MAY 1997 ECN-R--97-009

EUROPEAN BIOMASS SCENARIOS AND THE NEED FOR IMPORT OF BIOMASS

P. LAKO
D.J. GIELEN

Preface

ECN Policy Studies and ECN Fossil Fuels have conducted several studies with respect to the availability and procurement of biomass for the Netherlands. The aim of these studies is to get a better insight in:

- the long term perspective of biomass as a renewable energy source
- possible aims of import of biomass
- cost effectiveness of import of biomas
- perspectives of conversion of biomass into liquid fuels.

The ECN project number is 77080.

Abstract

This report deals with more or less sustainable biomass scenarios for Europe. Two scenarios are developed for more or less sustainable land use in Europe. The biomass potential for each of the European countries and for each of the two scenarios is analysed. The results are compared to biomass potentials from country specific studies and from another biomass scenario with figures for Europe. Furthermore, the motives for and the implications of import of biomass energy are analysed.

CONTENTS

SUMMARY

This report presents more or less sustainable biomass scenarios for Europe and deals with another important issue, the import of biomass.

In the literature an example can be found of a sustainable biomass scenario for Europe. Besides, for particular countries - Denmark, Sweden, and Finland - the biomass potential has been estimated in country studies.

First of all, two different biomass scenarios for Europe are defined. The first one is a scenario with emphasis on sustainability. This means ecological farming, equity with respect to imports and exports of agricultural products, and a relatively large protected area in the interest of nature and biodiversity.

In the second biomass scenario for Europe the area of energy crops is maximised. However, in this scenario equity considerations and protection of nature and wildlife are also important. Ecological farming methods and a balance in imports and exports of agricultural products could be within reach, with moderate changes in nutrition patterns compared to the 'sustainable' scenario.

Based on these assumptions, it is shown that the EU could meet 17% of its current primary energy use with biomass, notably agricultural and forest residues as well as energy crops. This is the maximum achievable on the long term (2050), based on current knowledge of the yield of energy crops. In 2020 some 11.5% of the primary energy demand of the EU could be met by biomass. These figures refer to the scenario with emphasis on maximum energy crops. In 'sustainable' scenario the percentages in that scenario are only marginally lower.

There are large differences in the biomass potential of EU countries. The highest shares of biomass in energy demand are to be found in Scandinavian and Mediterranean countries, with the exception of Italy. Ireland and Austria could meet up to 25% of their energy demand from biomass. The Netherlands and Belgium cannot expect to cover more than 7% of their (present) primary energy demand from indigenous biomass.

There is a good match between the results from this study and those of country studies for Denmark, Sweden, and Finland. The 'maximum energy crop' scenario shows much resemblance with that of Johansson *et al.*, if the figures from Johansson's scenario are applied to the EU area.

The target of 10% renewable energy in the Dutch primary energy use in year 2020 can be translated into targets for different renewables e.g., biomass. The biomass target could be met, if 2.5 to 3.0 Mt dry weight of biomass would be imported. Generally speaking, bio-energy contributes to the goal of more renewable energy and energy supply diversification. Also CO_2 emissions will be reduced significantly. From an environmental point of view, the price for energy farming is large scale and intensified land use, with the related detrimental environmental impacts. Imported biomass would be 95% to 175% more costly than coal.

A large number of options compete for cost-effective reduction of CO_2 emissions from power generation and from other energy conversions. Calculations for Western Europe indicate that energy crops are not always the most attractive option to reduce CO_2 emissions. As a consequence, material crops may be a more attractive option for CO_2 emission reduction on the long term than energy crops. Because waste biomaterials and waste from biomaterial processing can be used for energy production, biomaterials will result in a 'double dividend'. This feature increases the attractiveness of the biomaterials options.

From a CO_2 point of view, import of biomass from Uruguay makes sense, while import of biomass from Estonia is second best to substitution of biomass for oil shale in Estonia (e.g. by Joint Implementation).

With respect to the CO_2 reduction potential of import of biomass, 40 PJ of imported biomass can generate 18.4 PJ electricity and can reduce the national CO_2 emissions by approximately 1.9 Mt. This quantity is equivalent to 1% of the total CO_2 emission in the Netherlands.

1. INTRODUCTION

Johansson *et al.* [1] present a global sustainable energy and economy scenario until the year 2050. The sustainability of that scenario is questioned in a book review by Trainer [2]. He thinks their analysis is based on optimistic assumptions about energy conservation. In 2050 eight times the economic output of the year 1985 is to be achieved on only 1.74 times the world's energy consumption of 1985, implying that energy use per dollar of product would fall to 22% of the present amount. Trainer assumes the most likely figure to be more than twice as large [3].

It is questioned whether 25% CO_2 emission reduction in 2050, based on the scenario, is sustainable, taking into account IPCC findings. Oil use would be half the current level by 2050, while natural gas use would remain flat. Trainer thinks that such levels could only be maintained for a few decades.

There are strong reasons associated with ecological impacts and resource availability for concluding that *present* global levels of production and consumption are unsustainable. The Worldwatch Institute has given evidence on the probable peaking in the 1980-2010 period for the production of grain, meat, fish, wool, and timber, as well as the use of fertilizers, irrigated land, and total cropland [4]. Trainer thinks that renewable energy will not become available in such quantities and at such costs to permit current production and consumption to continue.

Questions of sustainability raised by Trainer will be kept in mind. However, this report deals with (sustainable) biomass scenarios for Europe and the need for import of biomass. First a sustainable land use scenario for Europe will be discussed (Chapter 2). Then biomass scenarios for Denmark, Sweden, and Finland will be highlighted (Chapter 3). Based on the analysis from these chapters, two different biomass scenarios for Europe will be outlined (Chapter 4). Chapter 5 gives a comparison between the results of the two biomass scenarios. In Chapter 6 the results are compared to estimates of the biomass potential for various countries and to estimates for the European biomass potential by Johansson *et al.* [1]. Chapter 7 gives an overview of the motives for and the implications of import of biomass energy. Finally, Chapter 8 presents a number of conclusions.

2. PRINCIPLES OF SUSTAINABLE AGRICULTURE

A sustainable agriculture scenario for the European Union (EU) has been presented by Lehmann *et al.* [5]. Lehmann *et al.* have assigned all EU countries to three regions according to climate and geographic location. For these regions they have defined recommendations for nutrition, considering the need for a sustainable agriculture (Table 1).

Nutrition patterns have to change dramatically: meat consumption per capita has to decrease to 25% of the current level. A reorientation towards ecological farming methods is inevitable. This would involve a reduction of emissions of ammonia, a solution for the problem of progressive soil degradation, appropriate forms of livestock farming and the closure of material and mineral cycles. Soil degradation is not only known in third world countries, but also in the EU: 1.4% of the total land surface in Europe is at least severely degraded. Note that soil degradation was more severe in past centuries. According to Lehmann *et al.*, ecological farming methods would result in 20% lower yields than conventional methods.

Table 2.1 *Scenario recommendations for nutrition (Lehmann et al. [5])* in g/cap.day

Foodstuffs	Demand today in EU	Recommendation for: northern EU	central EU	southern EU
Cereals	231	271	249	305
Potatoes	220	298	312	215
Pulses	-	50	50	50
Vegetables	320	236	223	366
Fruits	253	200	365	210
Dairy products	275	340	210	200
Cheese	41	50	50	50
Meat	253	51	58	53
Fish	-	38	28	30
Oil and fats	-	40	40	40

An area as large as 117,000 km^2 outside the EU, equivalent to the arable land areas of Venezuela, Colombia and Ecuador, is used for production of agricultural raw materials and products (coffee beans, cocoa beans, cotton etc.). This area (117,000 km^2) is also equal to almost 6 times the areable land of the Netherlands. Lehmann *et al.* assume that the consumption of agricultural products from outside the EU would be halved, and besides that the remaining half would be compensated by export of agricultural products (e.g. cereals) from the EU.

In 1989 about 37 million tons of animal fodder were imported by EU countries, 60% of which came from developing countries. Lehmann *et al.* assume that this import will be ended. This can only achieved by a drastic reduction of meat consumption, which is one of the assumptions. Some other assumptions made by Lehmann *et al.* are the following:

- An area as large as 10% of the total land area should be protected in the interest of nature and biodiversity.

C Land use for settlement and transport is assumed to stabilise.

Land use in a sustainable scenario for the EU, based on the aforementioned ecological and equity considerations, is shown in Table 2.

Table 2.2 *Land use today and in a sustainable agriculture scenario (Lehmann et al. [5])*

Land distribution	EU 1990			EU sustainable		
	ha/cap	1000 km^2	%	ha/cap	1000 km^2	%
Agricultural land	0.428	1,590	49	0.305	1,120	36
Unprot. wooded area	0.302	1,100	34	0.27	993	32
Built-up area	0.053	195	6	0.051	189	6
Other (degraded incl.)	0.093	241	10	0.095	350	11
Protected area	0.005	19.4	1	0.085	313	10
Unused agric. area	-	-	-	0.045	167	5
Total land area	0.89	3,245[1]	100	0.85	3,132[1]	100

1 The difference corresponds to the area of 117,000 km^2 outside the EU.

It proves that 167,000 km^2 could be made available for energy crops, industrial raw materials or foodstuff for export purposes. If it would be used for energy crops, the energy yield can be calculated, assuming on average 15 dry tons per ha with a heating value of 20 GJ per ton[1]. In that case energy crops could meet 10% of the primary energy demand of the EU.

Lehmann *et al.* conclude that current agricultural methods are not sustainable. Ecological and equity considerations have to be taken into account. Even then it seems feasible to preserve 5% of the EU land area for energy crops in order to meet 10% of (present) European energy demand.

1 These figures seem to be based on Johansson's scenario [1].

3. EXAMPLES OF NATIONAL BIOMASS SCENARIOS

3.1 Danish biomass scenario

Energy conservation and renewable energy are corner stones of the Danish energy policy. The Danish biomass potential is based on estimates from [6] [7] (Table 3.1). Use of straw and wood, and biogas production could be boosted in the short term, according to the Danish energy policy. If all agricultural and forest residues and waste streams would be fully utilised, additional potential could be made available from energy crops. Approximately 25 PJ could be harvested from 150,000 ha in 2005, and 45 PJ from 300,000 ha in 2025.

Table 3.1 *Estimated potential of biomass resources in Denmark*

Biomass resource	Production 1994	Estimated potential 2005	Estimated potential 2025	
	PJ	PJ	PJ	%[1]
Straw	11	42	39	4.8
Wood	18	20	23	2.8
Municipal waste	20	24	24	2.9
Biogas	2	31	31	3.8
Energy crops	-	25	45	5.5
Total	51	142	162	20

[1] Percentage of total primary energy demand in 1995 (817 PJ).

Sources: [6,7].

Biomass could meet 20% of Danish energy demand in 2025, compared to 6% in 1994. Ecological farming methods (Lehmann *et al.*, Chapter 2), have not been taken into account. If those principles (ecological farming, equity, etc.) would be accounted for, that would not jeopardize the biomass contribution of 20% to primary energy demand (see Chapter 6).

3.2 Swedish biomass scenario

Recently an analysis [8] has been presented of the biomass potential in Sweden, with due attention to local environmental impacts. Extensive logging-residue removal from the forest requires compensation for nutrient losses through ash recycling to ensure the long term productivity of the forest soil. Utilisation of logging residues combined with ash recycling has only a minor impact on biodiversity. Ongoing measures in Swedish forestry to preserve biodiversity, such as changing harvesting methods at final felling from clear cutting to selective cutting, increasing the proportion of old trees and dead wood, and preserving areas with a high variety of species, are much more important to ensure biodiversity in the forests.

Similarly, only part of the straw, about 2 dry ton per ha, can be utilised for energy purposes, as the rest is to be used for cattle or left in the field to ensure a high content of organic matter. Soils sensitive to erosion should be exempt from straw harvest. Perennial energy crops, such as *Salix* and reed canary grass, have less environmental impact than annual feed crops.

Current Swedish forest harvest corresponds to about 470 PJ/yr. About 45% of this energy equivalent is used for energy purposes, as follows:
C 158 PJ in the industrial sector for heat and power (paper and pulp),
C 21 PJ in district heating schemes,
C 31 PJ in individual houses.

The potential of wood, energy crops, straw and logging residues is shown in Table 3.2 (based on [8]).

Table 3.2 *Estimated potential of biomass resources in Sweden*

Biomass resource PJ	Production today	Production conditions today	Production conditions 2015	%
Wood fuels[2]	210	250	250	15
Energy crops[3]				
Reed canary grass	-	86	158	10
Salix	0.2	115	212	13
Straw	1	40	40	2
Logging residues[4]	22	72-79	190-235	11-14
Total[5]	233	470-477	678-722	41-43

[1] Percentage of total primary energy demand in 1995 (1656 PJ).
[2] Including byproducts from forestry and pulp production: bark, black liquor, etc.
[3] Yield for reed canary grass and *Salix* if all of 800,000 ha were available.
[4] Potential in 2015 based on estimated annual felling in 2015 and ash recycling.
[5] *Salix* and reed canary grass are assumed to be grown on 600,000 and 200,000 ha of arable land respectively.
Source: [8].

Today, about 22 PJ logging residues, 1 PJ straw, and 0.2 PJ *Salix* are used for energy purposes. The Biomass Commission of the Swedish Government has estimated that the surplus of arable land will increase to 800,000 ha around year 2005 due to productivity increases in agriculture. This is equivalent to 28% of the total cropland in Sweden.

Total biomass use could amount to 41-43% of present primary energy use, compared to 14% today. Due attention is paid to environmental constraints, such as sustainable forest management and biodiversity. However, it seems worthwhile to analyse the consequences of ecological and equity principles (Chapter 2) for the Swedish biomass potential more explicitly (Chapter 6).

3.3 Finnish biomass scenario

Two scenarios for biomass use in Finland have been presented in [9]. In Finland peat is an important fuel for district heating and industrial cogeneration. In Finland peat is considered as a so-called 'slowly renewable resource': in 1994 peat production was about 85 PJ, whereas annual growth of peat is estimated at 100 PJ/y. The two scenarios for Finland are a basic scenario and a maximum (biomass) scenario until 2010. Table 3.3 gives an overview of the two scenarios (based on [9]).

Table 3.3 *Estimated potential of biomass resources in Finland*

Biomass resource	Production 1992	Potential 2000		Potential 2010		
		Basic	Maximum	Basic	Maximum	
	PJ	PJ	PJ	PJ	PJ	%[1]
Peat	68	70	80	70	100	5-8
Wood fuels[1]	130	188	195	199	220	15-17
Energy crops	-	-	-	2	4	p.m.
Straws	-	2	4	4	8	0-1
Municipal waste	9	10	15	25	25	2
Total	207	270	294	300	357	23-28

[1] Percentage of total primary energy demand in 1994 (1283 PJ).
[2] Including byproducts from forestry and pulp production: bark, black liquor, etc.
Source: [9].

Biomass energy could meet 23 to 28% of the Finnish energy demand in year 2010. Energy crops are considered as unimportant until 2010, because Finland has an abundant potential of wood and forest residues.

4. BIOMASS SCENARIOS FOR EUROPE

4.1 Introduction

From the preceding chapters one can conclude that:

- There are strong reasons associated with ecological impacts and resource availability for concluding that *present* global levels of production and consumption are unsustainable (Chapter 1).
- A sustainable biomass scenario should be based on a sustainable agriculture scenario for Europe, and therefore take into account ecological and equity considerations (Lehmann *et al.*, Chapter 2).
- In some European countries (Denmark, Sweden, Finland) a high percentage of primary energy demand could be met by biomass energy (Chapter 3), although sustainability and equity are question marks.

The above mentioned principles of ecological farming, reservation of protected area, and equity should be considered for European biomass scenarios. Two scenarios are developed for land use in Europe. One is considered as sustainable, and the other as less sustainable. The underlying assumptions of these scenarios are described in Sections 4.2 and 4.3.

4.2 Sustainable biomass scenario

The principles of a sustainable agriculture scenario for Europe (Lehmann *et al.*, [5], Chapter 2) are the basis of the first scenario, which is considered as a sustainable biomass scenario. Emphasis is on ecological farming, equity and maximum protected area. An important requirement for this scenario is a drastic change in nutrition patterns. If this requirement is fulfilled, the agricultural area can be reduced proportionally. Besides, imports of animal fodder can be minimised. Finally, it is assumed that imports of agricultural products (cotton, coffee, tea) can be halved compared to current levels, and that export and import of agricultural products can be in balance.

Almost even important is the emphasis on protection of nature and wildlife. In accordance with international obligations, the percentage of land area destined as protected area (in the interest of nature and biodiversity) is increased to 10% in 2050 (4.5% in the Nordic countries Iceland, Norway, Sweden, and Finland). In this way the requirements from a sustainable European biomass scenario seem to be fulfilled, and the remaining land could be used for energy crops.

The changes in land area for the period 1993-2020 are as follows:

- The agricultural area in all of the countries declines by 12%, making room for energy crops and protected area.
- The area of unprotected forest and woodland declines by 7%, in favour of protected area.
- The protected area increases to 6% of the total land area, except for the aforementioned Nordic countries; in those countries it is 3% in 2020.
  As a result of these changes in land use, the area for energy crops grows to 0.045 ha per capita on average.

The changes in land area for the period 2020-2050 are as follows:

- The agricultural area declines by another 6% compared to 1993, which means that the agricultural area is 18% smaller than in 1993. The remaining agricultural area is 0.305 ha per capita, which would be sufficient for the changed nutrition patters assumed by Lehmann *et al.*
- The area of unprotected forest and woodland declines by another 3% compared to 1993; in 2050 the area of unprotected forest and woodland is 90% of the area in 1993; on average it is 0.29 ha per capita.
- The protected area increases to 10% of the total land area; in Iceland, Norway, Sweden, and Finland this area is 4.5% of the total land area.
- The area for energy crops increases to about 0.055 ha per capita on average.

Table 4.1 gives an overview of land use in such a scenario for each of the EU countries in the year 2050. This scenario would have drastic consequences for nutrition patterns (Chapter 2). A key assumption is that land use outside Europe for agricultural raw materials and products (coffee beans, cocoa beans, cotton, etc.) should be halved, and besides that imports and exports of agricultural products (expressed as the area needed for such imports and exports) should be in balance.

Another key assumption is that 10% of the total land area should be protected in the interest of nature and biodiversity. It proves to be very hard for Nordic countries (Iceland, Norway, Sweden, and Finland) to reach the goal of 10%. For those countries 4.5% seems a practical goal. With that exception all the considerations of Lehman *et al.* have been accounted for.

The area used for energy crops is assumed to increase from an average figure of 0.045 ha per capita in 2020 to 0.056 ha per capita in 2050. These figures are very ambitious, given the relative scarcity of land in a sustainable biomass scenario.

Table 4.1 *Land use in a sustainable European biomass scenario based on considerations of Lehmann et al. [5], year 2050 (ha/capita)*

	Cropland and perm.pasture	Forest and woodland	Prot. area	Energy crops	Total
Austria (A)	0.356	0.364	0.103	0.049	0.387
Belgium (B)	0.110	0.055	0.030	0.034	0.230
Switzerland (CH)	0.238	0.136	0.057	0.044	0.475
Germany (D)	0.173	0.115	0.043	0.042	0.373
Denmark (DK)	0.434	0.077	0.082	0.056	0.649
Spain (E)	0.553	0.366	0.089	0.050	1.116
France (F)	0.426	0.233	0.095	0.058	0.812
UK (GB)	0.242	0.038	0.041	0.050	0.370
Greece (GR)	0.456	0.498	0.124	0.066	1.143
Italy (I)	0.241	0.101	0.051	0.047	0.441
Ireland (IRL)	1.022	0.082	0.193	0.075	1.373
Iceland (ISL)	7.197	0.415	1.735	-0.075	9.272
Luxembourg (L)	0.260	0.200	0.065	0.048	0.573
Norway (N)	0.192	2.481	0.319	0.033	3.097
Netherlands (NL)	0.106	0.019	0.022	0.037	0.185
Portugal (P)	0.313	0.270	0.093	0.040	0.715
Sweden (S)	0.315	2.297	0.212	0.147	2.972
Finland (SF)	0.421	4.116	0.270	0.314	5.121
Total[1]	0.306	0.289	0.078	0.056	0.728

[1] Including Iceland, Norway, and Switzerland.

4.3 Scenario with maximum energy crops

The second biomass scenario has much in common with the first. The area of cropland and permanent pasture is assumed to decrease in favour of energy crops. Also the area covered by forests and woodlands decreases, making room for protected area. However, the area reserved as protected area is much more limited than in the first scenario. The area of agricultural land is large enough to fulfil the requirements of ecological farming and equity (balance in imports and exports of agricultural products expressed as the area needed for these products), although this is not explicitly assumed. Finally, the area of energy crops is maximised, which is mostly at the expense of protected area.

Note that the differences between the two scenarios are not very large. The ‘maximum energy crop’ scenario is less sustainable than the ’sustainable’ scenario, mainly because of the more relaxed attitude towards the requirement of protected area. The decrease of the agricultural and forest area is less pronounced than in the ’sustainable’ scenario. On balance the energy crop area is somewhat larger than in the ’sustainable’ scenario.

The changes in land area for the period 1993-2020 are as follows:

- The area of energy crops is maximised for each of the countries, taking into account the results from the first scenario. It is assumed that two thirds of the maximum level in 2050 will be realised in 2020.
- In 2020 2% of the total land area is allocated as protected area.
- The area of unprotected forest and woodland declines by 4% (-6% in the 'sustainable' scenario).
- The agricultural area decreases as a result from the creation of protected area and area for energy crops, while the forests and woodland area declines. The average decline is 5% (-12% in the 'sustainable' scenario).

The changes in land area for the period 2020-2050 are as follows:

- The area of energy crops is maximised for each of the countries. On average this area is larger than in the 'sustainable' scenario: 0.07 ha per capita, compared to 0.055 ha per capita in the 'sustainable' scenario.
- The allocation of protected area increases to 4% of the total land area.
- The area of unprotected forest and woodland declines by another 4%, so in 2050 the area of forest and woodland is 8% smaller than 1993 (-10% in the 'sustainable' scenario).
- Generally, the decline in agricultural area is less pronounced than in the 'sustainable scenario', except for Norway, Sweden, and Finland. In these countries the protected area (4%) is almost the same as in the 'sustainable' scenario (4.5%). A more moderate decline of the forest and woodland area means that additional agricultural area should be used for energy crops. In all of Western Europe, the average decline in 2050 is 13%, compared to 18% in the 'sustainable' scenario.

Table 4.2 gives an overview of land use in such a scenario for each of the EU countries in the year 2050. This scenario is not completely sustainable. For instance, the percentage of land area destined as protected area (in the interest of nature and biodiversity) is only 4% in 2050, compared to 10% according to international recommendations. The reduction of the agricultural area is more moderate compared to the 'sustainable' scenario. With more modest changes in nutrition patterns the same objectives as in the 'sustainable' scenario (ecological farming, equity) could be met.

Table 4.2 *European land use scenario with maximum energy crops (Lehmann et al. [5]), year 2050 (ha/capita)*

	Cropland and perm. pasture	Forest and woodland	Prot. area	Energy crops	Total
Austria (A)	0.397	0.372	0.041	0.062	0.387
Belgium (B)	0.117	0.056	0.012	0.045	0.230
Switzerland (CH)	0.256	0.139	0.023	0.057	0.475
Germany (D)	0.184	0.118	0.017	0.054	0.373
Denmark (DK)	0.461	0.079	0.033	0.077	0.649
Spain (E)	0.601	0.374	0.051	0.089	1.116
France (F)	0.460	0.238	0.038	0.075	0.812
UK (GB)	0.250	0.038	0.017	0.065	0.370
Greece (GR)	0.498	0.509	0.050	0.086	1.143
Italy (I)	0.255	0.104	0.021	0.061	0.441
Ireland (IRL)	1.113	0.084	0.077	0.098	1.373
Iceland (ISL)	7.306	0.425	1.542	0.000	9.272
Luxembourg (L)	0.280	0.204	0.026	0.062	0.573
Norway (N)	0.170	2.536	0.284	0.035	3.097
Netherlands (NL)	0.111	0.020	0.009	0.046	0.185
Portugal (P)	0.352	0.276	0.037	0.051	0.715
Sweden (S)	0.286	2.348	0.188	0.149	2.972
Finland (SF)	0.359	4.207	0.240	0.315	5.121
Total[1]	0.325	0.295	0.037	0.070	0.728

[1] Including Iceland, Norway, and Switzerland.

Notably the more relaxed attitude towards creation of protected area makes room for more energy crops than in the ’sustainable’ scenario. The area used for energy crops is assumed to increase from an average of 0.047 ha per capita in 2020 (slightly more than in the ’sustainable’ scenario) to as high as 0.07 ha per capita in 2050. Even if the target for protected area is less ambitious than in the ’sustainable scenario’, scarcity of land is evident, and the figures for the energy crop area are ambitious indeed.

5. BIOMASS POTENTIALS

5.1 Common yield assumptions

Differences in the scenarios presented in Chapter 4 refer to the areas potentially available for agriculture, forest and woodland, unprotected area, and energy crops. Both scenarios are based on the same yields of straw, wood from forestry, and energy from crops per ha. The assumptions with respect to yields are presented in Table 5.1.

Table 5.1 *Assumptions for yields of straw from cereals, wood from forestry, and biomass energy from energy crops (GJ/ha)*

Yield	Year 2020	Year 2050
Surplus straw from cereals	13[1]	13[2]
Wood fuels from forestry	22[3]	25
Biomass energy from energy crops	170-290[4]	220-290[5]

1 Except for Denmark (30 GJ/ha, [6,7]) and Sweden (36 GJ/ha, [8]).
2 Except for Denmark (30 GJ/ha, [6,7]).
3 Except for Denmark (47 GJ/ha, [6,7]) and Germany (14 GJ/ha, [10]).
4 Generally 290 GJ/ha, except for Germany (185 GJ/ha, [10]) and Nordic countries and Southern European countries[2] (170 GJ/ha).
5 Generally 290 GJ/ha, except for Nordic countries and Southern European countries (220 GJ/ha).

The yield of surplus straw from cereals depends on applications for straw in a particular country. In Denmark a high percentage is used as fuel. However, in Germany and the Netherlands a large percentage is used for cattle, etc. Therefore, an average value is used, which represents the amount of surplus straw available per ha of cereals. For Denmark and Sweden higher figures are used in 2020, and only for Denmark a higher figure is used in 2050.

The yield of wood fuels from forestry (including e.g. black liquor from pulping) is also an average figure per ha of forest and woodland. For Denmark and Germany higher and lower figures respectively have been assumed in 2020. In 2050 the yield of biomass energy per ha forest and woodland is slightly higher than in 2020.

The yield from energy crops could be relatively high already in 2020. However, the yield in Nordic and Southern European countries is considerably lower than in Middle European countries. For these Nordic and Southern European countries a higher figure is assumed in 2050 (220 GJ/ha), a figure which remains lower than the yield assumed for Middle European countries (290 GJ/ha).

2 Iceland, Norway, Sweden, Finland, Denmark, Portugal, Spain, Italy, Greece.

5.2 Sustainable biomass scenario

In the ‘sustainable’ scenario emphasis is on ecological farming, equity, and creation of protected area in the interest of nature and biodiversity. The area available for energy crops is rather limited. Land use in ha per capita has been shown in Table 4.1 (Chapter 4). Taking into account assumptions with respect to the yield for straw, wood, and energy crops (Section 5.1), results of this scenario for EU countries (in 2050) are shown in Figure 5.1.

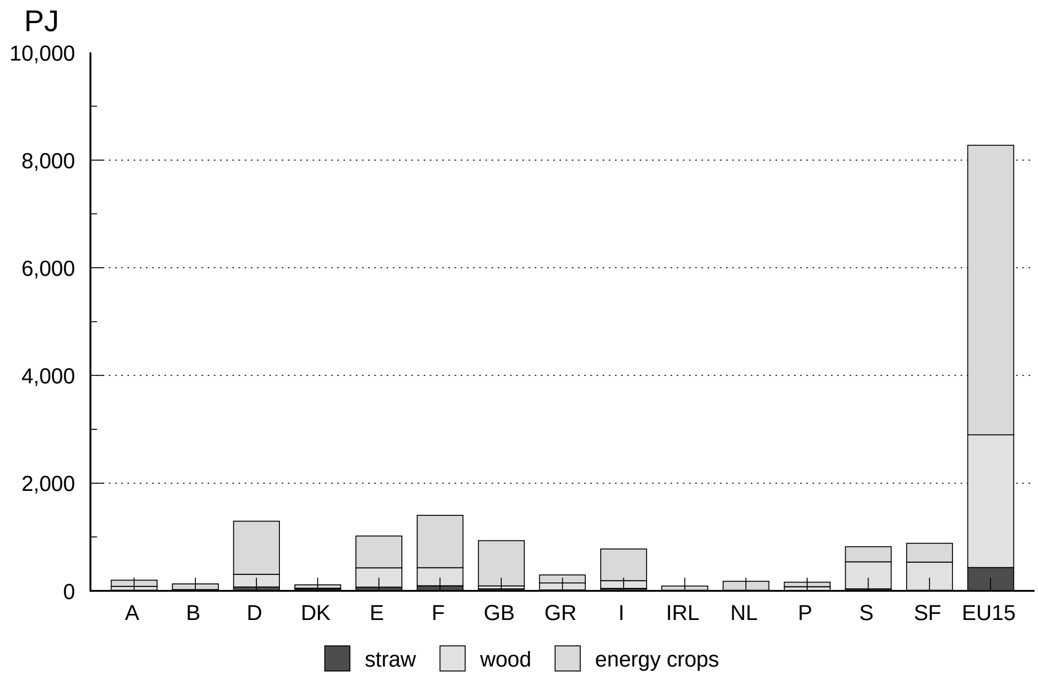

Figure 5.1 *Biomass potential (straw, wood/forest products, energy crops) of EU countries (2050), sustainable biomass scenario*

Biomass potential is highly dependent on the area available for agriculture, forestry, and energy crops. France, Germany, and Spain rank high with respect to biomass energy. Also the UK, Italy, Sweden, and Finland have relatively large biomass potentials.

The biomass potential can also be expressed as percentage of the primary energy demand of a particular country (Figure 5.2). Note that the current primary energy demand is used as yardstick. Countries with potentially the highest shares of biomass in their energy demand are Scandinavian and Mediterranean countries, with the exception of Italy. However, also Ireland and Austria could meet up to 20% of their energy demand from biomass. The Netherlands and Belgium cannot expect to cover more than 6% of their (present) primary energy demand from indigenous biomass.

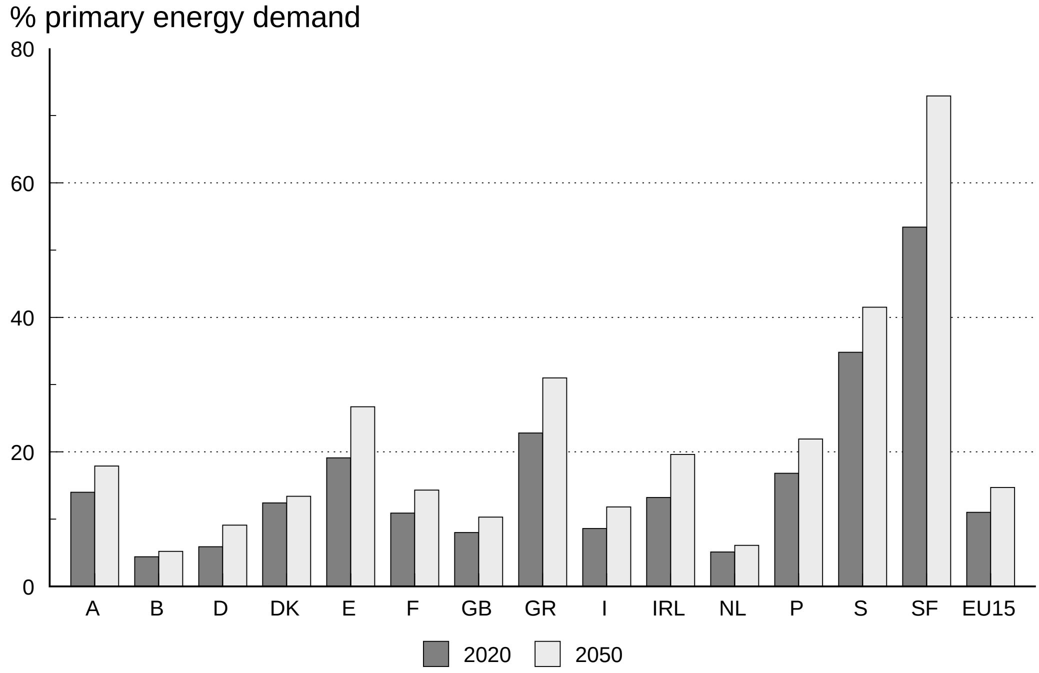

Figure 5.2 *Biomass potential as percentage of primary energy demand of EU countries (2020/2050), sustainable biomass scenario*

The protected area in the Scandinavian countries Norway, Sweden, and Finland is assumed to be 4.5% of total land area in 2050. Principally, this is not sufficient from the point of view of conservation of nature and biodiversity. However, it has been noticed (Chapter 3) that current forest management in those countries (notably Sweden) pays due attention to environmental constraints, such as sustainable forest management and biodiversity. Therefore, the shares of biomass in primary energy demand as shown in Figure 5.2 seem to be achievable in a 'sustainable' scenario.

5.3 Scenario with maximum energy crops

In the second scenario emphasis is on maximum energy crops. Ecological farming and equity are considered as less important, although this scenario could be in agreement with such principles, if nutrition patterns would be changed accordingly. Based on the land use in terms of ha per capita (Chapter 4), and the assumptions with respect to yields (Section 5.1), the results of this scenario for EU countries (in 2050) are shown in Figure 5.3.

France, Germany, Spain, the UK, Spain, Italy, Sweden, and Finland rank high with respect to biomass energy. A main difference between this scenario and the 'sustainable' scenario is the percentage of the total land area destined as protected area. In this scenario it is 4% in 2050 (2% in 2020), whereas protected area is generally 10% of the total land area in the `sustainable' scenario, except for Iceland, Norway, Sweden, and Finland (in those countries it is 4.5% of the total land area). Because of this difference, the biomass potential is higher in France, Germany, the UK, Spain, and Italy in the second scenario, and almost the same for Sweden and Finland.

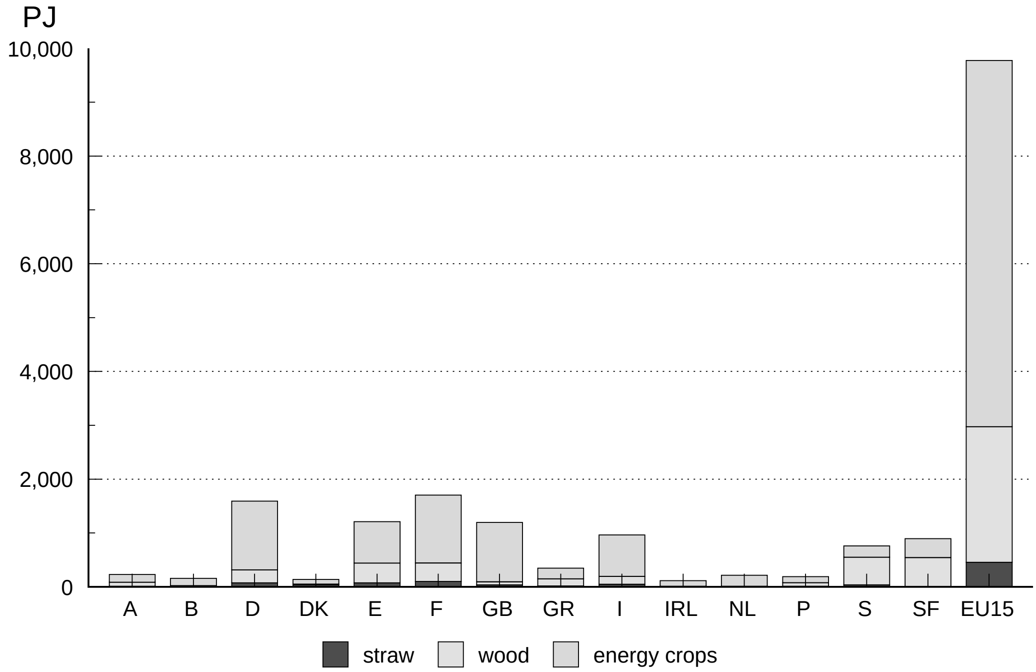

Figure 5.3 *Biomass potential (straw, wood/forest products, energy crops) of EU countries (2050), maximum energy crop scenario*

The biomass potential as percentage of the current primary energy demand is shown in Figure 5.4.

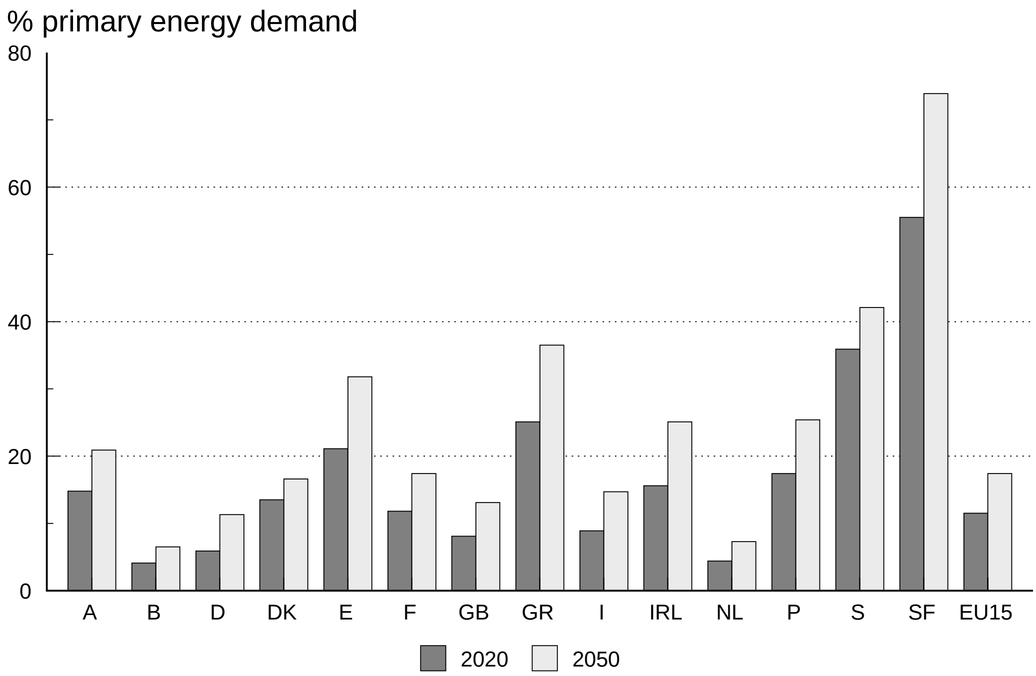

Figure 5.4 *Biomass potential as percentage of primary energy demand of EU countries (2020/2050), maximum energy crop scenario*

Countries with potentially the highest shares of biomass in their energy demand are Scandinavian and Mediterranean countries, except for Italy. Ireland and Austria could meet up to 25% of their energy demand from biomass. The Netherlands and Belgium cannot expect to cover more than 7% of their (present) primary energy demand from indigenous biomass.

For the total EU the potential of biomass could be about 17% in 2050 (11.5% in 2020), compared to about 15% in 2050 (11% in 2020) in the 'sustainable' scenario. For the year 2020 the difference in energy crop area for the two scenarios is negligible. This is because the 'sustainable' scenario presumes a steep decline in agricultural and forested area in favour of both energy crops and protected area until 2020. In the 'maximum energy crop' scenario the decline is less steep. For the year 2050, the difference in energy crop area is limited, as the countries Norway, Sweden, Finland do not show significant differences in protected area for both scenarios. Besides, in the scenario with maximum energy crops the drive to minimise the agricultural area is less pronounced than in the 'sustainable' scenario.

6. COMPARISON OF SCENARIOS

6.1 Introduction

In Chapter 4 the two European biomass scenarios have been described. Estimates of the agricultural area, the forest and woodland area, the protected area, and the energy crop area of each country have been presented. Chapter 5 showed the resulting biomass potentials for each country and for both of the scenarios. This chapter gives a comparison of these results with:

- Estimates of the biomass potential for distinct European countries.
- An estimate of the European biomass potential by Johansson *et al.* [1]

In Section 6.2 a comparison is made between the biomass potentials of Denmark, Sweden, and Finland according to the two scenarios (Chapter 4 and 5), and the potentials according to country specific studies. Section 6.3 gives a comparison of the potential of the EU for each of the two scenarios with the potential according to Johansson *et al.* [1].

6.2 Country specific comparison

6.2.1 Denmark

In Figure 6.1 a comparison is made between the scenario results from this study and those of a study specific for Denmark [6,7].

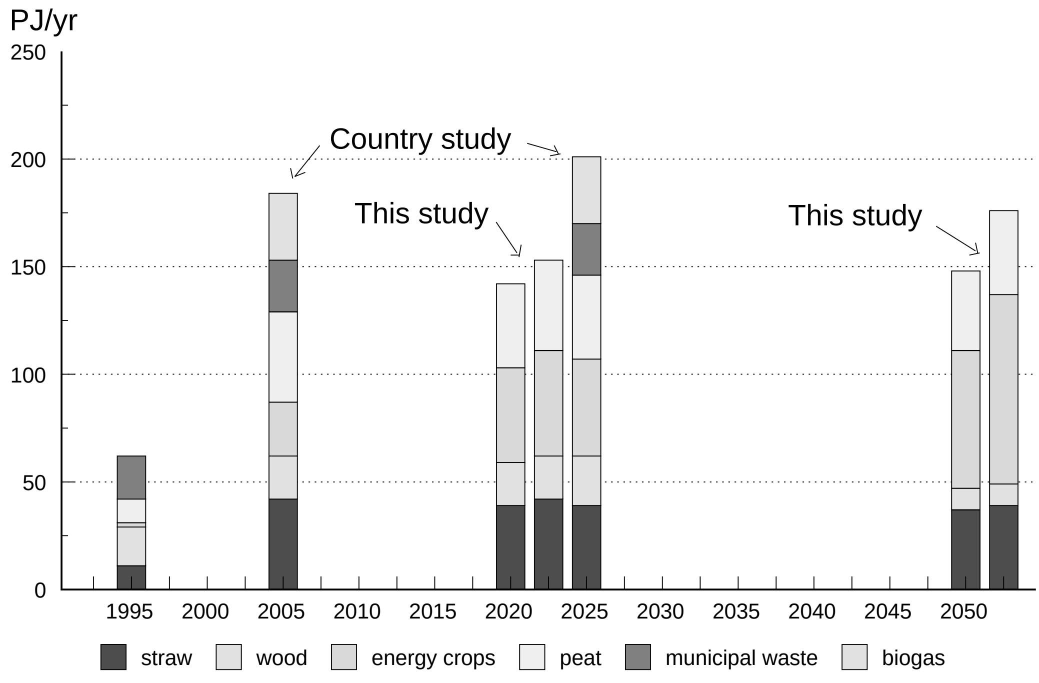

Figure 6.1 *Danish biomass potential according to this study and according to a country specific study [6,7]*

The country study gives a biomass potential including municipal waste and biogas. If the potential of municipal waste and biogas is added to the scenario results for year 2020, the results from this study are in agreement with those of the country study. The potential of energy crops for the country study is based on 150,000 ha in 2005 and 300,000 ha in 2025. Chapter 4 indicates a potential of 237,000 to 267,000 ha in year 2020.

The biomass potential of the country study for the year 2025 is equivalent to 20% of the Danish primary energy demand. This study indicates that the biomass potential - excluding municipal waste and biogas - in year 2050 is 13 to 17% of the primary energy demand; if the potential of municipal waste and biogas (from [6,7]) is added, the total biomass potential in year 2050 would be 20 to 23% of the primary energy demand.

It is concluded that there is a good match between the results from this study and those of the country study. Ecological farming methods, equity considerations, and creation of protected area, could be compatible with a biomass potential in 2050 of about 20% of the primary energy demand.

6.2.2. Sweden

Figure 6.2 presents a comparison is made between the scenario results from this study and those of a study specific for Sweden [8].

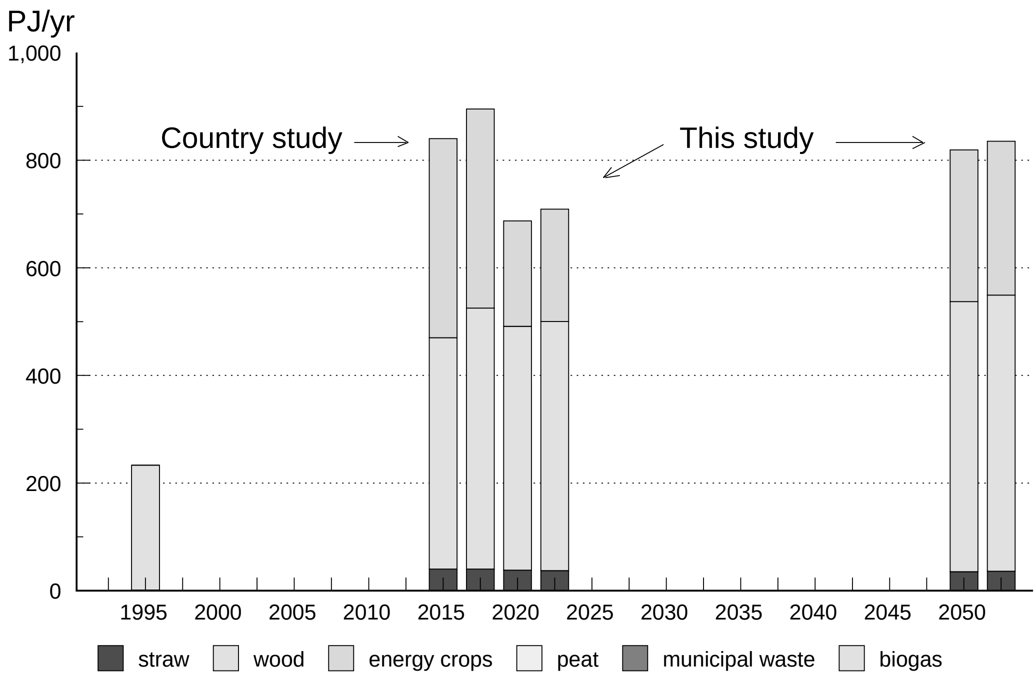

Figure 6.2 *Swedish biomass potential according to this study and according to a country specific study [8]*

The country specific study refers to the same categories of biomass as used in this study. The energy crop potential of the country study is based on 800,000 ha in 2015. In this study a similar area - 815,000 ha to 867,000 ha - for year 2020 is assumed. The differences in results for this timeframe are mainly due to more a optimistic yield for energy crops assumed in the country study. For year 2050 indicates a potential larger than in the country study for year 2015, because of an accordingly high yield of energy crops per ha, and a still higher area of energy crops.

Also in case of Sweden the match between the results from this study and those of the country study is satisfactory. Ecological farming methods, equity considerations, and creation of protected area, would be compatible with a biomass potential in 2050 of 40% of the primary energy demand, if the requirements with respect to protected area would not be too stringent.

6.2.3. Finland

Figure 6.3 compares the results from this study and those of a study specific for Finland [9].

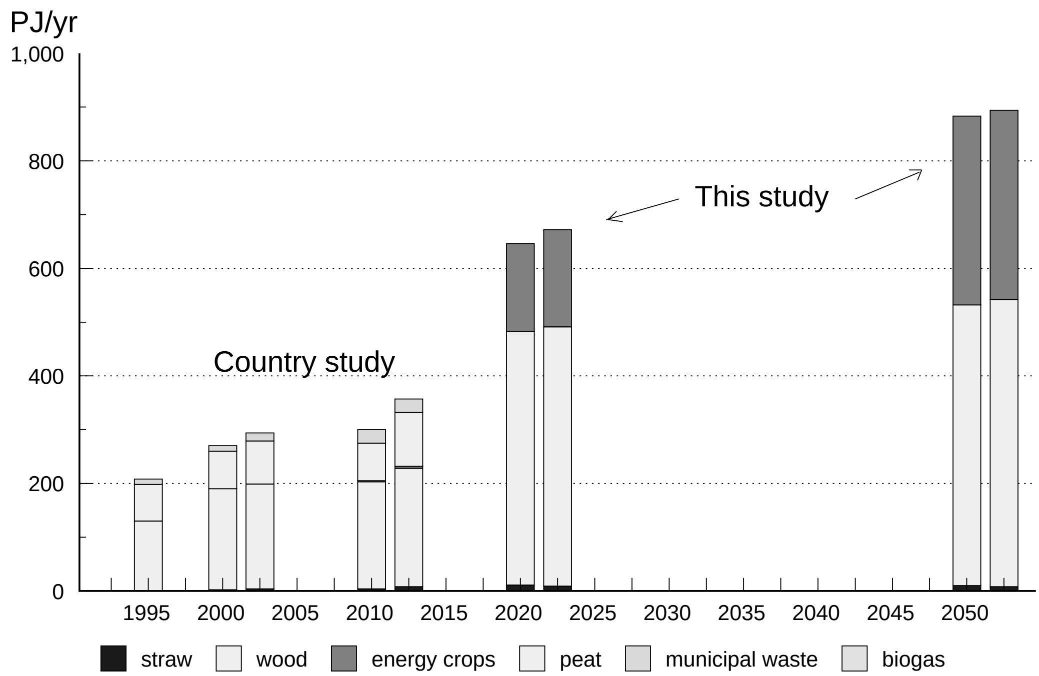

Figure 6.3 *Finnish biomass potential according to this study and according to a country specific study [9]*

The biomass potential of the country study is much smaller than the potential indicated by this study. Apart from differences with respect to peat, which is included in the country study (not in this study), the main difference between the studies is the area assumed to be available for energy crops. In the country study this area is estimated at no more than 50,000 ha in year 2010, because of economic considerations. However, in this study it is estimated at about 1 million ha in year 2020. This is in agreement with the observation that 0.5 - 1 million ha of Finnish agricultural land will become redundant from traditional farming during the next ten years [9]. The area available for energy crops in 2050 is estimated at 1.3 - 1.6 million ha in this study, which seems a bit speculative.

In case of Finland the results from this study differ from those of the country study, mainly because the area of energy crops in the country study is very limited. However, the potential of energy crops in this study could be in agreement with the analysis in the country study. Ecological farming methods, equity considerations, and creation of protected area, would be compatible with a biomass potential in 2050 of some 70% of the primary energy demand, if the requirements with respect to protected area would not be too stringent.

6.3 Comparison for the EU

The biomass scenarios outlined in Chapters 4 and 5 can be compared with that of Johansson *et al.* [1] (Chapter 1). The comparison refers to the EU[3]. The results are as follows (Table 6.1).

Table 6.1 *Biomass potential of the EU according to this study compared to estimates of Johansson et al. ([1]), year 2050 (PJ)*

	Recoverable residues				Energy crops	Total
	Agricultural products	Wood fuels	Biogas	Sub-total		
'Sustainable' scenario	430	2,460	-	2,890	5,380	8,270
'Maximum energy crop' scenario	450	2,520	-	2,970	6,800	9,770
Johansson [1][1]	845	1,300	325	2,470	7,400	9,870

[1] Figures from [1] (p. 632) have been applied to the EU area.

The 'maximum energy crop' scenario shows much resemblance with that of Johansson *et al.* [1], if the figures from Johansson's scenario are applied to the EU area. If the potential of biogas would be added to the total for the 'maximum energy crop' scenario, the total biomass potential for this scenario differs only a few percentages from Johansson's estimate. The potential of agricultural products and energy crops in this study is somewhat lower than the estimate of Johansson *et al.*, whereas the potential of wood fuels is larger. Johansson *et al.* assume that one-fourth of the forest residues is recoverable.

[3] Johansson's scenario presents figures for total Europe (including Eastern Europe). Taking into account the yield of biomass from biomass energy plantations, figures for the EU could be deducted from the orgininal figures of Johansson.

7. IMPORT OF BIOMASS ENERGY

7.1 Targets in the third white paper on energy policy

The third white paper on Dutch energy policy was issued in 1996 [11]. This white paper forms the basis of energy policy in the Netherlands for the period until 2020. One of the key elements of the energy strategy is 10% renewable energy in the Dutch primary energy mix in year 2020. This target is based on the vulnerability of the Dutch economy for developments in energy supply because of the current Dutch energy supply situation.

The Netherlands depend on oil and gas for 87% of their primary energy use. The price of these fossil fuels will increase in the long term. A switch to renewable energy is inevitable. The timing of this switch is in the middle of the next century. Natural gas resources of the Netherlands will become depleted on a shorter term. Therefore, the energy economy will be subject to price fluctuations of oil and gas on the world market. This market will be dominated by a limited number of suppliers. On top of the supply problems, the carbon dioxide (CO_2) issue can further deteriorate the position of fossil fuels. Coal would be affected most because of its high carbon content. Nuclear energy is a vulnerable option because of lack of public acceptance. Besides, the Dutch economy is comparatively energy intensive. Thus, these unfavourable conditions pose a risk on the long run.

Another advantage of renewable energy is its contribution to sustainable development. Sustainability is defined as the satisfying of the needs of the current generation without endangering the satisfaction of the needs of future generations. The third energy white paper considers sustainable development as an additional incentive for policies aiming for renewable energy.

Compared to other countries, the current contribution from renewable energy is limited. Renewables represent 1% of the Dutch energy supply. The main explanation for this comparatively small fraction is the limited availability of 'conventional' renewable energy like hydro power and biomass. 10% renewable energy implies a ten-fold increase in 25 years. The target of 288 PJ renewable energy in 2020 includes 120 PJ energy recovery from waste and biomass. This target should be considered as very ambitious, considering the Dutch situation with limited land availability. The target for biomass includes imports that are not further quantified. The underlying analysis includes 40 PJ of biomass imports [12].

This quantity is equal to 2.5 Mt dry weight of biomass. It can be grown on an area of 100,000-200,000 ha, depending on the biomass growth rate. These figures can be compared to the total Dutch agricultural land area of 2 million ha. From a logistics point of view, the policy goal of 40 PJ means 15 to 20 biomass loads of Capesize vessels (the largest size of bulk carriers).

7.2 Is biomass sustainable?

Sustainability is a rather vague concept. This complicates operationalisation. With regard to biomass, a tree fixes the same amount of carbon that is released when it used as a fuel. As a consequence, biomass has a closed carbon balance (if the problem of deforestation and desertification due to biomass harvesting is neglected).

Apart from the carbon cycle, biomass is part of the nutrient cycle. Potassium and phosphorus are extracted from the soil and are released when the biomass decomposes. In the case of combustion, these elements are included in the (fly-)ashes. These nutrients must be recycled into the soil in order to prevent soil depletion. Apart from the nutrient cycle, the water cycle of a region can be significantly affected by large scale biomass plantations. For example, eucalyptus and coniferous trees are notorious for their water requirements.

Apart from the nutrient balance and the water balance, biomass plantations can have consequences for the environment that are of a completely different kind. Especially the impact on land use is important. Biomass plantations will be situated on marginal soils, in existing forest areas or in areas that are not yet cultivated. The soils of better quality will probably be used for food and material production, because the prices of these crops are much higher. The need for food products will increase in the long term because of the population growth envisaged.

Biomass plantations will mainly be situated on marginal soils that - from a Dutch perspective - are often considered to be ecologically valuable. Biomass plantations will result in increased use of land resources. As a consequence, the natural values of the land will decrease. Biomass crops can result in monocultures, fragmentation of ecosystems because of new roads and fences, and in a reduction of biodiversity. Unfortunately there is not yet consensus among Life Cycle Analysis (LCA) experts how such effects should be measured. It is completely unclear how such disadvantages must be weighed against decreased CO_2 emissions.

Not all biomass plantations are detrimental to the environment. In regions that have formerly been deforested or where desertification occured, biomass plantations can contribute to the biodiversity, improve the climatological conditions, improve the water balance and reduce erosion. As a consequence, areas for biomass plantations should be carefully selected in order to achieve a maximum contribution to sustainability.

Biomass plantations in agricultural land areas are in a middle position concerning their environmental impacts. The estimation of the impacts depends to a large extent on the definition of the autonomous developments (the reference situation). If the reference situation is a return of agricultural land to nature, biomass plantations would have a negative environmental impact. However, if the reference situation is the use as agricultural land, biomass plantations may result in a beneficial environmental impact. Generally, it is assumed that surplus agricultural land will be detined as nature. In that case the comparison is between energy crops and land use for nature.

Generally speaking, bioenergy contributes to the goal of more renewable energy and energy supply diversification. Also CO_2 emissions will be reduced significantly. From an environmental point of view, the price for energy farming is large scale and intensified land use, with the related detrimental environmental impacts.

The impacts of long-range transport of the relative energy-extensive biomass have not been considered in this analysis. The energy content of biomass is 12-16 GJ/t compared to 26 GJ/t for coal. For large cargo vessels (65,000 dwt) the fuel consumption for the round trip Uruguay-Rotterdam-Uruguay is around 0.5 GJ/t (return trip without cargo). This is equal to 3-5% of the energy content of the biomass.

7.3 Costs of biomass energy

Delivery costs of biomass are shown in Table 7.1. The figures for Estonia are based on wood residues that are available in limited quantities in a short term. The figures for Uruguay are based on dedicated energy crops with a much higher potential. Biomass delivery costs should be compared to the price of coal (3.5 NLG/GJ). The comparison shows that biomass delivery costs are 95% to 175% above the current coal price. If these costs are translated in costs per kWh, power production costs would increase by 40 to 75%.

Tabel 7.1 *Delivery costs of imported biomass*

	Estonia [NLG/GJ]	Uruguay (NLG/GJ]
Wood as harvested	1.14	1.68
Local transport	0.56	0.78
Sea transport	2.01	4.01
Preparation	3.11	3.11
Total	6.82	9.58

Source: [13]

7.4 Biomass energy or biomaterials

The fifth UN/ECE-FAO study about the European wood market for the next 25 years provides some insight into the long term developmenets from the viewpoint of forestry and wood suppliers. The study analyses the materials application of biomass and the availability of wood [14]. The main results are shown in Table 7.2.

Table 7.2 *Developments in the European wood supply and fiber supply*

Source [10^6 m^3/EQ[1]	Base Case 1990	Base Low 2020	Base High 2020
European wood crops	392	480	489
Waste paper	72	178	206
Process waste	47	74	80
Net imports	55	130	164
Total	566	862	939

1 EQ = roundwood equivalents

Table 7.2 indicates an increase in the demand for wood products by 46 to 66%. This increase will be covered by additional wood crops, additional recycling and additional imports. The increase in wood crops of 22-25% is modest compared to the increase of recycling and imports. The increasing European wood demand will be met by increased harvests from the existing forest area. This supply should pose no problem. On one hand, the standing stock is still increasing. On the other hand, the age distribution of the forest is not balanced. As a consequence, more old trees must be harvested in the next decades, raising the potential harvests in year 2020.

This analysis indicates that no major problems can be expected for the next decades regarding the competition of energy crops and traditional material crops for the period 2000-2020. On the long term, materials substitution may be more attractive for CO_2 emission reduction than fossil fuel substitution. A large number of options compete for cost-effective reduction of CO_2 emissions from power generation and from other energy conversions. Calculations for Western Europe indicate that energy crops are not always the most attractive option to reduce CO_2 emissions (see Figure 7.1). As a consequence, material crops may on the long run be a more attractive option for CO_2 emission reduction than energy crops. Because waste biomaterials and waste from biomaterial processing can be used for energy production, biomaterials will result in a 'double dividend'. This feature increases the attractiveness of the biomaterials options.

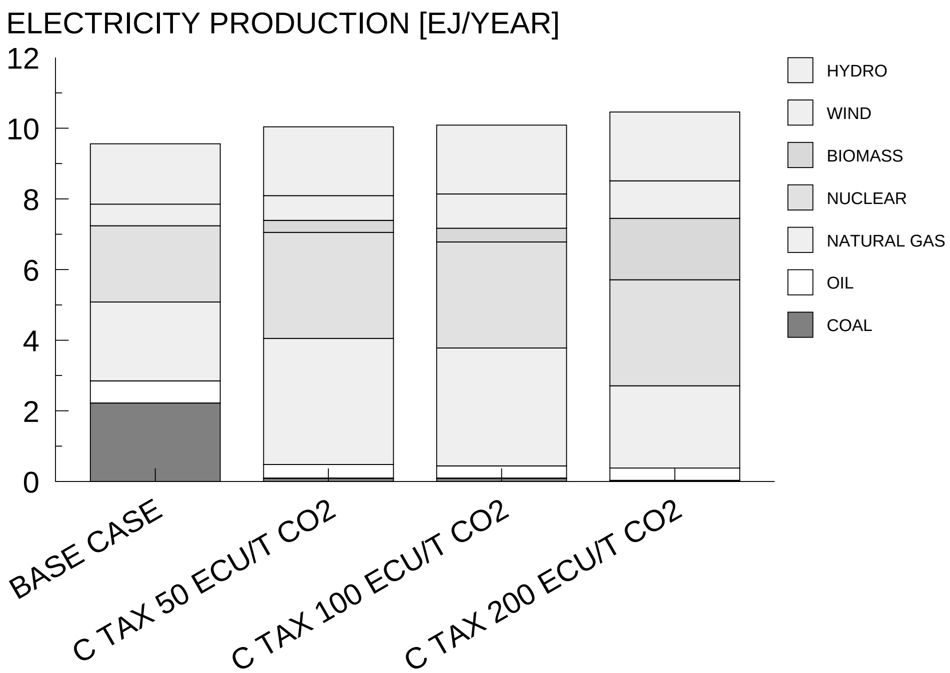

Figure 7.1 *Changing Western European electricity supply with increasing* CO_2*-penalties (Rational Perspective scenario, 2020)*

7.5 Case-studies: Uruguay and Estonia

Several studies for Dutch biomass imports have analysed the potentials of Uruguay and Estonia. These countries seem attractive because of their location at sea, relatively low labour costs and the availability of significant land areas. Both countries can produce much more than the 40 PJ that are aimed for in the Dutch policy plans.

In both countries biomass production will be based on new plantations. Estonian wood is currently mainly shipped to Scandinavia to be processed into sawn timber and pulp wood. Plans exist for a national Estonian paper and pulp industry. With regard to the production potential, the major part of the Estonian forests is rather swampy. Wood can only be produced from these areas after installation of sufficient drainage or with small-scale methods (e.g. horses).

It is expected that only 25 PJ will be left for exports in 2010. Large-scale biomass production could also be used to enhance the national Estonian energy supply situation.

In Uruguay, forests currently cover only 4% of the total land area. Approximately 35% of these forests are wood plantations, mainly Eucalyptus. The wood plantation area increases at a rate of 15% per year. This wood is mainly used for fiber and sawn timber production. These developments are included in the increased European wood material imports in Table 7.1. However, there is still sufficient land available in Uruguay to raise the biomass production.

In Uruguay, extensively used pastures are converted into biomass plantations. In Estonia, non-productive land is converted into biomass plantations. In Uruguay, 0.5% of the land area is concerned. In Estonia, 5% of the land area would be concerned. These figures show that the relative impact is higher for Estonia than for Uruguay. Some key characteristics of both countries are compared in Table 7.3.

Table 7.3 *Energy and socio-economic characteristics of Estonia and Uruguay [15]*

		Estonia	Uruguay
Population density	[km^2]	37.6	18.6
Land area	[1000 km^2]	43.2	173.6
Forest area	[%]	31	4
Agriculture area	[%]	11	78
Non-productive area	[%]	36	10
GNP 1994	[US$/cap]	6,460	7,200
Biomass yield	[t/ha/yr]	5-10	20-25
Electricity demand 1993	[kWh/cap]	6,528	1,575

Significant differences exist between the CO_2 intensity of their current energy supply. Estonian power production is largely based on local oil shale. This fossil fuel gives a very high specific CO_2 emission, higher than for coal (360 kg CO_2/GJ_e versus 235 kg CO_2/GJ_e for a Dutch coal fired power plant). As a consequence, substitution of biomass for oil shale in power generation in Estonia could result in a more significant reduction of CO_2 emissions than substitution of biomass for coal in the Netherlands.

In Uruguay, 85% of power generation is based on hydro power [16]. Still there is a significant potential to increase hydro power production even further. Therefore, biomass use for power generation in Uruguay does not result in CO_2 reduction (except in a case where this electricity is exported to Argentina or Brazil).

From a point of view, import of biomass from Uruguay makes sense, while import of biomass from Estonia is second best to substitution of biomass for oil shale in Estonia (e.g. by Joint Implementation).

With regard to the other environmental impacts of large scale biomass plantations, water supply is no problem in both countries because of sufficient precipitation. Biomass plantations in Estonia may result in a decline of the existing natural swamp areas. In Uruguay, no negative environmental impacts are expected, if part of the existing pastures is converted into biomass plantations. In order to prevent nutrient losses and to ensure the long term productivity of the soil of plantations, ash from biomass conversion plants should be reshipped to the country of origin.

7.6 Potential contribution from biomass energy to CO_2 reduction

The government issued guidelines for calculation of the CO_2 impact of projects in the framework of the fund for the enhancement of the economic structure (FES). These guidelines indicate that electricity is generated in the reference situation with a specific CO_2 emission of 103 kg per GJ electricity (corresponding to a gas fired power plant with 54% efficiency). The CO_2 emission of transport of biomass from South America is almost equal to the emission during coal transport from Australia. This emission is neglected in the analysis. The efficiency of biomass fired power plants is lower than for gas fired power plants, as biomass requires an additional gasification stage. The energy efficiency of biomass gasification is approximately 85%. Therefore, the net efficiency for the biomass fired power plant (based on gasification) is approximately 46%. 40 PJ of biomass can generate 18.4 PJ electricity and can reduce the national CO_2 emissions by approximately 1.9 Mt. This quantity is equivalent to 2% of the total CO_2 emission in the Netherlands.

8. CONCLUSIONS

European biomass scenarios

This report deals with more biomass scenarios for Europe, one more and another less sustainable. The potential of biomass energy of European countries and Europe is assessed, and the need for import of biomass is analysed.

Two scenarios are developed for land use in Europe. In the first scenario emphasis is on ecological farming, equity and maximum protected area. An important requirement for this scenario is a drastic change in nutrition patterns. If this requirement is fulfilled, the agricultural area can be reduced proportionally. From equity considerations, imports of animal fodder can be minimised. It is also assumed that imports of agricultural products (cotton, coffee, tea) can be halved compared to current levels, and that export and import of agricultural products can be in balance. Besides, nature and wildlife are protected by allocation of 10% of the total land area as protected area (in accordance with international obligations). For the Nordic countries Iceland, Norway, Sweden, and Finland the ratio is assumed to be 4.5%.

The second biomass scenario has much in common with the first. The area of cropland and permanent pasture is assumed to decrease in favour of energy crops. Also the area covered by forests and woodlands decreases, making room for protected area. However, the area reserved as protected area is much more limited than in the first scenario. The area of agricultural land is large enough to fulfil the requirements of ecological farming and equity (balance in imports and exports of agricultural products expressed as the area needed for these products), although this is not explicitly assumed. Finally, the area of energy crops is maximised, which is mostly at the expense of protected area.

For the total EU the potential of biomass could be about 17% of the primary energy demand in 2050 (11.5% in 2020) in the 'maximum energy crop' scenario, compared to about 15% in 2050 (11% in 2020) in the 'sustainable' scenario. For the year 2020 the difference in energy crop area for the two scenarios is negligible. This is because the 'sustainable' scenario presumes a steep decline in agricultural and forested area in favour of both energy crops and protected area until 2020. In the 'maximum energy crop' scenario the decline is less steep. For the year 2050, the difference in energy crop area is limited, as the countries Norway, Sweden, Finland do not show significant differences in protected area for both scenarios. Besides, in the scenario with maximum energy crops the drive to minimise the agricultural area is less pronounced than in the 'sustainable' scenario.

Countries with potentially the highest shares of biomass in their energy demand are Scandinavian and Mediterranean countries, with the exception of Italy. Ireland and Austria could meet up to 25% of their energy demand from biomass. The Netherlands and Belgium cannot expect to cover more than 7% of their (present) primary energy demand from indigenous biomass. These percentages refer to the 'maximum energy crop' scenario. For the 'sustainable' scenario the percentages are slightly lower. These are percentages of current primary energy use.

It is concluded that there is a good match between the results from this study and those of a country study for Denmark. Ecological farming methods, equity considerations, and creation of protected area, could be compatible with a biomass potential in 2050 of about 20% of the (current) primary energy demand in Denmark.

Also in case of Sweden the match between the results from this study and those of the country study is satisfactory. Ecological farming methods, equity considerations, and creation of protected area, would be compatible with a biomass potential in 2050 of 40% of the primary energy demand, if the requirements with respect to protected area would not be too stringent.

In case of Finland the results from this study differ from those of the country study, mainly because the area of energy crops in the country study is very limited. However, the potential of energy crops in this study could be in agreement with the analysis in the country study. Ecological farming methods, equity considerations, and creation of protected area, would be compatible with a biomass potential in 2050 of some 70% of the primary energy demand, if the requirements with respect to protected area would not be too stringent.

The 'maximum energy crop' scenario shows much resemblance with that of Johansson *et al.* [1], if the figures from Johansson's scenario are applied to the EU area. If the potential of biogas would be added to the total for the 'maximum energy crop' scenario, the total biomass potential for this scenario differs only a few percentages from Johansson's estimate. The potential of agricultural products and energy crops in this study is somewhat lower than the estimate of Johansson *et al.*, whereas the potential of wood fuels is larger. Johansson *et al.* assume that one-fourth of the forest residues is recoverable.

Import of biomass energy

The third white paper on Dutch energy policy was issued in 1996. This white paper forms the basis of energy policy in the Netherlands for the period until 2020. One of the key elements of the energy strategy is 10% renewable energy in the Dutch primary energy mix in year 2020.

The target of 10% renewable energy in 2020 could be met, if 2.5 Mt dry weight of biomass would be imported. This amount of biomass can be grown on an area of 100,000-200,000 ha, depending on the biomass growth rate. These figures can be compared to the total Dutch agricultural land area of 2 million ha. From a logistics point of view, the policy goal of 40 PJ means 15 to 20 biomass loads of Capesize vessels (the largest size of bulk carriers).

Generally speaking, bioenergy contributes to the goal of more renewable energy and energy supply diversification. Also CO_2 emissions will be reduced significantly. From an environmental point of view, the price for energy farming is large scale and intensified land use, with the related detrimental environmental impacts.

Delivery costs of imported biomass should be compared to the price of coal (3.5 NLG/GJ). Imported biomass would be 95% to 175% more costly than coal. If these costs are translated in costs per kWh, power production costs would increase by 40 to 75%.

The analysis indicates that no major problems can be expected for the next decades regarding the competition of energy crops and traditional material crops for the period 2000-2020. On the long term, materials substitution may be more attractive for CO_2 emission reduction than fossil fuel substitution. A large number of options compete for cost-effective reduction of CO_2 emissions from power generation and from other energy conversions. Calculations for Western Europe indicate that energy crops are not always the most attractive option to reduce CO_2 emissions. As a consequence, material crops may on the long run be a more attractive option for CO_2 emission reduction than energy crops. Because waste biomaterials and waste from biomaterial processing can be used for energy production, biomaterials will result in a 'double dividend'. This feature increases the attractiveness of the biomaterials options.

From a CO_2 point of view, import of biomass from Uruguay makes sense, while import of biomass from Estonia is second best to substitution of biomass for oil shale in Estonia (e.g. by Joint Implementation).

With regard to the other environmental impacts of large scale biomass plantations, water supply is no problem in both countries because of sufficient precipitation. Biomass plantations in Estonia may result in a decline of the existing natural swamp areas. In Uruguay, no negative environmental impacts are expected, if part of the existing pastures is converted into biomass plantations.

With respect to the CO_2 reduction potential of import of biomass, 40 PJ of imported biomass can generate 18.4 PJ electricity and can reduce the national CO_2 emissions by approximately 1.9 Mt. This quantity is equivalent to 2% of the total CO_2 emission in the Netherlands.

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