bredberg (2004).
p) Data from Rockler (2004).
q) Data from Burvall & Segerud (1993).
r) The weight of the dumper was assumed equal to the weight of a small harvester.
s) The technical life time was assumed as twice the economic life time.
t) See Table A.I-7.
u) The total solar transformity = [the weighted value with regard to the weights of the equipment] = (12.0 x 2.60 x 10^{12} + 2.0 x 1.52 x 10^{12} + 3.5 x 1.52 x 10^{12}) / 17.5 sej/kg = 2.26 x 10^{12} sej/kg.

Table A.J-41a. *Data for pellet production*

Item	Drum dryer	Hammer mill	Pellet press	Counter-flow cooler	Silo for storage	Peripheral equipment	Con-struction	Office and computer equipment
Investment[a] [SEK]	22524,048	3378,607	5631,012	2252,405	8164,967	4082,484	8164,967	938,502
Economic life time [year]	15[b]	15[c]	15[d]	15[e]	20[f]	10[g]	20[h]	5[e]
Interest rate [%]	6%	6%	6%	6%	6%	6%	6%	6%
Capital costs [SEK/year]	2319,138	347,871	579,785	231,914	711,859	554,679	711,859	222,797
Service & maintenance costs[a] [SEK/year]	563,101	610,026	732,032	46,925	206,470	65,695	84,465	4693
Other costs[a] [SEK/year]	112,620	18,770	28,155	9385	37,540	18,770	37,540	4693
Total service & maintenance costs [SEK/year]	675,721	628,796	760,187	56,310	244,011	84,465	122,005	9385
$E_{electricity\ required}$[i] [$MJ/t_{dm}$]	128.0[j]	84.7[k]	170.0[l]	17.0[m]		33.9[n]		

a) Data from Zakrisson (2002), recalculated to SEK from the exchange rate for Euro (€) to SEK in June 2001 and the Swedish consumer price index for the period July 2001 through June 2002. The exchange rate for Euro to SEK in June 2001 was 9.201 SEK/€ (Central bank of Sweden, 26-Aug-2004 (URL)), and the change in the Swedish consumer price index for the period July 2001 through June 2002 was 2.0% (http://www.ssd.scb.se/databaser/makro/temp/tmp20041214111358481PR0101C5.xls; 14-Dec-2004).

b) The economic life time for drum dryers was estimated by Zakrisson (2002) to be 10 years. In this work, the economic life time for drum dryers was assumed as 15 years.

c) The economic life time for hammer mills was estimated by Zakrisson (2002) to be 10 years. In this work, the economic life time for hammer mills was assumed as 15 years.

d) The economic life time for pellet presses was estimated by Zakrisson (2002) to be 10 years. In this work, the economic life time for pellet presses was assumed as 15 years.

e) Data from Zakrisson (2002).

f) The economic life time for silos for storage of pellets was estimated by Zakrisson (2002) to be 50 years. In this work, the economic life time for silos for storage of pellets was assumed as 20 years.

Table A.J-41a *continued*

g) The economic life time for peripheral equipment was estimated by Zakrisson (2002) to be 50 years. In this work, the economic life time for peripheral equipment was assumed as 10 years.
h) The economic life time for constructions was estimated by Zakrisson (2002) to be 50 years. In this work, the economic life time for constructions was assumed as 20 years.
i) The moisture content of the pellets was assumed as 10%.
j) See Table A.J-41b.
k) The amount of electricity required for milling in a pellet plant with a production of 80,000 metric ton of pellets was estimated by Zakrisson (2002) to be 1.694 GWh/year. Thus, the amount of electricity required per ton of dry matter = $1.694 \times 10^9 \times 3600 / (80{,}000 \times (1 - 0.10))$ J/t_{dm} = 84.7 MJ/t_{dm}.
l) The amount of electricity required for pelletizing in a pellet plant with a production of 80,000 metric ton of pellets was estimated by Zakrisson (2002) to be 3.400 GWh/year. Thus, the amount of electricity required per ton of dry matter = $3.400 \times 10^9 \times 3600 / (80{,}000 \times (1 - 0.10))$ J/t_{dm} = 170.0 MJ/t_{dm}.
m) The amount of electricity required for cooling of the pellets in a pellet plant with a production of 80,000 metric ton of pellets was estimated by Zakrisson (2002) to be 339 MWh/year. Thus, the amount of electricity required per ton of dry matter = $339 \times 10^6 \times 3600 / (80{,}000 \times (1 - 0.10))$ J/t_{dm} = 17.0 MJ/t_{dm}.
n) The amount of electricity required for peripheral equipment in a pellet plant (*e.g.* dosing feeders, feeding screws and fans) with a production of 80,000 metric ton of pellets was estimated by Zakrisson (2002) to be 678 MWh/year. Thus, the amount of electricity required per ton of dry matter = $678 \times 10^6 \times 3600 / (80{,}000 \times (1 - 0.10))$ J/t_{dm} = 33.9 MJ/t_{dm}.

Table A.J-41b. *Data for pellet production*

Item	Total industrial plant	Total costs in €	Drum dryer
Investment costs [SEK]	55136,993[a]	6046,386	22524,048[b]
Economic life time [year]			15[b]
Interest rate [%]			6%
Capital costs [SEK/year]	5679,901[a]	622,864	2319,138[b]
Service & maintenance costs [SEK/year]	2313,407[a]	253,691	563,101[b]
Other costs [SEK/year]	267,473[a]	29,331	112,620[b]
Total service & maintenance costs [SEK/year]	2580,881	283,022	675,721[b]
Annual production [t_{dm}/year]	72,000[c]		
$E_{gross\ energy\ use}$ [MJ/t_{H2O}]			3100[d]
$E_{recovered}$ [MJ/t_{H2O}]			2550[e]
$E_{fan\ and\ screws}$ [MJ/t_{H2O}]			144[e]
FH_{in} [%]			50[f]
FH_{out} [%]			10[f]
$E_{gross\ energy\ use}$ [MJ/t_{dm}]			2755.6[g]
$E_{gross\ energy\ use}$ [TJ]			198.4[h]
$HHV_{sawdust}$ [MJ/kg_{dm}]			19.9[i]
$m_{fuel\ demand}$ [t_{dm}/year]	14,487[j]		14,487[j]
$E_{fuel\ demand}$ per ton dry matter of biomass [GJ/t_{dm}]	4.004[k]		4.004[k]
$E_{recovered}$ [MJ/t_{dm}]	2267[l]		2267[l]
$E_{recovered}$ used in district heating [TJ]	163.2[m]		163.2[m]
HHV of dried biomass [MJ/kg_{dm}]			19.9[i]
$E_{electricity\ required}$ [MJ/t_{dm}]	433.55[n]		128.0[o]
$E_{electricity\ required}$ [GJ/year]	31,216		
Biomass cost per ton dry matter [SEK/t_{dm}]	1052[p]		
Cost of wood fuel required at drying [SEK/year]	15242,369	1671,496	
Cost of electricity [SEK/kWh]	0.30[f]		
Cost of electricity [SEK/year]	2601,300	285,262	
Working time, man hours per year [h/year]	21,000[q]		
Personnel costs including overtime allowance, sickness benefit and holiday pay [SEK/h]	170.00[r]		
Personnel costs including overtime allowance, sickness benefit and holiday pay [SEK/year]	3570,000		
Additional personnel costs for administration and marketing [SEK/year]	1032,352[s, t]		
Total personnel costs [SEK/year]	4602,352	504,699	
Cost of interest for stored pellets [SEK/year]	1351,443[s, u]	148,201	
O & M costs[v] [SEK/year]	25026,901	2744,479	
Dry matter losses of raw material [%]	0.1%[f]		
Biomass input as raw material [t_{dm}/year]	72,072		
Cost of biomass used as raw material [SEK/year]	75830,783	8315,691	
Total annual costs [SEK/year]	106537,586	11683,034	
Specific capital costs[w] [SEK/t_{dm}]	78.89		
Specific O & M costs[w] [SEK/t_{dm}]	347.60		
Specific costs for expendables[w] [SEK/t_{dm}]	18.77		

Table A.J-41b *continued*

Item	Total industrial plant
Total biomass input (fuel and raw material) [t_{dm}/year]	86,559
Weight [t]	100[f]
Technical life time [years]	30[x]
Annual manufacturing hours [h/year]	7972[q]
Technical life time [hours]	239,160
Wear per hour [kg/h]	0.418[y]
Wear per ton biomass [kg/t_{dm}]	0.039[z]
Solar transformity [sej/kg]	2.60E+12[aa]

a) The sum of costs calculated by means of Table A.J-41a.
b) See Table A.J-41a.
c) The production of pellets was estimated to be 80,000 t/year, according to Zakrisson (2002). The moisture content of the pellets was assumed as 10%. Thus, the production of pellets regarding dry matter = 80,000 x (1 – 0.10) t_{dm}/year = 72,000 t_{dm}/year.
d) Data from Wimmerstedt (1999).
e) Data from Wimmerstedt & Linde (1998).
f) Assumed value.
g) The gross amount of heat required for drying [MJ/t_{dm}] = ($E_{gross\ energy\ use}$ [MJ/t_{H2O}]) x (($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ in}$) – ($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ out}$)) / ($m_{pellets,\ dm}$/year])
h) The gross amount of heat required for drying [TJ] = ($E_{gross\ energy\ use}$ [TJ/t_{H2O}]) x (($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ in}$) – ($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ out}$))
i) See Table A.B-1c. Sawdust was assumed as the fuel used for the generation of flue gas used for drying and as the raw material for pellet production.
j) The efficiency was assumed as equal to the efficiency of the moving grate boiler chosen as a reference plant for district heating generation from combustion of undensified biomass, excluding flue gas condensation. The heat effect output of the boiler excluding flue gas condensation = 15.0 MW (Olsson, 2004). $E_{biomass\ input,\ HHV}$ = 21.797 MW (see Table A.J-44, footnote h). Thus, the boiler efficiency = 15.0 / 21.797 = 68.8%. The amount of heat produced per ton dry matter of biomass = 19.9 x 0.688 GJ/t_{dm} = 13.691 GJ/t_{dm}. Thus, the amount of fuel required = 1.984 x 10^5 / 13.691 t_{dm}/year = 14,487 t_{dm}/year.
k) The amount of fuel required for generation of flue gas used for drying [GJ/t_{dm}] = 14,487 x 19.9 / 72,000 GJ/t_{dm} = 4.004 GJ/t_{dm}.
l) The amount of heat recovered at drying [MJ/t_{dm}] = ($E_{recovered}$ [MJ/t_{H2O}]) x (($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ in}$) – ($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ out}$)) / ($m_{pellets,\ dm}$/year])
m) The amount of heat recovered at drying [TJ] = ($E_{recovered}$ [TJ/t_{H2O}]) x (($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ in}$) – ($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ out}$))
n) The total amount of electricity required, calculated by means of Table A.J-41a.
o) The amount of electricity required at drying [MJ/t_{dm}] = ($E_{electricity}$ [MJ/t_{H2O}]) x (($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ in}$) – ($m_{pellets,\ dm}$/year]) / (1 – $MC_{pellets,\ out}$)) / ($m_{pellets,\ dm}$/year])
p) The cost of sawdust after road transport (see Table 6-A9).
q) Data from Zakrisson (2002).
r) The specific personnel costs were assumed as equal to the specific personnel costs in silviculture and forestry, *i.e.* 170 SEK/h_u (see Tables A.J-3 through A.J-14).
s) The exchange rate for Euro to SEK in June 2001 was 9.201 SEK/€ and the Swedish consumer price for the period July 2001 through June 2002 was 2.0% (see Table A.J-41a, footnote a).

Table A.J-41b *continued*

t) Additional personnel costs for administration and marketing was 110,000 €/year in 1997 (Zakrisson, 2002). Thus, additional personnel costs for administration and marketing in June 2002 = 110,000 x 9.201 x 1.02 SEK/year = 1032,352 SEK/year.
u) The cost of interest for stored pellets was 144,000 €/year in 1997 (Zakrisson, 2002). Thus, the cost of interest for stored pellets in June 2002 = 144,000 x 9.201 x 1.02 SEK/year = 1351,443 SEK/year.
v) The sum of total service & maintenance costs, cost of wood fuel required at drying, cost of electricity and total personnel costs.
w) Costs per metric ton dry matter of pellets produced.
x) The technical life time was assumed as twice the economic life time.
y) The wear per operating hour = m_{plant} / (technical life time)
z) The wear per ton biomass [kg/t_{dm}] = (the wear per operating hour [kg/h]) / (the biomass supply [t_{dm}/h]). The total biomass supply = 86,559 / 7972 t_{dm}/h = 10.86 t_{dm}/h. Thus, the wear per ton biomass = 0.418 / 10.86 kg/t_{dm} = 0.039 kg/t_{dm}.
aa) The solar transformity for the plant was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

Table A.J-42. *Data for small-scale firing boilers*

Item	Wood firing	Costs in €	Pellets firing	Costs in €
Investment [SEK]	70,000[a]	7,676	70,000[a]	7,676
Economic life time[b] [years]	15		15	
Interest rate [%]	6.0		6.0	
Capital costs [SEK/year]	7207	790	7207	790
Electricity [kWh/year]			128[c]	
Electricity [MJ/year]			462	
Electricity cost per unit[b] [SEK/kWh]	0.30		0.30	
Energy costs [SEK/year]			38.50[c]	
Service & maintenance costs[c] [SEK/year]	1000		1000	
Other costs [SEK/year]				
Total service & maintenance costs [SEK/year]	1000		1000	
Personnel costs[b] [SEK/year]	3000		3000	
O & M costs [SEK/year]	4000	439	4039	443
Annual heat production[d] [kWh/year]	20,000		20,000	
Annual heat production [MJ/year]	72,000		72,000	
Average power output [kW]	21.3[e]		12.0[f]	
Operating time[g] [h/year]	939		1667	
Boiler efficiency, based on the LHV [%]	82.0[h]		82.5[i]	
Fuel demand[j] [kWh_{LHV}/year]	24,390		24,242	
Fuel demand[j] [MJ_{LHV}/year]	87,805		87,273	
$HHV_{biomass}$ [MJ/kg_{dm}]	20.9[k]		19.9[l]	
Moisture content[b] [%]	20		10	
$LHV_{biomass}$[m] [MJ/kg_{dm}]	18.97		18.31	
Biomass supply[n] [t_{dm}/year]	4.629		4.767	
Biomass supply[o] [kg_{dm}/h]	4.9		2.9	
Heat production [GJ/t_{dm}]	15.553		15.104	
Biomass costs [SEK/t_{dm}]	424[p]		1497[q]	
Biomass costs [SEK/year]	1961		7138	
Total annual costs[r] [SEK/year]	13,169		18,384	
Specific capital costs [SEK/t_{dm}]	1556.93		1511.94	
Specific O & M costs [SEK/t_{dm}]	864.08		847.18	
Direct energy required per ton dry matter [MJ/t_{dm}]			96.92	
Weight[b] [t]	2.0		2.0	
Technical life time[s] [years]	30		30	
Technical life time [hours]	28,169		50,000	
Wear per operating hour[t] [kg/h]	0.071		0.040	
Wear per ton biomass[u] [kg/t_{dm}]	14.40		13.99	
Solar transformity[v] [sej/kg]	2.60E+12		2.60E+12	

a) See Table 4-1, footnote g.
b) Assumed values.
c) See Table 4-1, footnote l.
d) The typical heat demand for a single family-house in Sweden is 20,000 kWh per year, or 72.0 GJ per year (Swedish Energy Agency, 2002).
e) The average power output at wood firing in the boiler model called *Arimax 35* is 21.3 kW (Jansson, 2004b).
f) The average power output at pellet firing in the boiler model called *BeQuem* is 12.0 kW (Löfgren & Windestål, 2001).

Table A.J-42 *continued*

g) Annual operating time = (annual heat production) / (average power output)
h) The boiler efficiency based on the LHV at wood firing in the boiler model called *Arimax 35* = 82.0% (Jansson, 2004b).
i) The boiler efficiency based on the LHV at pellet firing in the boiler model called *BeQuem* = 82.5% (Löfgren & Windestål, 2001).
j) The fuel demand = (annual heat production) / (boiler efficiency)
k) The HHV of whole trees = 20.9 MJ/kg_{dm} (see Table A.B-1c).
l) The HHV of pellets was assumed as equal to the HHV of sawdust, *i.e.* 19.9 MJ/kg_{dm} (see Table A.B-1c).
m) $LHV_{biomass} = HHV_{biomass} - 1.32 - 2.45$ x ((moisture content)$_{biomass}$ / (1 – (moisture content)$_{biomass}$) [MJ/kg_{dm}] (Nylinder, 1979)
n) The biomass supply [t_{dm}/year]= (the fuel demand [GJ_{LHV}/year]) / (LHV [GJ/t_{dm}])
o) The biomass supply [kg_{dm}/h]= (the biomass supply [kg_{dm}/year]) / (annual operating time [h/year])
p) Cost of fuel wood after forwarding (see Table A.I-15).
q) Cost of pellets (see Table A.I-16).
r) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
s) The technical life time was assumed as twice the economic life time.
t) The wear per operating hour = m_{boiler} / (technical life time)
u) The wear per ton biomass [kg/t_{dm}] = (the wear per operating hour [kg/h]) / (the biomass supply [t_{dm}/h])
v) The solar transformity for boilers was assumed equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

Table A.J-43. *Data for pellets boiler used for district heating generation*

Item	Pellets boiler	Costs in €
Investment [MSEK]	20.000[a]	2193,223
Economic life time [years]	15[b]	
Interest rate	6%	
Capital costs [MSEK/year]	2.059	225,820
Electricity [MWh/year]	449[c]	
Electricity [TJ/year]	1.616	
Electricity cost per unit [SEK/kWh]	0.30[b]	
Electricity costs [MSEK/year]	0.135	
Service & maintenance costs [MSEK/year]	0.050[c]	
Personnel costs [MSEK/year]	0.120[c]	
O & M costs [MSEK/year]	0.305	33,414
Annual heat production [GJ/year]	116,471[d]	
Operating time [h/year]	5088[e]	
Biomass supply [t/year]	7079[d]	
Biomass supply [t_{dm}/year]	6513[f]	
Biomass supply [t_{dm}/h]	1.28	
$LHV_{biomass}$ [MJ/kg]	17.64[d]	
Biomass supply [GJ_{LHV}/year]	124,874	
Boiler efficiency, based on the LHV [%]	93.3[g]	
Heat production [GJ/t_{dm}]	17.884	
Biomass costs [SEK/t_{dm}]	1497.41[h]	
Biomass costs [MSEK/year]	9.752	
Total annual costs [MSEK/year]	12.116[i]	1328,663
Specific capital costs [SEK/t_{dm}]	316.19	
Specific O & M costs [SEK/t_{dm}]	46.79	
Direct energy required per ton dry matter [MJ/t_{dm}]	248.19	
Weight [t]	25[b]	
Technical life time [years]	30[j]	
Technical life time [hours]	152,640	
Wear per operating hour [kg/h]	0.164[k]	
Wear per ton biomass [kg/t_{dm}]	0.128[l]	
Solar transformity [sej/kg]	2.60E+12[m]	

a) See Table 4-1, footnote h.
b) Assumed values.
c) See Table 4-1, footnote m.
d) Data from Alvin (2005).
e) The boiler is used for maximum load during winter time, from October until March/April (Alvin, 2005). The number of days for the period October through April = 212 (213 at leap year). Thus, the annual operating time = 212 x 24 h = 5088 h.
f) The moisture content of the pellets used = 8.0 % (Alvin, 2005). Thus, the dry matter amount of fuel required = 7079 x (1 – 0.08) t_{dm}/year = 6513 t_{dm}/year.
g) $\eta_{LHV} = E_{produced} / E_{biomass\ input,\ LHV}$
h) Cost of pellets (see Table A.I-17).
i) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
j) The technical life time was assumed as twice the economic life time.
k) The wear per operating hour = m_{boiler} / (technical life time)
l) The wear per ton biomass [kg/t_{dm}] = (the wear per operating hour [kg/h]) / (the biomass supply [t_{dm}/h])
m) The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

Table A.J-44. *Data for moving grate boiler designed for undensified biofuels and used for district heating generation*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Investment[a] [MSEK]	51.849	51.849	51.849	51.849	51.849	51.849	51.849	51.849
Economic life time[b] [years]	15	15	15	15	15	15	15	15
Interest rate	6%	6%	6%	6%	6%	6%	6%	6%
Capital costs [MSEK/year]	5.339	5.339	5.339	5.339	5.339	5.339	5.339	5.339
Electricity[c] [MJ/t_{dm}]	157.9	157.9	157.9	157.9	157.9	157.9	157.9	157.9
Electricity [TJ/year]	1.884	1.884	1.877	1.877	1.877	1.972	1.972	1.914
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	0.157	0.157	0.156	0.156	0.156	0.164	0.164	0.160
Service & maintenance costs[d] [MSEK/year]	3.843	3.843	3.844	3.844	3.844	3.836	3.836	3.840
Personnel costs[e] [MSEK/year]	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
O & M costs[f] [MSEK/year]	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Operating time[g] [h/year]	5088	5088	5088	5088	5088	5088	5088	5088
Biomass supply[h] [TJ/year]	248.5	248.5	248.5	248.5	248.5	248.5	248.5	248.5
$HHV_{biomass}$[i] [MJ/kg_{dm}]	20.8	20.8	20.9	20.9	20.9	19.9	19.9	20.5
Biomass supply[j] [t_{dm}/year]	11,947	11,947	11,890	11,890	11,890	12,487	12,487	12 122
Biomass supply [t_{dm}/h]	2.35	2.35	2.34	2.34	2.34	2.45	2.45	2.38
Biomass costs[k] [SEK/t_{dm}]	435.31	575.69	307.55	319.96	522.94	1052.15	1052.15	1054.02
Biomass costs [MSEK/year]	5.201	6.878	3.657	3.804	6.218	13.139	13.139	12.777
Total annual costs[l] [MSEK/year]	15.539	17.216	13.995	14.143	16.556	23.477	23.477	23.115
Specific capital costs [SEK/t_{dm}]	446.85	446.85	448.99	448.99	448.99	427.51	427.51	440.40
Specific O & M costs [SEK/t_{dm}]	418.51	418.51	420.52	420.52	420.52	400.40	400.40	412.47
Boiler efficiency, based on the HHV[m] [%]	82.6	82.6	82.6	82.6	82.6	82.6	82.6	82.6
Heat production[n] [TJ/year]	205.21	205.21	205.21	205.21	205.21	205.21	205.21	205.21
Weight[b] [t]	100	100	100	100	100	100	100	100

Table A.J-44 *continued*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Technical life time[o] [years]	30	30	30	30	30	30	30	30
Technical life time [hours]	152,640	152,640	152,640	152,640	152,640	152,640	152,640	152,640
Wear per operating hour[p] [kg/h]	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.655
Wear per ton biomass[q] [kg/t_{dm}]	0.279	0.279	0.280	0.280	0.280	0.267	0.267	0.275
Solar transformity[r] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

Table A.J-44 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Investment[a] [MSEK]	51.849	51.849	51.849	51.849
Economic life time[b] [years]	15	15	15	15
Interest rate	6%	6%	6%	6%
Capital costs [MSEK/year]	5.339	5.339	5.339	5.339
Electricity[c] [MJ/t_{dm}]	157.9	157.9	157.9	157.9
Electricity [TJ/year]	2.002	2.156	2.098	1.972
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	0.167	0.180	0.175	0.164
Service & maintenance costs[d] [MSEK/year]	3.833	3.820	3.825	3.836
Personnel costs[e] [MSEK/year]	1.000	1.000	1.000	1.000
O & M costs[f] [MSEK/year]	5.000	5.000	5.000	5.000
Operating time[g] [h/year]	5088	5088	5088	5088
Biomass supply[h] [TJ/year]	248.5	248.5	248.5	248.5
$HHV_{biomass}$[i] [MJ/kg_{dm}]	19.6	18.2	18.7	19.9
Biomass supply[j] [t_{dm}/year]	12,679	13,654	13,289	12,487
Biomass supply [t_{dm}/h]	2.49	2.68	2.61	2.45
Biomass costs[k] [SEK/t_{dm}]	504.58	763,15	1255.08	95.87
Biomass costs [MSEK/year]	6.397	10.420	16.678	1.197
Total annual costs[l] [MSEK/year]	16.736	20.758	27.017	11.536
Specific capital costs [SEK/t_{dm}]	421.07	390.99	401.73	427.51
Specific O & M costs [SEK/t_{dm}]	394.37	366.20	376.26	400.40
Boiler efficiency, based on the HHV[m] [%]	82.6	82.6	82.6	82.6
Heat production[n] [TJ/year]	205.21	205.21	205.21	205.21
Weight[b] [t]	100	100	100	100

Table A.J-44 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Technical life time[o] [years]	30	30	30	30
Technical life time [hours]	152,640	152,640	152,640	152,640
Wear per operating hour[p] [kg/h]	0.655	0.655	0.655	0.655
Wear per ton biomass[q] [kg/t_{dm}]	0.263	0.244	0.251	0.267
Solar transformity[r] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12

a) See Table 4-1, footnote h.
b) Assumed values.
c) The required amount of electricity = 0.5 GWh / 45 GWh_{LHV} of heat generated. LHV_{fuel} = 2.15 MWh/t. The moisture content = 52.5%. A fuel feed of 8 t/h generates a heating effect of 15 MW (Olsson, 2004). $E_{biomass}$/h = 2.15 x 8 MWh = 17.2 MWh. $H_{boiler, LHV}$ = 15 / 17.2 = 87.21%. Thus, 45 GWh_{LHV} produced heat requires (45 / 0.8721) GWh_{LHV} biomass = 51.60 GWh_{LHV} of biomass. Corresponding weight of biomass = (51.60 / 2.15) kt = 24.0 kt, and corresponding weight of dry matter = 24.0 x (1 – 0.525) kt_{dm} = 11.4 kt_{dm}. The required amount of electricity per ton dry matter = 0.5 x 3.6 / 11.4 GJ/t_{dm} = 157.9 MJ/t_{dm}.
d) Service & maintenance costs = (O & M costs) – (personnel costs) – (electricity costs)
e) The personnel costs for the plant, consisting of two boilers, are 1.250 MSEK/year (Olsson, 2004). The personnel costs for the reference boiler were assumed as 1.000 MSEK/year.
f) Data from Olsson (2004).
g) The boiler is used during winter time, from September/October until April/May, depending on the climate (Olsson, 2004). The annual operating time was assumed as equal to the annual operating time of the pellets boiler used for district heating generation, *i.e.* 5088 h (see Table A.J-43, footnote e).
h) Biomass input = 8000 kg/h and the moisture content = 52.5% (Olsson, 2004). Input of dry matter = 8000 x (1 – 0.525) kg/h = 3800 kg/h. The biomass consists of logging residues and bark (Olsson, 2004) and the composition was assumed as 50% of logging residues and 50% of bark. Thus, the HHV of the biomass composition = (20.5 x 0.50 + 20.8 x 0.50) MJ/kg_{dm} = 20.65 MJ/kg_{dm} and the biomass input = 3800 x 20.65 MJ/h = 3800 x 20.65 / 3600 MW = 21.797 MW. Maximum heat effect = 15.0 MW (Olsson, 2004). $\eta_{boiler, HHV}$ = 15.0 / 21.797 = 68.82%. $E_{biomass} = E_{heat} / \eta_{boiler}$. E_{heat} = 171.0 TJ/year (Olsson, 2004). Thus, the annual energy amount of biofuel required = 171.0 / 0.6882 TJ = 248.5 TJ.
i) See Table A.B-1c.

Table A.J-44 *continued*

j) $m_{biomass, dm} = E_{biomass, HHV}$ / HHV
k) Cost of biomass assortments before conversion (see Tables A.I-3 through A.I-14).
l) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
m) The total heat effect output with flue gas condensation is estimated by Olsson (2004) to be 18.0 MW. $E_{biomass\ input, HHV}$ = 21.797 MW (see footnote h). Thus, the boiler efficiency = 18.0 / 21.797 = 82.58%
n) $E_{heat} = E_{biomass} \times \eta_{boiler}$
o) The technical life time was assumed as twice the economic life time.
p) The wear per operating hour = m_{boiler} / (technical life time)
q) The wear per dry matter of biomass = (the wear per operating hour) / (biomass supply [t_{dm}/h])
r) The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60×10^{12} sej/kg (see Table A.H-7).

Table A.J-45. *Data for CHP plant*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Investment[a] [MSEK]	689.000	689.000	689.000	689.000	689.000	689.000	689.000	689.000
Specific investment costs for CHP[b] [MSEK]	333.900	333.900	333.900	333.900	333.900	333.900	333.900	333.900
Economic life time[c] [years]	15	15	15	15	15	15	15	15
Interest rate	6%	6%	6%	6%	6%	6%	6%	6%
Capital costs [MSEK/year]	70.941	70.941	70.941	70.941	70.941	70.941	70.941	70.941
Specific capital costs for CHP [MSEK/year]	34.379	34.379	34.379	34.379	34.379	34.379	34.379	34.379
Electricity[d] [MJ/t_{dm}]	515.02	515.02	515.02	515.02	515.02	515.02	515.02	515.02
Electricity [TJ/year]	111.84	111.84	111.30	111.30	111.30	116.89	116.89	113.47
Electricity cost per unit[c] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	8.372	8.372	9.275	9.275	9.275	9.741	9.741	9 456
Service & maintenance costs[d] [MSEK/year]	5.600	5.600	5.600	5.600	5.600	5.600	5.600	5.600
Personnel costs[d] [MSEK/year]	2.120	2.120	2.120	2.120	2.120	2.120	2.120	2.120
O & M costs [MSEK/year]	17.040	17.040	16.995	16.995	16.995	17.461	17.461	17 176
Operating time[e] [h/year]	8000	8000	8000	8000	8000	8000	8000	8000
Biomass supply[d] [PJ/year]	4.517	4.517	4.517	4.517	4.517	4.517	4.517	4.517
$HHV_{biomass}$[f] [MJ/kg_{dm}]	20.8	20.8	20.9	20.9	20.9	19.9	19.9	20.5
Biomass supply[g] [t_{dm}/year]	217,147	217,147	216,108	216,108	216,108	226,968	226,968	220,325
Biomass supply [t_{dm}/h]	27.14	27.14	27.01	27.01	27.01	28.37	28.37	27.54
Biomass costs[h] [SEK/t_{dm}]	435.31	575.69	307.55	319.96	522.94	1052.15	1052.15	1054.02
Biomass costs [MSEK/year]	94.526	125.009	66.464	69.145	113.011	238.805	238.805	232.226
Total annual costs[i] [MSEK/year]	182.507	212.990	154.401	157.081	200.948	327.207	327.207	320.344
Specific capital costs [SEK/t_{dm}]	326.70	326.70	328.27	328.27	328.27	312.56	312.56	321.98
Specific O & M costs [SEK/t_{dm}]	78.47	78.47	78.64	78.64	78.64	76.93	76.93	77.96
Heat efficiency, based on the HHV[j] [%]	66.8	66.8	66.8	66.8	66.8	66.8	66.8	66.8

Table A.J-45 *continued*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Heat production[k] [PJ/year]	3.015	3.015	3.015	3.015	3.015	3.015	3.015	3.015
Electric power efficiency, based on the HHV[l] [%]	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.7
Electric power production[m] [TJ/year]	1.340	1.340	1.340	1.340	1.340	1.340	1.340	1.340
Conversion losses, based on the HHV[n] [%]	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Weight[c] [t]	1000	1000	1000	1000	1000	1000	1000	1000
Technical life time[o] [years]	30	30	30	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[p] [kg/h]	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167
Wear per ton biomass[q] [kg/t_{dm}]	0.154	0.154	0.154	0.154	0.154	0.147	0.147	0.151
Solar transformity[r] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

Table A.J-45 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Investment[a] [MSEK]	689.000	689.000	689.000	689.000
Specific investment costs for CHP[b] [MSEK]	333.900	333.900	333.900	333.900
Economic life time[c] [years]	15	15	15	15
Interest rate	6%	6%	6%	6%
Capital costs [MSEK/year]	70.941	70.941	70.941	70.941
Specific capital costs for CHP [MSEK/year]	34.379	34.379	34.379	34.379
Electricity[d] [MJ/t_{dm}]	515.02	515.02	515.02	515.02
Electricity [TJ/year]	118.68	127.81	124.39	116.89
Electricity cost per unit[c] [SEK/kWh]	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	9.890	10.651	10.366	9.741
Service & maintenance costs[d] [MSEK/year]	5.600	5.600	5.600	5.600
Personnel costs[d] [MSEK/year]	2.120	2.120	2.120	2.120
O & M costs [MSEK/year]	17.610	18.371	18.086	17.461
Operating time[e] [h/year]	8000	8000	8000	8000
Biomass supply[d] [PJ/year]	4.517	4.517	4.517	4.517
$HHV_{biomass}$[f] [MJ/kg_{dm}]	19.6	18.2	18.7	19.9
Biomass supply[g] [t_{dm}/year]	230,442	248,168	241,533	226,968
Biomass supply [t_{dm}/h]	28.81	31.02	30.19	28.37
Biomass costs[h] [SEK/t_{dm}]	504.58	763.15	1255.08	95.87
Biomass costs [MSEK/year]	116.275	189.389	303.142	23.155
Total annual costs[i] [MSEK/year]	204.827	278.702	392.169	112.182
Specific capital costs [SEK/t_{dm}]	307.85	285.86	293.71	293,71
Specific O & M costs [SEK/t_{dm}]	76.42	74.03	74.88	74,88
Heat efficiency, based on the HHV[j] [%]	66.8	66.8	66.8	66.8
Heat production[k] [PJ/year]	3.015	3.015	3.015	3.015

Table A.J-45 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Electric power efficiency, based on the HHV[l] [%]	29.7	29.7	29.7	29.7
Electric power production[m] [TJ/year]	1.340	1.340	1.340	1.340
Conversion losses, based on the HHV[n] [%]	3.6	3.6	3.6	3.6
Weight[c] [t]	1000	1000	1000	1000
Technical life time[o] [years]	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000
Wear per operating hour[p] [kg/h]	4.167	4.167	4.167	4.167
Wear per ton biomass[q] [kg/t_{dm}]	0.145	0.134	0.138	0.147
Solar transformity[r] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12

a) See Table 4-1, footnote i.
b) Additional investment costs for CHP (*e.g.* steam turbine, generator and other steel qualities used in the construction) in 1999 – 2000 is estimated by Westin (2004) to be 315 MSEK. Change in consumer price index for January 2000 – June 2002 = 6.0% (Statistics Sweden, 14-Dec-2004 (URL)). Thus, additional investment costs for CHP in June 2002 = 315 x 1.06 MSEK = 333.9 MSEK.
c) Assumed values.
d) See Table 4-1, footnote n.
e) Data from Mälarenergi AB (2004 (URL)).
f) See Table A.B-1c.
g) $m_{biomass, dm} = E_{biomass, HHV} / HHV$
h) Cost of biomass assortments before conversion (see Tables A.I-3 through A.I-14).
i) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)

Table A.J-45 *continued*

j) $P_{heat\ output}$ = 133.73 MW (see Table 4-1, footnote bb). The biomass input, based on the HHV = 200.34 MW (see Table 4-1, footnote t). Thus, the heat efficiency, based on the HHV = 133.73 / 200.34 = 66.75%.
k) $E_{heat} = E_{biomass} \times \eta_{heat}$
l) P_e = 59.42 MW (see Table 4-1, footnote bb).The biomass input, based on the HHV = 200.34 MW (see Table 4-1, footnote t). Thus, the electric power efficiency, based on the HHV = 59.42 / 200.34 = 29.66%.
m) $E_{electric\ power} = E_{biomass} \times \eta_{electric\ power}$
n) Conversion losses = 1 – (electric power efficiency) – (heat efficiency)
o) The technical life time was assumed as twice the economic life time.
p) The wear per operating hour = m_{boiler} / (technical life time)
q) The wear per dry matter of biomass = (the wear per operating hour) / (biomass supply [t_{dm}/h])
r) The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

Table A.J-46. *Data for the IGCC plant*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Investment[a] [MSEK]	742.203	742.203	742.203	742.203	742.203	742.203	742.203	742.203
Economic life time[b] [years]	15	15	15	15	15	15	15	15
Interest rate	6%	6%	6%	6%	6%	6%	6%	6%
Capital costs [MSEK/year]	76.419	76.419	76.419	76.419	76.419	76.419	76.419	76.419
Electricity[c] [MJ/t_{dm}]	728.66	728.66	732.16	732.16	732.16	697.13	697.13	718.15
Electricity [TJ/year]	149.76	149.76	149.76	149.76	149.76	149.76	149.76	149.76
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	12.480	12.480	12.480	12.480	12.480	12.480	12.480	12.480
Service & maintenance costs[d] [MSEK/year]	22.266	22.266	22.266	22.266	22.266	22.266	22.266	22.266
Personnel costs[e] [MSEK/year]	12.868	12.868	12.868	12.868	12.868	12.868	12.868	12.868
O & M costs [MSEK/year]	47.614	47.614	47.614	47.614	47.614	47.614	47.614	47.614
Operating time[b] [h/year]	8000	8000	8000	8000	8000	8000	8000	8000
Biomass supply[f] [MW]	148.43	148.43	148.43	148.43	148.43	148.43	148.43	148.43
Biomass supply [PJ/year]	4.275	4.275	4.275	4.275	4.275	4.275	4.275	4.275
$HHV_{biomass}$[g] [MJ/kg_{dm}]	20.8	20.8	20.9	20.9	20.9	19.9	19.9	20.5
Biomass supply[h] [t_{dm}/year]	205,529	205,529	204,545	204,545	204,545	214,824	214,824	208,537
Biomass supply [t_{dm}/h]	25.69	25.69	25.57	25.57	25.57	26.85	26.85	26.07
Biomass costs[i] [SEK/t_{dm}]	435.31	575.69	307.55	319.96	522.94	1052.15	1052.15	1054.02
Biomass costs [MSEK/year]	89.468	118.321	62.908	65.445	106.965	226.028	226.028	219.801
Total annual costs[j] [MSEK/year]	213.502	242.354	186.942	189.479	230.998	350.061	350.061	343.835
Specific capital costs [SEK/t_{dm}]	371.82	371,82	373.61	373.61	373.61	355.73	355.73	366.46
Specific O & M costs [SEK/t_{dm}]	60.72	60.72	61.01	61.01	61.01	58.09	58.09	59.85
Gross efficiency, based on the HHV[k] [%]	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7
Gross electric power production[l] [PJ/year]	1.996	1.996	1.996	1.996	1.996	1.996	1.996	1.996

Table A.J-46 *continued*

Item	Logging residues from final felling	Logging residues from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust	Bark
Net electric power production[m] [PJ/year]	1.846	1.846	1.846	1.846	1.846	1.846	1.846	1.846
Weight[b] [t]	1000	1000	1000	1000	1000	1000	1000	1000
Technical life time[n] [years]	30	30	30	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[o] [kg/h]	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167
Wear per ton biomass[p] [kg/t_{dm}]	0.162	0.162	0.163	0.163	0.163	0.155	0.155	0.160
Solar transformity[q] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

Table A.J-46 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Investment[a] [MSEK]	742.203	742.203	742.203	742.203
Economic life time[b] [years]	15	15	15	15
Interest rate	6%	6%	6%	6%
Capital costs [MSEK/year]	76.419	76.419	76.419	76.419
Electricity[c] [MJ/t_{dm}]	686.62	637.58	655.09	697.13
Electricity [TJ/year]	149.76	149.76	149.76	149.76
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	12.480	12.480	12.480	12.480
Service & maintenance costs[d] [MSEK/year]	22.266	22.266	22.266	22.266
Personnel costs[e] [MSEK/year]	12.868	12.868	12.868	12.868
O & M costs [MSEK/year]	47.614	47.614	47.614	47.614
Operating time[b] [h/year]	8000	8000	8000	8000
Biomass supply[f] [MW]	148.43	148.43	148.43	148.43
Biomass supply [PJ/year]	4.275	4.275	4.275	4.275
$HHV_{biomass}$[g] [MJ/kg_{dm}]	19.6	18.2	18.7	19.9
Biomass supply[h] [t_{dm}/year]	218,112	234,890	228,610	214,824
Biomass supply [t_{dm}/h]	27.26	29.36	28.58	26.85
Biomass costs[i] [SEK/t_{dm}]	504.58	763.15	1255.08	95.87
Biomass costs [MSEK/year]	110.054	179.256	286.922	20.594
Total annual costs[j] [MSEK/year]	234.087	303.289	410.956	144.628
Specific capital costs [SEK/t_{dm}]	350.37	325.34	334.28	355.73
Specific O & M costs [SEK/t_{dm}]	57.22	53.13	54.59	58.09
Gross efficiency, based on the HHV[k] [%]	46.7	46.7	46.7	46.7
Gross electric power production[l] [PJ/year]	1.996	1.996	1.996	1.996
Net electric power production[m] [PJ/year]	1.846	1.846	1.846	1.846

Table A.J-46 *continued*

Item	Willow	Reed canary grass	Straw	Recovered wood
Weight[b] [t]	1000	1000	1000	1000
Technical life time[n] [years]	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000
Wear per operating hour[o] [kg/h]	4.167	4.167	4.167	4.167
Wear per ton biomass[p] [kg/t_{dm}]	0.153	0.142	0.146	0.155
Solar transformity[q] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12

a) See Table 4-1, footnote j.
b) Assumed values.
c) Electric power required for the process = 5.2 MW; net power output = 64.1 MW; the net $efficiency_{LHV}$ = 46.2%; $LHV_{biomass}$ = 18.9 MJ/kg_{dm} (Sydkraft, 2000). The biomass flow = 64.1 x 3.6 / (0.462 x 18.9) t_{dm}/h = 26.428 t_{dm}/h. The amount of electricity required if logging residues is used as fuel = 5.2 / (26.428 / 3600 x (18.9 + 1.32) / 20.8) MJ/t_{dm} = 728.66 MJ/t_{dm}.
d) The service & maintenance costs were assumed as 3.0% of the investment cost, according to Aleberg, Litzén & Schwartz (1995). Thus, the service & maintenance costs = 0.03 x 742.203 MSEK = 22.266 MSEK.
e) The service & maintenance and personnel costs = 35.134 MSEK (see Table 4-1, footnote o). Thus, the personnel costs = (35.134 – 22.266) MSEK = 12.868 MSEK.
f) See Table 4-1, footnote u.
g) See Table A.B-1c.
h) $m_{biomass, dm} = E_{biomass, HHV} / HHV$
i) Cost of biomass assortments before conversion (see Tables A.I-3 through A.I-14).
j) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
k) Gross electric power output = 69.3 MW (Sydkraft, 2000). The biomass input, based on the HHV = 148.43 MW. Thus, the gross electric power efficiency, based on the HHV = 69.3 / 148.43 = 46.69%.
l) $E_{electric\ power,\ gross} = E_{biomass} \times \eta_{electric\ power}$
m) $E_{electric\ power,\ net} = E_{electric\ power,\ gross} - E_{electric\ power\ required\ in\ the\ process}$

Table A.J-46 *continued*

n) The technical life time was assumed as twice the economic life time.
o) The wear per operating hour = m_{boiler} / (technical life time)
p) The wear per dry matter of biomass = (the wear per operating hour) / (biomass supply [t_{dm}/h])
q) The solar transformity for boilers was assumed as equal to the solar transformity for tractors, *i.e.* 2.60×10^{12} sej/kg (see Table A.H-7).

Table A.J-47. *Data for hydrogen production*

Item	Logging residues from final felling	Logging residues from thinning	Trees from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust
Investment[a] [MSEK]	1940.090	1940.090	1940.090	1940.090	1940.090	1940.090	1940.090	1940.090
Economic life time[b] [years]	15	15	15	15	15	15	15	15
Interest rate [%]	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Capital costs [MSEK/year]	199.757	199.757	199.757	199.757	199.757	199.757	199.757	199.757
Electricity[c] [GJ/t_{dm}]	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008
Electricity [TJ/year]	418.71	418.71	416.70	416.70	416.70	416.70	437.64	437.64
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	34.892	34.892	34.725	34.725	34.725	34.725	36.470	36.470
Service & maintenance costs[d] [MSEK/year]	58.203	58.203	58.203	58.203	58.203	58.203	58.203	58.203
Personnel costs[e] [MSEK/year]	22.156	22.156	22.323	22.323	22.323	22.323	20.578	20.578
O & M costs[f] [MSEK/year]	115.251	115.251	115.251	115.251	115.251	115.251	115.251	115.251
Operating time[b] [h/year]	8000	8000	8000	8000	8000	8000	8000	8000
Biomass supply[b] [MW]	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0
Biomass supply [PJ/year]	8.640	8.640	8.640	8.640	8.640	8.640	8.640	8.640
$HHV_{biomass}$[g] [MJ/kg_{dm}]	20.8	20.8	20.9	20.9	20.9	20.9	19.9	19.9
Biomass supply[h] [t_{dm}/year]	415,385	415,385	413,397	413,397	413,397	413,397	434,171	434,171
Biomass supply [t_{dm}/h]	51.92	51.92	51.67	51.67	51.67	51.67	54.27	54.27
Biomass costs[i] [SEK/t_{dm}]	435.31	575.69	319.96	307.55	319.96	522.94	1052.15	1052.15
Biomass costs [MSEK/year]	180.820	239.132	132.269	127.141	132.269	216.181	456.814	456.814
Total annual costs[j] [MSEK/year]	495.828	554.140	447.276	442.148	447.276	531.189	771.821	771.821
Specific capital costs [SEK/t_{dm}]	480.90	480.90	483.21	483.21	483.21	483.21	460.09	460.09
Specific O & M costs [SEK/t_{dm}]	277.46	277.46	278.79	278.79	278.79	278.79	265.45	265.45
Efficiency, based on the HHV[k] [%]	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7

Table A.J-47 *continued*

Item	Logging residues from final felling	Logging residues from thinning	Trees from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust
Hydrogen production[l] [PJ/year]	6.111	6.111	6.111	6.111	6.111	6.111	6.111	6.111
Weight[b] [t]	2000	2000	2000	2000	2000	2000	2000	2000
Technical life time[m] [years]	30	30	30	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[n] [kg/h]	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333
Wear per ton biomass[o] [kg/t_{dm}]	0.160	0.160	0.161	0.161	0.161	0.161	0.154	0.154
Solar transformity[p] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

Table A.J-47 *continued*

Item	Bark	Willow	Reed canary grass	Straw	Recovered wood
Investment[a] [MSEK]	1940.090	1940.090	1940.090	1940.090	1940.090
Economic life time[b] [years]	15	15	15	15	15
Interest rate [%]	6.0	6.0	6.0	6.0	6.0
Capital costs [MSEK/year]	199.757	199.757	199.757	199.757	199.757
Electricity[c] [MJ/t_{dm}]	1.008	1.008	1.008	1.008	1.008
Electricity [TJ/year]	424.84	444.34	478.52	465.73	437.64
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	35.403	37.029	39.877	38.811	36.470
Service & maintenance costs[d] [MSEK/year]	58.203	58.203	58.203	58.203	58.203
Personnel costs[e] [MSEK/year]	21.645	20.019	17.171	18.237	20.578
O & M costs[f] [MSEK/year]	115.251	115.251	115.251	115.251	115.251
Operating time[b] [h/year]	8000	8000	8000	8000	8000
Biomass supply[b] [MW]	300.0	300.0	300.0	300.0	300.0
Biomass supply [PJ/year]	8.640	8.640	8.640	8.640	8.640
$HHV_{biomass}$[g] [MJ/kg_{dm}]	20.5	19.6	18.2	18.7	19.9
Biomass supply[h] [t_{dm}/year]	421,463	440,816	474,725	462,032	434,171
Biomass supply [t_{dm}/h]	52.68	55.10	59.34	57.75	54.27
Biomass costs[i] [SEK/t_{dm}]	1054.02	504.58	763.15	1255.08	95.87
Biomass costs [MSEK/year]	444.230	222.425	362.286	579.885	41.622
Total annual costs[j] [MSEK/year]	759.238	537.433	677.293	894.893	356.630
Specific capital costs [SEK/t_{dm}]	473.96	453.15	420.78	432.34	460.09
Specific O & M costs [SEK/t_{dm}]	273.45	261.45	242.77	249.44	265.45
Efficiency, based on the HHV[k] [%]	70.7	70.7	70.7	70.7	70.7
Hydrogen production[l] [PJ/year]	6.111	6.111	6.111	6.111	6.111

Table A.J-47 *continued*

Item	Bark	Willow	Reed canary grass	Straw	Recovered wood
Weight[b] [t]	2000	2000	2000	2000	2000
Technical life time[m] [years]	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[n] [kg/h]	8.333	8.333	8.333	8.333	8.333
Wear per ton biomass[o] [kg/t_{dm}]	0.158	0.151	0.140	0.144	0.154
Solar transformity[p] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

a) See Table 4-2, footnote e.
b) Assumed values.
c) The electric power required for the process at 428.4 MW_{HHV} biomass input = 22.4 MW, and the biomass feed = 80.0 t_{dm}/h (Hamelinck & Faaij, 2002). The amount of electricity required = 22.4 x 3600 / 80 MJ/t_{dm} = 1.008 GJ/t_{dm}.
d) The service & maintenance costs were assumed as 3.0% of the investment cost, according to Aleberg, Litzén & Schwartz (1995). Thus, the service & maintenance costs = 0.03 x 1940.090 MSEK = 58.203 MSEK.
e) Personnel costs = (O & M costs) – (electricity costs) – (service & maintenance costs)
f) Total O & M costs = 12.638 M€ = 12.638 x 9.119 MSEK = 115.251 MSEK.
g) See Table A.B-1c.
h) $m_{biomass,\ dm} = E_{biomass,\ HHV}$ / HHV
i) Cost of biomass assortments before conversion (see Tables A.I-3 through A.I-14).
j) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
k) Data from Hamelinck & Faaij (2002).
l) $E_{hydrogen} = E_{biomass} \times \eta$
m) The technical life time was assumed as twice the economic life time.
n) The wear per operating hour = m_{plant} / (technical life time)
o) The wear per dry matter of biomass = (the wear per operating hour) / (biomass supply [t_{dm}/h])
p) The solar transformity for the plant was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x10^{12} sej/kg (see Table A.H-7).

Table A.J-48. *Data for methanol production*

Item	Logging residues from final felling	Logging residues from thinning	Trees from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust
Investment[a] [MSEK]	2146.528	2146.528	2146.528	2146.528	2146.528	2146.528	2146.528	2146.528
Economic life time[b] [years]	15	15	15	15	15	15	15	15
Interest rate [%]	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Capital costs [MSEK/year]	221.012	221.012	221.012	221.012	221.012	221.012	221.012	221.012
Electricity[c] [MJ/t_{dm}]	778.5	778.5	778.5	778.5	778.5	778.5	778.5	778.5
Electricity [TJ/year]	323.38	323.38	321.83	321.83	321.83	321.83	338.00	338.00
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	26.948	26.948	26.819	26.819	26.819	26.819	28.167	28.167
Service & maintenance costs[d] [MSEK/year]	64.396	64.396	64.396	64.396	64.396	64.396	64.396	64.396
Personnel costs[e] [MSEK/year]	23.324	23.324	23.453	23.453	23.453	23.453	22.105	22.105
O & M costs[f] [MSEK/year]	114.668	114.668	114.668	114.668	114.668	114.668	114.668	114.668
Operating time[b] [h/year]	8000	8000	8000	8000	8000	8000	8000	8000
Biomass supply[b] [MW]	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0
Biomass supply [PJ/year]	8.640	8.640	8.640	8.640	8.640	8.640	8.640	8.640
$HHV_{biomass}$[g] [MJ/kg_{dm}]	20.8	20.8	20.9	20.9	20.9	20.9	19.9	19.9
Biomass supply[h] [t_{dm}/year]	415,385	415,385	413,397	413,397	413,397	413,397	434,171	434,171
Biomass supply [t_{dm}/h]	51.92	51.92	51.67	51.67	51.67	51.67	54.27	54.27
Biomass costs[i] [SEK/t_{dm}]	435.31	575.69	319.96	307.55	319.96	522.94	1052.15	1052.15
Biomass costs [MSEK/year]	180.820	239.132	132.269	127.141	132.269	216.181	456.814	456.814
Total annual costs[j] [MSEK/year]	516.501	574.813	467.949	462.821	467.949	551.862	792.494	792.494
Specific capital costs [SEK/t_{dm}]	532.07	532.07	534.62	534.62	534.62	534.62	509.04	509.04
Specific O & M costs [SEK/t_{dm}]	276.05	276.05	277.38	277.38	277.38	277.38	264.11	264.11
Efficiency, based on the HHV[k] [%]	58.9	58.9	58.9	58.9	58.9	58.9	58.9	58.9

Table A.J-48 *continued*

Item	Logging residues from final felling	Logging residues from thinning	Trees from thinning	Trees from early thinning	Fuel wood from industrial wood cuttings	Fuel wood from non-forest land	Wood chips	Sawdust
Methanol production[l] [PJ/year]	5.091	5.091	5.091	5.091	5.091	5.091	5.091	5.091
Weight[b] [t]	2000	2000	2000	2000	2000	2000	2000	2000
Technical life time[m] [years]	30	30	30	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[n] [kg/h]	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333
Wear per ton biomass[o] [kg/t_{dm}]	0.160	0.160	0.161	0.161	0.161	0.161	0.154	0.154
Solar transformity[p] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

Table A.J-48 *continued*

Item	Bark	Willow	Reed canary grass	Straw	Recovered wood
Investment[a] [MSEK]	2146.528	2146.528	2146.528	2146.528	2146.528
Economic life time[b] [years]	15	15	15	15	15
Interest rate	6.0	6.0	6.0	6.0	6.0
Capital costs [MSEK/year]	221.012	221.012	221.012	221.012	221.012
Electricity[c] [MJ/t_{dm}]	778.5	778.5	778.5	778.5	778.5
Electricity [TJ/year]	328.11	343.18	369.57	359.69	338.00
Electricity cost per unit[b] [SEK/kWh]	0.30	0.30	0.30	0.30	0.30
Electricity costs [MSEK/year]	27.342	28.598	30.798	29.974	28.167
Service & maintenance costs[d] [MSEK/year]	64.396	64.396	64.396	64.396	64.396
Personnel costs[e] [MSEK/year]	22.929	21.674	19.474	20.298	22.105
O & M costs[f] [MSEK/year]	114.668	114.668	114.668	114.668	114.668
Operating time[b] [h/year]	8000	8000	8000	8000	8000
Biomass supply[b] [MW]	300.0	300.0	300.0	300.0	300.0
Biomass supply [PJ/year]	8.640	8.640	8.640	8.640	8.640
$HHV_{biomass}$[g] [MJ/kg_{dm}]	20.5	19.6	18.2	18.7	19.9
Biomass supply[h] [t_{dm}/year]	421,463	440,816	474,725	462,032	434,171
Biomass supply [t_{dm}/h]	52.68	55.10	59.34	57.75	54.27
Biomass costs[i] [SEK/t_{dm}]	1054.02	504.58	763.15	1255.08	95.87
Biomass costs [MSEK/year]	444.230	222.425	362.286	579.885	41.622
Total annual costs[j] [MSEK/year]	779.910	558.105	697.966	915.565	377.303
Specific capital costs [SEK/t_{dm}]	524.39	501.37	465.56	478.35	509.04
Specific O & M costs [SEK/t_{dm}]	272.07	260.13	241.55	248.18	264.11
Efficiency, based on the HHV[k] [%]	58.9	58.9	58.9	58.9	58.9
Methanol production[l] [PJ/year]	5.091	5.091	5.091	5.091	5.091

Table A.J-48 *continued*

Item	Bark	Willow	Reed canary grass	Straw	Recovered wood
Weight[b] [t]	2000	2000	2000	2000	2000
Technical life time[m] [years]	30	30	30	30	30
Technical life time [hours]	240,000	240,000	240,000	240,000	240,000
Wear per operating hour[n] [kg/h]	8.333	8.333	8.333	8.333	8.333
Wear per ton biomass[o] [kg/t_{dm}]	0.158	0.151	0.140	0.144	0.154
Solar transformity[p] [sej/kg]	2.60E+12	2.60E+12	2.60E+12	2.60E+12	2.60E+12

a) See Table 4-2, footnote f.
b) Assumed values.
c) The electric power required for the process at 432.4 MW_{HHV} biomass input = 17.3 MW, and the biomass feed = 80.0 t_{dm}/h (Hamelinck & Faaij, 2002). The amount of electricity required = 17.3 x 3600 / 80 MJ/t_{dm} = 778.50 MJ/t_{dm}.
d) The service & maintenance costs were assumed as 3.0% of the investment cost, according to Aleberg, Litzén & Schwartz (1995). Thus, the service & maintenance costs = 0.03 x 2146.528 MSEK = 64.396 MSEK.
e) Personnel costs = (O & M costs) – (electricity costs) – (service & maintenance costs)
f) Total O & M costs = 12.575 M€ = 12.575 x 9.119 MSEK = 114.668 MSEK.
g) See Table A.B-1c.
h) $m_{biomass, dm} = E_{biomass, HHV} / HHV$
i) Cost of biomass assortments before conversion (see Tables A.I-3 through A.I-14).
j) Total annual costs = (capital costs) + (O & M costs) + (biomass costs)
k) Data from Hamelinck & Faaij (2002).
l) $E_{methanol} = E_{biomass} \times \eta$
m) The technical life time was assumed as twice the economic life time.
n) The wear per operating hour = m_{plant} / (technical life time)
o) The wear per dry matter of biomass = (the wear per operating hour) / (biomass supply [t_{dm}/h])
p) The solar transformity for the plant was assumed as equal to the solar transformity for tractors, *i.e.* 2.60 x 10^{12} sej/kg (see Table A.H-7).

Table A.J-49. *Data for black liquor gasification combined cycle (BLGCC) and black liquor gasification with methanol production (BLGMe)*

Item	BLGCC	BLGMe
Pulp production[a] [t_{90}/(24h)]	2000	2000
Operating time[b] [h/year]	8000	8000
Pulpwood consumption[c] [m^3_{fub}/t_{90}]	5.10	5.10
Pulpwood supply[d] [t_{dm}/year]	1405,103	1405,103
Pulpwood supply[e] [PJ/year]	28.004	28.004
Additional requirement of bark [t_{dm}/year]		191,200[f]
Additional requirement of bark [PJ/year]		3.920[g]
Black liquor [t_{dm}/year]	1160,667[h]	1140,000[i]
$HHV_{black\ liquor}$[j] [MJ/kg_{dm}]	14.5	14.5
Black liquor [PJ/year]	16.830	16.530
Black liquor solids per ton of pulp [t_{dm}/t_{90}]	1.74[k]	1.71[l]
Gross electric power production [PJ/year]	4.822[m]	
Net electric power production [PJ/year]	4.128[n]	
Excess of electric power in the pulp process [PJ/year]	2.568[o]	
Steam production [PJ/year]	5.963[p]	
Excess of heat in the pulp process [PJ/year]	1.133[q]	
Methanol production [PJ/year]		8.951[r]

a) Data according to Ekbom *et al.* (2003).
b) Assumed values.
c) Data from KAM (2000).
d) The weighted basic density of wood in Sweden = 413.3 kg_{dm}/m^3_f (see Table 3-4, footnote j). The pulpwood supply = 2000 / 24 x 8000 x 5.10 x 413.3 x 10^{-3} t_{dm}/year = 1405,103 t_{dm}/year.
e) HHV_{wood} = 19.9 MJ/kg_{dm} (see Table A.B-1c). Thus, the pulpwood supply = 1405,103 x 19.9 GJ/year = 28.004 PJ/year.
f) Additional requirement of bark = 23.9 t_{dm}/h (Ekbom *et al.*, 2003). Thus, the annual additional amount of bark required = 23.9 x 8000 t_{dm}/year = 191,200 t_{dm}/year.

Table A.J-49 *continued*

g) HHV_{bark} = 20.5 MJ/kg_{dm} (see Table A.B-1c). Thus, the annual additional amount of bark required = 191,200 x 20.5 GJ/year = 3.920 PJ/year.
h) The amount of black liquor received = 3482 t_{dm}/(24h) (KAM, 2000). Thus, the annual amount of black liquor received = 3482 / 24 x 8000 t_{dm}/year = 1160,667 t_{dm}/year.
i) The amount of black liquor received = 3420 t_{dm}/(24h) (Ekbom *et al.*, 2003). Thus, the annual amount of black liquor received = 3420 / 24 x 8000 t_{dm}/year = 1140,000 t_{dm}/year.
j) Data from Ekbom *et al.* (2003).
k) The amount of black liquor received = 3482 t_{dm}/(24h) (see footnote h). Thus, the amount of black liquor solids per ton of pulp = 3482 / 2000 t_{dm}/t_{90} = 1.741 t_{dm}/t_{90}.
l) The amount of black liquor received = 3420 t_{dm}/(24h) (see footnote i). Thus, the amount of black liquor solids per ton of pulp = 3420 / 2000 t_{dm}/t_{90} = 1.710 t_{dm}/t_{90}.
m) The amount of steam generated via black liquor gasification = 12.1 GJ/t_{90}, and the amount of steam generated via combustion of bark = 1.1 GJ/t_{90}. The amounts of electric power generated in the back pressure turbine and the condensing turbine are 370 kWh/t_{90} and 170 kWh/t_{90} respectively, and the amount of electric power generated in the gas turbine is 1514 kWh/t_{90} (KAM, 2000). Thus, the amount of gross electric power generated via BLGCC = ((370 +170) x 12.1 / 13.2 +1514) x 3.6 x 2000 / 24 x 8000 x 10^{-9} PJ/year = 4.822 PJ/year.
n) The net amount of electric power generated via BLGCC = 1720 kWh/t_{90} (KAM, 2000). Thus, the annual net amount of electric power generated = 1720 x 3.6 x 2000 / 24 x 8000 x 10^{-9} PJ/year = 4.128 PJ/year.
o) The excess amount of electric power in the pulp process = 1070 kWh/t_{90} (KAM, 2000). Thus, the annual excess amount of electric power in the pulp process = 1070 x 3.6 x 2000 / 24 x 8000 x 10^{-9} PJ/year = 2.568 PJ/year.
p) The total amount of steam produced via BLGCC = 12.1 GJ/t_{90} (KAM, 2000). The steam consumptions in the back pressure turbine and condensing turbine at KAM's reference pulp mill with a recovery boiler are 2.9 GJ/t_{90} and 2.3 GJ/t_{90} respectively. The amount of heat released with the cooling water from the turbine condenser at KAM's reference pulp mill with a recovery boiler = 4.2 GJ/t_{90}. The amounts of electric power generated in the back pressure turbine and the condensing turbine at KAM's reference pulp mill with a recovery boiler are 788 kWh/t_{90} and 616 kWh/t_{90} respectively (KAM, 2000). The steam consumption in the back pressure turbine and the condensing turbine and the amount of heat released with the cooling water from the turbine condenser at BLGCC was assumed as proportional to the electric power production in the back pressure turbine and the condensing turbine compared to KAM's reference pulp mill with a recovery boiler. Thus, the amount of steam produced via BLGCC excluding the amount of steam used for electric power production = (12.1 – 2.9 x 370 / 788 – (2.3 + 4.2) x 170 / 616) x 2000 / 24 x 8000 x 10^{-6} PJ/year = 5.963 PJ/year.
q) The excess amount of heat in the pulp process at BLGCC = 1.7 GJ/t_{90} (KAM, 2000). Thus, the annual excess amount of heat in the pulp process = 1.7 x 2000 / 24 x 8000 x 10^{-6} PJ/year = 1.133 PJ/year.
r) The methanol production = 1183 t/(24h) (Ekbom *et al.*, 2003). $HHV_{methanol}$ = 22.7 MJ/kg (Larson & Katofsky, 1994). Thus, the annual amount of methanol produced = 1183 / 24 x 8000 x 22.7 GJ/year = 8.951 PJ/year.