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EXPLORATION OF THE LAND POTENTIAL FOR THE PRODUCTION OF BIOMASS FOR ENERGY IN THE NETHERLANDS

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Abstract—The energy potential for energy crops and biomass residues in the Netherlands is assessed. The analysis explores the possible use of land for biomass production in the future. Various government memorandums and analyses of the expected future land use in various sectors have served as the basis for the assessment of the supply of and the demand for land in the future. In this study the potential supply of agricultural land is based on expected productivity increments in agriculture and assumptions with respect to the future demand for agricultural products. Various future claims for infrastructure, forestry, urban areas and nature are subtracted from the expected supply. The net projected supply of land ranges from zero to 52 000 ha in 2000 to 110 000–250 000 ha in 2015. The supply of agricultural land depends however on a number of supra-national factors, such as the European agricultural policy, world market developments and the agricultural production in the countries in Eastern Europe. Uncertainties remain, therefore, and the projected supply of agricultural land should be considered as a possible scenario based on current trends. If the calculated land potential is used for energy crops like miscanthus and short rotation coppice, this land could contribute 0–10 PJ in 2000 and 27–59 PJ in 2015. Secondary biomass yields, such as those from forestry, agricultural residues, wood from prunings, etc., could contribute a further 34 PJ in 2000, decreasing to approximately 28 PJ in 2015. Taken together these potentials could satisfy 1–1.5% of the energy requirements of the Netherlands in 2000 and 1.5–2.5% in 2015, provided that energy farming is an economically feasible activity for farmers.

Keywords—Land-use; spatial potential; energy farming; biomass energy; biomass residues.

1. INTRODUCTION

From about 1990 onwards there has been renewed interest in many parts of the world in the possible utilization of energy crops to produce heat, electricity and fuels. Two of the driving forces are concern about global warming and technological developments (e.g. in gasification technology) that make utilization of biomass for energy economically more attractive. Furthermore, in industrialized countries (EU and U.S.A.) overproduction in agriculture means that there is increasing interest in new options for farming and land-use, especially in the growth of crops for non-food applications. Energy crops like rapeseed are already being grown on a relatively large scale in countries like Germany and France, whereas in Brazil sugar cane and in the U.S.A. cereals and corn are being used on a large scale for ethanol production.[1] It is expected, however, that the growth of lignocellulosic perennial crops, such as willow and Miscanthus, will become especially attractive because of their favourable energetic and economic performance.[2–4]

The EU has recognized the potential of 'new' energy crops, such as short rotation forestry (e.g. willow, poplar and eucalyptus) and perennial grasses (like miscanthus), by allowing the production of such crops on set-aside land and has maintained the set-aside subsidies. The land area that falls under the set-aside settlement is substantial: 10%, or about 13 million hectares (mha) of agricultural land of the EU-12 over the past years.[5] However, the percentage of land that falls under this set-aside settlement is affected by the EU agricultural policy and is strongly related to cereal production in the EU. For 1997 the percentage has been lowered to 5%.[5]

Biomass production for energy purposes will most probably only take place on a large scale when all demands for food and fibre are met by the current agricultural system. Food and fibre are high value products and their production will therefore have priority over energy crops. Consequently, the question that arises is how much land will become available to produce biomass for energy purposes. This question has been addressed in various studies.

Hall et al.[2,3] have discussed the energy potential of biomass (both energy crops and biomass residues) on a worldwide scale. They considered it feasible that 10% of the total cropland and land used for commercial forestry (either worldwide or per world region) could be used for energy crops. This assumption means about 38 mha for Europe as a whole, or approximately 15 mha for the EU-12 (including land used for commercial forestry). It is, however, recognized that site-specific factors will be very important and that regional assessments are needed to achieve a more detailed view.

The study 'Ground for choices' by the Netherlands Scientific Council for Governmental Policy (WRR) gives a comprehensive overview of the main factors that influence land supply and land demand in the EU-12.[6] The main results of the study are given in Fig. 1. The figure shows that, according to the WRR, between 50 and 100 mha might come available in the EU-12 in a time frame of approximately 20–25 years. Such enormous areas of land, if utilized for biomass energy production, represent a large energy potential. (With an average annual yield of 12 dry tonne per hectare, the use of 50–100 mha could result in an energy production of 11–22 EJ (18 GJ/tonne heating value), which is approximately 20–40% of the total primary energy use in the EU-12. This amount is about equivalent to the present total import of energy.)

The study by the WRR was done on an aggregated level. The Netherlands, for example, were divided into only four agricultural regions. The analysis focused on implementation by the best technical means; thus it was assumed that farmers will adopt the most efficient methods to produce food and fibre. Clearly, this situation does not occur in every context. Claims for the expansion of urban areas and nature development were also

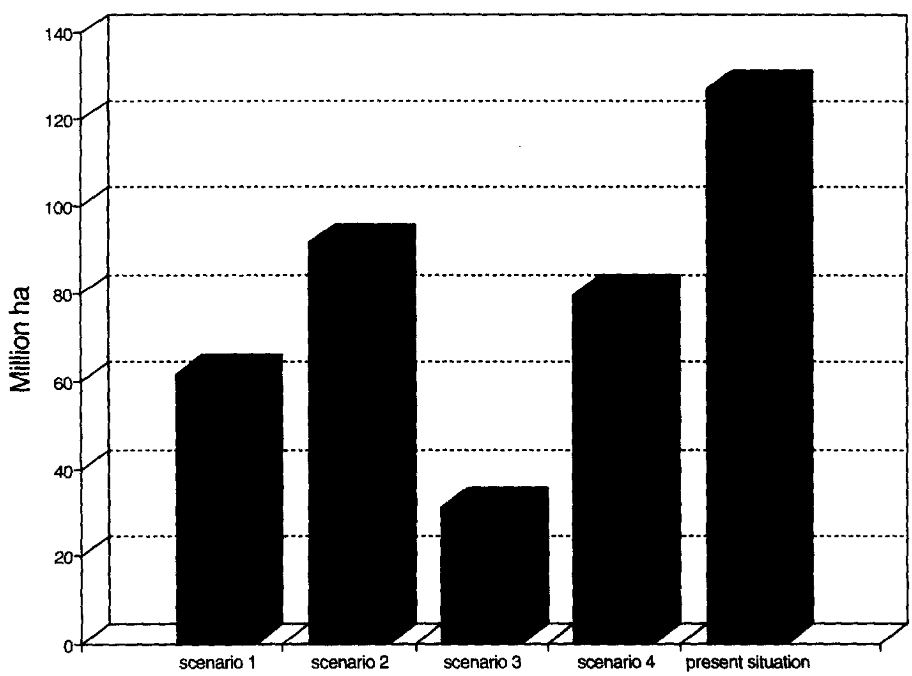

Fig. 1. Present and future demand for agricultural land in Europe (EU-12) according to the WRR. The results are based on study of four different scenarios.[6] Scenario 1 'free market'. Lowest possible production costs and minimal trade restrictions. Scenario 2 'regional development'. Priority given to the development of employment in rural areas and strong EU-policy. Scenario 3 'nature and landscape'. Priority given to preservation of and realization of the maximum surface of nature areas. Scenario 4 'environmental constraints'. Minimization of emissions from agriculture which sets stringent limitations for production methods.

investigated, but the study did not take into account competing claims for the same land or possible combinations of land-use, such as nature and agriculture.

The WRR recognizes that in many cases current farming in the EU is not sustainable. This leads to problems like eutrophication, nitrogen leaching, soil degradation, dehydration and dispersion of agrochemicals. The council indicates that intensive agriculture within strict environmental constraints can prevent these problems. However, other researchers and institutes argue that the problems will be solved if current agricultural production methods are replaced by less intensive and integrated farming practices. This would lead to a greater land use per unit of product produced and thus to a smaller surplus or even to a shortage of agricultural land. For example, Biewinga *et al.*[7] have calculated that when large claims for nature development, replacement of agricultural imports (like fodder), expansion of forest and, especially, extensification of land-use for food production are taken into account, there may be a shortage of up to 28 mha or a surplus of 19 mha in 2005 in the EU-12.

Lehman *et al.*, however, have adopted a similar approach to that of Biewinga *et al.* They calculate that there will be a surplus of agricultural land of 40 mha after the year 2010.[8] They assumed strict environmental constraints for the agricultural sector and they also took aspects like the replacement of the import of agricultural products into account.

Kaltschmitt *et al.*, who calculated the amount of land in Germany that could be available for energy farming, followed a different approach. They assumed that all set-aside land could be used for this purpose. Furthermore, they estimated that the overproduction in the EU would be reduced to zero. For Germany this would result in the potential availability of 1 mha, i.e. approximately 9% of the total arable land.[9]

Table 1 summarizes the main characteristics of the approaches followed in these studies, as well as their main results. Most of them indicate a (potential) surplus of agricultural land in the EU in the relatively near future. The size of this surplus, however, depends on a large number of factors. The general conclusion is that the future availability of land for biomass energy production will be determined largely by agricultural policy and market developments. Another conclusion is that the above-mentioned studies are aggregated exercises that provide limited insight into developments on a regional scale.

In this article we want to address the question what the potential for biomass production for energy purposes in the Netherlands might be over the next 5–20 years. The WRR study indicates that the Netherlands is one of the few countries where a shortage of land might occur in the near future. However, also a surplus almost equal to the total amount of ara-

Table 1. Studies concerning land-use in the EU, the approach adopted and the main results and conclusions

Study	Approach	Results
Hall *et al.* Renewable energy[2]	Assumes that 10% of current land used for food crops and commercial forestry may become available on a worldwide basis.	Results in 38 mha for Europe as a whole and 15 mha for the EU-12.
Biewinga *et al.* Sustainability of energy crops in Europe[7]	Analysis of demand for land in the EU taking demand for food crops, fodder and fibre into account.	Results in a shortage of 28 mha for the EU-12 up to a surplus of 19 mha in 2005.
Lehman *et al.*[8]	Comparable to approach of Biewinga *et al.*	Limited potential up to 2010, but up to 40 mha after that year.
WRR; Ground for choices[6]	Evaluates the technical improvement potential in agricultural productivity under various constraints (environmental, economic).	Taking expected future demand for cropland and land for other functions into account, a surplus of 40–100 mha cropland in the EU-12 is possible in 2015.
Kaltschmitt *et al.*[9]	Considers the current surpluses in agricultural production which is translated to a related land area. Approach implemented for Western Germany.	1 mha or approximately 9% of arable land in Western Germany could become available.

ble land is calculated, depending on the scenario considered. The other studies mentioned do not give any better insight on a national or regional scale.

To estimate the physical potential for energy farming in the Netherlands one needs more detailed insight into the possibilities for biomass production and into possible conflicts that might arise as a result of the significant production of energy crops. This in turn requires a more detailed analysis of the supply of and demand for land for food and fibre production and other purposes.

In this study we will use explorative forecasting, more specifically the scenario technique, to obtain an answer to our question. Consequently, current and expected trends in the demand for and supply of land will be analyzed in detail. So far no study has attempted to focus on the detailed analysis of various (possible) land claims and the potential of land for energy farming on the basis of formulated policy and trends.

In Section 2 we analyze the (potential) supply of land from the agricultural sector. We also investigate the claims that are being made on that land inside and outside the agricultural sector for a number of purposes. Our investigation is based on a review of various studies and policy papers.

Section 3 deals with the potential use of land available for biomass production and the production of energy carriers. It should be noted that land solely used for energy crops is not necessarily the only source of biomass. Biomass residues, such as from agriculture (like straw) and forestry (like thinnings), are also suitable and can represent a significant potential.[10] The amount of land used for other functions therefore influences the potential of biomass as an energy source. Consequently, secondary biomass production in relation to land-use developments will also be investigated in this section. In Section 4 the results obtained are discussed. In addition, final conclusions are drawn about the availability of land for biomass production and the potential for producing energy from biomass in the Netherlands.

2. LAND: SUPPLY AND DEMAND

Figure 2(a) shows the present use of land in the Netherlands and Fig. 2(b) gives a breakdown of the arable land according to the main categories of agricultural use. The total land surface is 3.4 mha. Agriculture is dominant in the total land-use. Future claims on land for non-agricultural functions may be determining whether agricultural land is available for

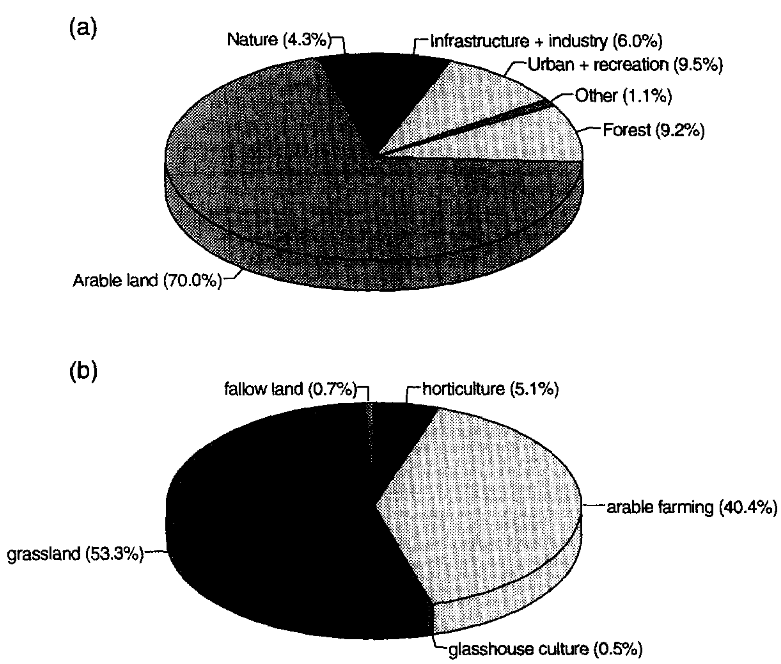

Fig. 2. Current land-use in the Netherlands. The total land surface is 3.4 mha, excluding 0.76 mha of surface waters (source: Land-use Statistics 1993).[37] (b) Current use of agricultural land in the Netherlands (source: Agricultural Statistics 1995).[21].

alternative use. (Compared to the total area of agricultural land derived from the land use statistics, the total agricultural land area given in the agricultural statistics is somewhat lower. This is due to the difference in methods used for composing these statistics: the land-use statistics are composed on the basis of aerial photography; the agricultural statistics are based on questionnaires.[11] In this study we will use the agricultural statistics for figures with respect to agricultural land-use.)

In this section both the potential supply of land from the agricultural sector and the demand for land for a variety of functions will be analyzed. Various policy papers relating to land-use and physical planning will serve as input, as well as a number of studies and statistics dealing with developments in land-use in the Netherlands. By analyzing trends in the demand for and the supply of (agricultural) land and policy objectives with respect to physical planning, insight is obtained into whether or not there might be a surplus of land in the future in the Netherlands. Simultaneously, insight is gained into the uncertainties and variations in policies and developments that affect the demand for and the supply of land.

First, in Section 2.1, developments in agriculture will be discussed. Section 2.2 explores expected land claims from non-agricultural sectors. Section 2.3 summarizes the estimated supply and demand regarding agricultural land and draws conclusions about the land that is potentially available for energy crops.

2.1. *Developments in agriculture*

A number of factors that affect the demand for and the supply of arable land in a given region (e.g. country) can be distinguished:

1. The demand for food and other agricultural products such as fibres. This demand is in the first place determined by population growth and the 'average' diet. When focusing on the need for arable land in a certain region (like a country) one needs to take into account the import and export of agricultural products in the region.
2. The (market) price for those food and agricultural products. Prices of agricultural products largely determine whether or not farming activities are economically sound in a certain region. They therefore affect the claims made on land for agricultural purposes.
3. The productivity of agriculture or the intensity at which agricultural production takes place. Given a certain demand for agricultural products, the required acreage to meet this demand can vary strongly depending on the average production per hectare. Issues influencing the productivity of agriculture are environmental standards, economic criteria and the availability of capital and (knowledge) infrastructure.
4. The demand for land for other functions, such as for infrastructure, industry, housing and nature.
5. The loss of agricultural land due to, for example, erosion. However, erosion is not a problem in the Netherlands.

In the case of the Netherlands, the first two factors are strongly influenced by external forces: EU agricultural policy (subsidies, market control, export policy) and world market prices. The popularity of a crop will depend on its profitability for farmers. Economic factors also determine to what extent the import or export of agricultural products is attractive. Especially in a liberalized market, agricultural products might be largely imported or their export might be restricted because other producers offer lower prices and vice versa. The third factor is to some extent interlinked with the first two factors, since high prices and a high demand may result in more intensive agriculture.

Taking the indicated factors into account we will discuss past and potential future developments in the agricultural sector of the Netherlands, and then we will attempt to estimate the area of agricultural land that might be available for other purposes.

2.1.1. *Developments in agriculture in the Netherlands*. Developments that affect agriculture in the Netherlands with a focus on economic aspects, both at the farm and the macro-economic level, are published annually by the Agricultural Economic Institute (LEI) in the so-called Agriculture Economic Reports.[12] Over the period 1985–1994 there was a decrease in agricultural production. The main explanation for this decrease is the policy of the EU and especially the introduction of production limits for dairy products. In the period 1976–1994, the number of farms decreased (average 1.7% per year discontinuation percentage). In the same period, the total surface of arable land dropped by approximately 100 000 ha, which is a decrease of 5%. The number of farms decreased by 29% in that period, resulting in an increase in the average area per farm from 13 to 17 ha. In recent years the discontinuation has risen, and was as high as 2.5% in 1995. The main reasons for the discontinuation of farms are: economic motives such as bankruptcy, disease or disablement of the farmer, no successor, and so-called 'warm' redevelopment; the latter implies that the farm owner sells his farm to another party, which can be another farmer, a municipality or another government body.[12,60]

The expected supply of agricultural land up to the year 2000 has also been evaluated by the Agricultural Economic Institute (LEI), in a study by Bethe called 'Regional land balances'; it deals with the supply of and the demand for agricultural land.[13] The supply of land is based on developments in the discontinuation of farms. The discontinuation percentage per type of farm and the average farm size were the basis for the projections of land supply. On average a discontinuation percentage of 1.9% per year up to the year 2000 is assumed. The largest supply stems from dairy farms (average 2.6%). As a result, a supply of 280 000 ha can be expected between 1995 and 2000. If this trend is extrapolated to the year 2015, the total gross supply would be 700 000 ha.

More recent model calculations indicate an even higher discontinuation rate for farms up to the year 2015 (up to 2.8% per year in certain scenarios), which may further increase the supply of agricultural land.[14]

Recently the Agricultural Economics Institute has published a comprehensive follow-up of the study by Bethe, called 'Regional land balances until 2015'.[15] The demand for and the supply of land in the Netherlands is evaluated with the help of three economic scenarios: European Coordination (EC), Global Competition (GC) and Divided Europe (DE), developed by the Central Planning Bureau (CPB) of the Netherlands.[16] This study projects the supply of land, the demand for land, prices of land and development of various agricultural sectors in relation to the three economic scenarios. Various environmental constraints are taken into account.

The study indicates, just as in the assessment by Bethe, that about 700 000 ha agricultural land will become available up to 2015. However, this is a gross supply of land. Land is demanded for non-agricultural functions and agriculture itself claims land, for example by farmers expanding their land.

The study assumed that claims for non-agricultural functions always have priority over agriculture. The remaining land is what is left for agriculture. Inherent to this approach, no surplus of land is obtained in any scenario. All remaining land is used for agriculture, although the total agricultural production and the margins for farmers vary per scenario. Also modest to strong decreases in the prices of land are obtained in all the situations investigated. The main explanations are changes in the EU agricultural policy as a result of the phasing out of subsidies and increased competition in a liberalized world market. Those developments are expected to lead to continuing rationalization and increased productivity of agriculture in the Netherlands.[15]

2.1.2. *Potential availability of agricultural land for other purposes.* The previous discussion illustrates that it is very difficult to predict developments in agriculture, even in conjunction with more detailed analyses of the sector and economic models. Dominant factors in the development of the agricultural sector remain the EU agricultural policy, international agreements and the reaction of Dutch agriculture to these developments, e.g. by further intensifying agriculture or by expanding it.

The mobility (supply) of land is expected to remain rather high. The introduction of a new crop can therefore be achieved, provided it is an economically attractive option for farmers or other landowners. An economic model has been used for the regional land balances to simulate the economic performance of various agricultural sectors.[17] At the current stage a model that includes energy crops at various price levels and simulates to what extent energy crops might compete with conventional agriculture is beyond the scope of this research. Instead a different approach will be adopted to calculate the potential availability of agricultural land up to 2015. This will be based on expected productivity increments in agriculture. Figures concerning these increments will be based on analyses of trends and constraints made by Hoogevorst and van

Table 2. Current acreages, potential productivity increments up to 2015 and required acreage in 2015, assuming that the agricultural production has to satisfy the demands of a 7% population growth in 2015

	Acreage in 1994 (1000 ha)[21]	Productivity increments up to 2015[15,18,19]	Required acreage in 2015, including 7% population growth
Cereals and maize	178.0	31%	145.5
Potatoes	110.9	10.6%	107.3
Industrial potatoes	60.8	7.9%	60.3
Sugar beet and fodder beet	116.6	26.3%	81.6
Green maize (fodder)	228.5	assumed to be 20%[a]	212.6
Other agriculture	104.3	assumed to be 15%[b]	97.0
Horticulture	110.2	assumed to be 15%[b]	102.5
Grassland/milk production[c]	1050.6	31%	858.1
Totals (ha)	1959.9		1664.9

[a]Productivity increment for green maize is estimated lower than for e.g. corn maize, since the whole crop is used for fodder.

[b]Productivity increments given by RIVM for onions (17%), legumes (14%) and commercial crops (12%) are considered representative for other types of agriculture and for horticulture as a whole. On average a 15% productivity increment is assumed in this study.

[c]Milk production is dominant in grassland use; an area of 965 000 ha is in use for dairy cattle.[21] The productivity increment is assumed to be representative for the entire sector. Meat production is not included here since the largest part of meat production is not bound to a certain land surface (cattle, pigs, poultry).

Egmond *et al.* for the period 1995–2020.[18,19] These increments in production for main agricultural crops and for milk are given in Table 2. The actual realization of these increments will depend on a number of factors, such as the need for increased cost effectiveness due to international competition and environmental constraints.

Next, we assume that in the Netherlands the production of food per capita will remain constant. Also it is assumed that no shifts in diet or production patterns will occur up to 2015. Population growth is, however, taken into account. In 1995, the Netherlands had 15.4 million inhabitants.[20] The Central Planning Bureau projects a population of 16.5 million in two of three evaluated scenarios in 2015.[16] This implies a population growth of about 7% between 1995 and 2015. We will correct the total agricultural production of 1995 by this percentage to estimate the agricultural production in the year 2015. Note that this approach implies that exports grow by 7% as well.

Table 2 provides an overview of the current (1995) area per main agricultural sector and the required area in 2015, including the mentioned productivity increments and the desired 7% growth of agricultural production. The areas given exclude glasshouse horticulture (10 200 ha in 1995) and fallow land (14 400 ha in 1995). (In the context of the EU agricultural policy, arable land is set aside with financial support in order to reduce surplus agricultural production. In the Netherlands in 1995 this policy resulted in a total area of 14 400 ha being set aside[21]). We assume that these areas remain constant over time.

This exercise results in a total land surface for the required agricultural production amounting to 1 667 000 ha in 2015, instead of 1 960 000 ha in 1995; a reduction of 15%. The theoretical surplus of agricultural land is therefore 293 000 ha in 2015. Together with the above-mentioned 14 400 ha of fallow land, the potential availability of agricultural land for other purposes can therefore be estimated at about 300 000 ha.

2.2. *Land claims from non-agricultural functions*

A substantial number of government memoranda describe policies that cover land-use in the Netherlands. A brief overview of memoranda used in this study is given in Table 3. On the basis of these documents, we will analyze per category of land-use (such as forestry, nature development, urban areas, industry and infrastructure) what land claims can be expected on longer term.

2.2.1. *Forestry.* Almost all forests in the Netherlands fulfil a number of functions, like possibilities for recreation, wood production, nature and landscape. Forests covers a modest 9% of the total land area (see Fig. 2(a)). An important policy objective is to increase the forest area in order to meet a larger part of the domestic demand for wood. In 1993, the Netherlands were only 10% self supporting in

Table 3. Overview of policy documents and memoranda that affect land-use in the Netherlands

Memorandum/data/author	Function/policy field	Objective and main content
Policy plan on forestry, December 1993, Ministery of Agriculture, Nature and Fisheries[22]	Forestry	Policy with regard to forestry in the period 1994–2020 with attention to expansion of forestry
Nature Policy Plan, June 1990, Ministry of Agriculture, Nature and Fisheries.[24]	Nature and landscape	Strategic plan for nature development and landscape for the period 1990–2020. Main objective is preservation, restoration and development of nature and landscape by means of the Ecological Main Structure
Scheme Green Space. September 1993, Ministry of Agriculture, Nature and Fisheries and the Ministry of Housing, Physical Planning and Environment[25]	Rural area	Covers concrete initiatives for agriculture and horticulture, nature, landscape, recreation, tourism, forestry and fisheries up to 2000. Attention to integration of various themes
VINO/VINEX. Fourth memorandum on physical planning, 1993, Ministry of Housing, Physical Planning and Environment[34]	National environmental, town and country planning	Plan covering spatial aspects of most other memoranda until 2015. Important are the projections for house-building and rural area
Transfer study, April 1994. Memorandum on the evaluation of military training grounds, 1991, Ministries of Defence, of Housing, Physical Planning and Environment and of Agriculture, Nature and Fisheries[31]	Defense	Policy with regard to restructuring the armed forces and transfer of military training grounds from natural areas to agricultural areas

this respect. The objective is to increase this to 17% by 2000 and to 25% by 2050.[22]

The present area of forest is about 335 000 ha. Up to 2020, an expansion of 75 000 ha is planned.[22] This results in an average annual claim of about 2000 ha/yr up to 2000 and about 2400 ha/yr thereafter. These projections are consistent with the estimates made by Kamminga *et al.* in a study on future claims on agricultural land.[23]

2.2.2. *Nature*. From the beginning of the nineties, governmental policy has aimed to develop nature at the expense of agricultural land. At present, nature areas cover only 4% of the total surface of the Netherlands. This percentage is generally considered too low for the sustainable preservation of nature in the Netherlands. The creation of a so-called National Ecological Network (NEN) should change this situation.[24] The NEN consists of core areas, nature development areas and migration zones. A significant part of the core areas consists of current nature reserves. Expansion of these areas is planned and is already ongoing. Implementation of the NEN also implies that the amount of agricultural land which is subject to various restrictions—varying from the moment of harvest to no use or very restricted use of fertilizer and agrochemicals—will be expanded. Farmers are generally financially compensated for such restricted management. Finally, the NEN should make connections between various nature reserves to enable species to migrate via migration zones. These can consist of (small) landscape elements, 'green corridors', small rivers, etc.[24–27,61]

The current area of land for nature, excluding forests, is about 120 000 ha. The NEN must be implemented by 2020. By that time the NEN should cover 19% of the total land surface of the Netherlands.[23] This surface, however, also includes a large agricultural area in which functions for nature and agriculture are combined. In 2020 a total area of land for nature (excluding forest) of 250 000 ha is foreseen. (IUCN rules propose in general to reserve 10% of the land surface for nature. The Dutch objectives do exceed this standard—total surface of the NEN amounts to almost 20% of the Dutch land surface. However, depending on how one defines nature, the NEN might not be considered 100% nature area, since it includes for example, partly extensively managed agricultural land as well). Also the area of agricultural land under restricted management is to be expanded. The claim on agricultural land in order to realize the NEN results in an average demand of about 4250 ha/yr up to the year 2005 and a demand of about 3000 ha/yr between 2005 and 2020.[24] This figure is consistent with the estimates made by Bethe.[13] Kamminga *et al.*, however, suggest that claims will be up to 7100 ha/yr until the year 2015, assuming a scenario that gives high priority to preservation and development of nature.[28] This shows that the way the NEN is implemented may substantially influence the potential surplus of agricultural land. The actual implementation of the NEN is also determined by the availability of funds which may meet constraints.[29]

For this study we will use the projection of the policy paper. Note, however, that a large part of land claimed for nature as projected in the nature policy plan may be suitable for energy crops that require very low emission levels of fertilizers and agrochemicals, especially in buffer zones.

2.2.3. *Military training grounds.* The master plan on military training grounds, published in 1991, states that the total land area used for training should decrease from 23 000 ha to 17 000 ha.[30] This objective has already been largely achieved. Military training grounds are mostly located in nature areas. Lately this has been considered to be undesirable, especially in the context of the realization of the NEN.[31] Training grounds should therefore be partly relocated to agricultural areas. This would involve a claim on agricultural land of about 3000 ha within 15 years.[31,32]

2.2.4. *Urban areas.* The Netherlands is densely populated. Population growth and a continuous decline of the number of people per residence result in an increase in the number of houses. The size of this growth and also the required surface involved is, however, a point of discussion. In 1993, there were over 6 million residences.[33] Several forecasts have been made regarding the required additional number of dwellings in 2005 and 2015. The estimates of the required additional number of dwellings vary between 560 000 and 690 000 houses for 2005 and between 1 200 000 and 1 800 000 for 2015.[34,35] According to the fourth memorandum on physical planning (VINEX, see Table 2), these new houses should be concentrated as far as possible in or close to the main cities.

Taking the range in estimates for the required number of dwellings into account one arrives at a total demand for land of 2200–2500 ha/yr up to the year 2015.[34] It is to some extent uncertain how many dwellings can be built in urban areas. It is therefore possible that substantial rural areas will have to be used for building. The claim on agricultural land is estimated to be 750–850 ha/yr by the VINEX.[34] Bethe indicates that considerably more agricultural land might be needed: nearly 1700 ha/yr.[13]

Kamminga *et al.* project a relatively wide range for the claim on agricultural land due to the expansion of urban areas: a minimum of 750 ha/yr up to approximately 2750 ha/yr.[23] However, these estimates include space for infrastructure and industry. In this study we will use an average value of about 1250 ha/yr between VINEX and Bethe for the period 1995–2015. Note that the area of land required for urbanization might substantially increase if the policy to concentrate further construction in and near the larger cities fails.

2.2.5. *Infrastructure and industry.* Very limited information is available about expected claims on land for industry and infrastructure in the Netherlands. Currently, 6% of the land surface of the Netherlands is used for infrastructure and industry (see Fig. 2(a)): 60 000 ha for industry and 140 000 ha for infrastructure. The land-use for both increased in the period 1979–1985, but the actual annual claim varied. In the fourth memorandum on physical planning, a claim of 850 ha/yr was observed from 1983 to 1985.[34] This memorandum, as well as Bethe, argues that a slight growth in claims on agricultural land for industry and infrastructure is realistic.[13,34] It is assumed that this growth will increase slightly to 1000 ha/yr in the period after 2000.[13] We will use this value in this study. The true claim for land will strongly depend on economic developments. New planned large infrastructural works, however, underline an expected increase in the claim for land in this category.

2.2.6. *Recreation.* Land having recreation as its main function was about 82 000 ha in 1989.[36] This includes sport terrains, allotments, parks and specific terrains like camping-sites. Forest with a recreative function was included in the total surface of forest (in 1985 this was 18 000 ha).[37] A growth in land-use for recreation is observed, especially close to the cities. However, recreation is already included in the land claims for forest, urban areas and nature. Therefore, land claims for recreation will not be dealt with separately in this study.

2.2.7. *Total claims on agricultural land for non-agricultural functions purposes.* Table 4 gives an overview of the claims on agricultural land of all non-agricultural purposes that were discussed. Average annual claims have been calculated from total claims over given periods of time. A number of projections cover a time-

Table 4. Overview of the claims for land for non-agricultural purposes in the Netherlands

Function	Present surface (ha)	Future planned surface (ha)	Target year	Average claim per year (ha/yr)	Total claim 2000 (ha)	Total claim 2015 (ha)
Forest	335 000	410 000	2020	2000–2400[b]	12 000	48 000
Nature (excluding forest)	120 000	250 000	2020	4150–2900[b]	41 500	85 000
Military training grounds[a]	23 000	max 17 000	2010	200	2000	3000
Urban area[a]	210 000	265 000–274 000	2015	1250[c]	12 500	31 300
Industry and infrastructure[a]	200 000	210 000	2000	1000	10 000	25 000
Recreation	80 000	80 000		included in forest, urban area and nature[d]		
Total	970 000	1 230 000–1 240 000		8600–7800[b]	78 000	192 000
Total 'hard' claims				2500	24 500	59 000

[a]'Hard' claims.
[b]Expected implementation rate after 2005.
[c]Minimum projected annual claim is 750 ha/yr, but this seems optimistic. Here an average figure is given.
[d]Claims for recreational forest are included in forest. Claims for 'urban' recreation areas are included in urban area.

frame up to 2020. When required, a correction is made to obtain the average claim up to 2015. Important non-agricultural functions that require substantial areas of land in the Netherlands are expansion of urban areas, forestry and nature development.

The total land claim until 2000 is about 78 000 ha. For the year 2015 the figure is 192 000 ha. Claims for urban areas, industry and infrastructure and military training grounds can be considered as being hard claims. They are 24 500 ha in 2000 and 59 000 ha in 2015. The others can be considered as 'soft' claims, the realization of which depends on, amongst other things, available funding. It can be argued that implementation of short rotation coppice can also be counted as forestry. The implementation of the National Ecological Network constitutes the largest claim on agricultural land, but might leave room for the production of biomass as well.

2.3. *Integrating demand and supply*

Combining all demand for and the potential supply of agricultural land results in the figures presented in Table 5.

A net potential supply of agricultural land of 110 000–250 000 ha is found for the year 2015. When an estimate is made for the year 2000 via a linear interpolation, the net potential supply of agricultural land varies from zero to 52 000 ha. The ranges are caused by differentiating between the so-called hard claims that will most certainly have priority over agriculture (urbanization, infrastructure), and other claims involving nature development and forest expansion.

As can be seen from Table 5, both hard claims and other non-agricultural claims are significant compared to the total supply of agricultural land. However, the supply itself remains the dominating factor for the potential availability of land for alternative crops.

Table 5. Spatial potenial for energy farming on agricultural land in 2000 and 2015 with 1990 as base year

Year	2000 (ha)	2015 (ha)
Supply of land	76 000	305 000
Hard non-agricultural claims[a]	24 500	59 000
Other non-agricultural claims[b]	53 500	133 000
Spatial potential[c]	0–52 000	113 000–246 000

[a]Claims for urban development, infrastructure and industry.
[b]Claims from forestry and for nature development.
[c]Range created by distinguishing between hard claims and other claims.

3. PRODUCTION OF BIOMASS AND ENERGY POTENTIAL

3.1. *Energy farming*

The aim of this paper is to identify the technical potential of biomass production as an energy source in the Netherlands. More precisely, we want to know the (maximum possible) energy value of this potential. For this purpose we assume that the potential surplus of agricultural land can be utilized for the production of energy crops. In the Dutch context, the total net energy yield per hectare is highest for perennial grasses (like miscanthus) and short rotation coppice (such as willow). For these crops, yields of about 12 oven dry tonnes per hectare per year (odt/ha/yr) or more are considered to be possible.[38,39] The net energy yield (thus including energy use for planting, fertilizers, etc.) could amount to about 200–250 GJ/ha/yr (assuming yields of 12–15 odt/ha/yr),[4] compared to 85–175 GJ/ha/yr (range for actual and attainable yields) for crops like wheat and sugar beet.[4,7,40] Both miscanthus and willow can be grown under Dutch conditions, although which crop is best suited for a given area will depend on local conditions, especially soil quality and water availability. In general, willow prefers wetter soils. Miscanthus grows better on drier (sandy) soils.

Projected average yields, expressed in oven dry tonnes per hectare per year, in 2000 and 2015 for miscanthus and willow that will be used for further calculations are given in Table 6. Difference is made between higher and lower quality soils with respect to obtainable yields. These yields are derived from Nonhebel.[41] Twenty percent higher yields are assumed to be obtainable in 2015 because of further improvement in both the crops themselves and the cultivation systems.[3,38,39]

For the calculation of the total energy potential, the energy content of the biomass crop is taken into account in terms of the lower heating value to permit comparison with national energy statistics: 18 GJ/odt for miscanthus and willow.[10] Furthermore, the energy input of the cultivation itself is taken into account. Values of 0.9 GJ/odt and 1.0 GJ/odt are used for the higher and lower yields, respectively. These values include all crop production operations up until harvest, but exclude transport to a conversion facility and further pre-treatment.[40]

With the projected yields, the energy input required for cultivation and the supply of land one can calculate the energy potential. A correction is made for the yields obtainable in relation to soil quality: according to Research Station for Agriculture, the arable land of the Netherlands can be divided in two main categories with roughly two yield levels: 725 000 ha is counted as the high level, 1 280 000 ha as the lower level.[42] Bethe has analyzed the gross supply of agricultural land in terms of these two categories.[13] If relatively little land is claimed for nature development (realization of the NEN), the ratio between high and lower yield land is 1:1.4. If a large claim for nature is made the ratio shifts to 1:1.2.[40,42] It is assumed that the same ratios apply for the year 2000 and 2015 (see Table 6). The yields given will be applied at the mentioned ratios in order to calculate of the total potential energy production from energy crops.[43] This results in a potential net energy production from energy crops of 27–59 PJ/yr in 2015 and, by interpolation, 0–10 PJ/yr in 2000 from energy crops.

3.2. *Secondary biomass production and biomass residues related to land-use*

Secondary biomass production occurs during forestry, agriculture and the maintenance of nature areas and public parks. These categories will be discussed separately overleaf.

Table 6. Projected average yields for willow and miscanthus in 2000 and 2015

	Yields in oven-dry tonnes (odt) per hectare per year				
	Lower yield 2000	Higher yield 2000	Lower yield 2015[a]	Higher yield 2015[a]	Energy content (GJ/ton) (LHV)
Willow	11	13	14	16	18
Miscanthus	11	12	13	15	18

[a]The yield in 2015 is assumed to be 20% higher than in 2000 because of expected improvement in both crops and cultivation systems.[3,38,39]

Table 7. Quantities of harvestable wood in 1993 and projections for 2000 and 2015[45,47]

Year	Total surface (1000 ha)[a]	Annual growth (million m^3/yr)[b]	Non-harvestable (million m^3/yr)	Total harvest (million m^3/yr)	A + B:C-ratio[c]	Harvestable residues (million m^3/yr)
1993	335 + 112	3.3	0.8	2.5	1:2	1.7
2000	348 + 112	3.4	0.85	2.5	1:1.5	1.6
2015	385 + 112	3.6	0.9	2.7	1:1	1.4

[a]The 112 000 ha represents other plantings besides forest.
[b]1 cubic metre is equivalent to 0.53 oven-dry tonne.[46,47]
[c]A + B:C ratio expresses the ratio between timber and fiber quality wood and wood residues (thinnings), which are potentially suitable for energy production.

Waste streams, like organic domestic waste, sludges and waste wood, are not considered here since their production is independent of land-use.

3.2.1. *Forestry residues.* Forests and other plantings are maintained by thinning and pruning activities. Clearcutting produces timber. Part of the wood and twigs remain in the forest, either for recycling of minerals or for preservation.

Table 7 presents the quantities of harvestable wood in 1993 and projections for the years 2000 and 2015. The figure of 335 000–385 000 ha is mainly production forest with secondary functions. The area of 112 000 ha is other plantings, such as recreational areas outside urban zones. Production and harvestable volumes are expressed in cubic metres (one cubic metre equals about 0.53 oven dry tonne).[44] On average, the growth is 7.5 m^3/ha/yr.[44,45] As described in the forestry paper, the total forested land surface is planned to increase by 13 000 ha up to the year 2000 and by another 50 000 ha from 2000 to 2015 (see Table 4).[22] Such young forest will, however, have a lower growth rate. A rate of about 5 m^3/ha/yr is considered representative for the additional surface; we will use this value for further calculations.[46,47]

Harvestable wood is divided into three classes: A, B and C, of which A and B are high quality woods suitable for timber. C-quality wood consists mainly of thinnings and could become available for energy production. At present the ratio between A + B and C is 1:2, mainly because a large part of the forest is relatively young. This ratio is expected to change gradually to 1:1 in 2015 (and 2:1 in 2050), which will reduce the potential supply of fuel wood in the future (see Table 8).[44] The lower heating value of dry wood is about 18 GJ/dry tonne. This results in a total potential wood production for energy purposes of 16 PJ in 2000 and about 13 PJ in 2015.

3.2.2. *Nature.* The possible biomass harvest in nature reserves could consist of turf from heather covered areas, willow cuttings, reed, hay, and thinnings. So far the notion that har-

Table 8. Production and energy potential of secondary biomass yields

Function	Forestry[a]	Nature		Infrastructure	Public parks	Agriculture
Type of biomass	Thinnings/forest residues	Turf	Reed	Verge grass	Prunings	Straw
Current acreage (ha)	447 000	35 000	11 000	37 000	> 16 000	149 000
Acreage 2000 (ha)[b]	447 000–460 000	–	–	–	–	–
Acreage 2015 (ha)[b]	447 000–497 000	–	+	+	–	112 000[c]
Yield (ton d.m./ha yr^{-1})	2.0	1.4	4.5	5.1	–	3.7[e]
Present yield (ktonne d.m./yr)	900	50	44	188	250	551
Yield 2015 (ktonne d.m./yr)[b]	640–750	–	+	+	+	278
Heating value (LHV) (GJ/tonne ds)	18	16[d]	16[d]	15	18	16
Current gross energy yield (PJ/yr)	15.8	0.8	0.07	2.6	4.4	8.3
Gross energy yield 2015 (PJ/yr)[b]	11.2–13.1	–	+	+	+	4.2

[a]Forestry includes part of recreation areas and nature.
[b]' – ' implies no future projections are available; ' + ' implies an increase compared to 1990 but reliable quantification is not possible. Relatively minor contributions are expected.
[c]25% reduction in the acreage for cereals, based on the figures in Table 2.
[d]Heating value of turf and reed set equal to the heating value of straw.
[e]The mentioned yield is not the maximum straw production, but a reasonable level for removal. Part of the straw is to be left on the land to maintain the organic matter content of the soil, especially in crop rotation systems including sugar beet and potatoes which are normally applied in the Netherlands.

vested biomass could be used for energy purposes has not played any role in the maintenance of nature reserves and therefore no surplus of such biomass is actually available. Wood harvests are already included in the yields from forests and hay is used for fodder. What remains is turf and reed.

Turf is removed especially due to the desire to remove nutrients from heather. At present this biomass material is largely composted. The composition is similar to green waste from, for example, the maintenance of parks. A total annual production of 50 000 odt (oven dry tonne) from an area of 35 000 ha is reported.[48] With a lower heating value of about 15 GJ/tonne this results in an energy potential of nearly 1 PJ/yr.

The area of reed is approximately 11,000 ha; most of it located in nature areas. Reported biomass production from reed is 4–5 odt/ha/yr.[49] Part of this has a useful application, such as use for thatch. Therefore reed will not be fully available for energy production. Reed does, however, represent a (technical) potential. This potential is expected to increase in the future due to nature development. The total current supply is about 44 ktonne odt/yr, which is equivalent to about 1 PJ (heating value set equal to straw, about 16 GJ/dry tonne).

In the future, the removal of nutrients and an increasing surface of nature ares could very well lead to more harvesting of turf and reed and to increased utilization of hay and thinnings for energy purposes. The potential quantities, however, are uncertain. Therefore these options are not taken into account in our projections for the year 2015.

3.2.3. *Infrastructure*. Verges of roads and edges of waterways are maintained by regular mowing. This produces so-called verge grass. The production of verge grass and its potential availability for energy purposes has been assessed by Siemons *et al.*[50] They estimate an annual production of 470 000 tonnes wet verge grass (60% moisture content; 188 000 tonnes dry matter). This amount originates from a surface of 37 000 ha. Consequently an average annual biomass production of 5.1 odt/ha is achieved. With a lower heating value of 15 GJ/tonne this results in a supply of 3 PJ/yr.

An increase in the production of verge grass can be expected since the number of roads is increasing. This expansion, and its impact on biomass production, is, however, hard to quantify, so we will not take this aspect into account in our projections for the future.

3.2.4. *Public parks and urban areas*. Wood production from recreation areas was already included in residues from forestry. Therefore, only wood from public parks in urban areas remains. In 1989, public parks covered an area of about 16 000 ha.[37] Only overall figures with respect to wood waste from public parks are available. Of the total production of 415 000 dry tonnes, 60% consists of woody material.[46,47] This suggests a total annual yield of about 27 odt/ha and a yield of woody material of 16 odt/ha, which is obviously not correct. A possible explanation for this is that municipalities, which are mainly responsible for the maintenance of public parks, also maintain other areas that produce biomass.

The annual production of 250 000 tonnes of woody material will be taken into account here. With a lower heating value of about 18 GJ/tonne this results in an energy potential of about 5 PJ/yr. Again, an increase in biomass production can be expected because of the increasing 'built on' area in the future. Quantification is, however, difficult, so we will assume a stable supply in our projections for the future.

3.2.5. *Agriculture*. Siemons *et al.*[51] conclude that agriculture hardly produces any surplus of organic material, since most is used as fertilizer or as fodder. The one exception is straw: 550 000 tonnes were produced in 1989 from 149 000 ha.[50] This results in an average annual production of 3.7 odt/ha. With a lower heating value of about 16 GJ/odt, this results in a potential energy supply of 9 PJ/yr.

It should be noted, however, that straw production can fluctuate rather strongly from year to year. In view of the possible reduction in the acreage for agriculture, straw production is expected to drop. We assume a reduction of 25% for 2015, because the acreage of cereals is projected to decrease by a similar percentage on the basis of the potential need for cropland in 2015 (see Table 2).

3.3. *Energy potential*

The average annual secondary biomass production per hectare per type of land use is shown in Fig. 3 and is compared with energy farming. In Table 8 the results are summarized for all land-use categories discussed. For some categories, the future production is unknown. In Table 8 the symbol (+) indicates an

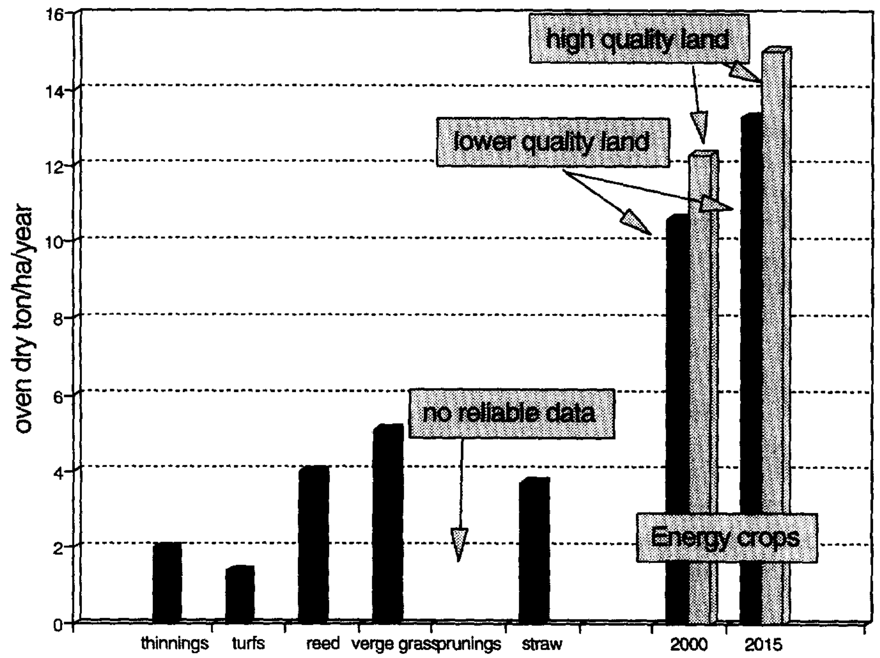

Fig. 3. Average biomass production per hectare for both secondary biomass production and energy farming.

expected increase, but no available data. The summation of the energy potentials therefore includes only the available quantitative estimates.

The current potential gross energy yield of the above-mentioned sources is about 34 PJ/yr, with thinnings (16 PJ/yr) and straw (9 PJ/yr) as main contributors. The total potential is expected to drop to about 28 PJ in 2015 because of a declining acreage of cereal production (which reduces the supply of straw) and a reduced supply of forestry residues due to aging of the forest. Thinnings from commercial forestry, wood from maintenance activities of public parks and straw remain the most important contributors to the potential of secondary biomass production. The harvesting and utilization of biomass from nature areas could possibly be developed further.

The energy potential of both energy farming and secondary biomass production are summarized in Fig. 4. The figure indicated that in theory in the year 2000 a total of 34–44 PJ could be available and in the year 2015, in total, 54–88 PJ. (TERESII, The European Renewable Energy Study—1995, mentions that in the year 2010 the energy potential from energy crops in the Netherlands could amount to over 50 PJ, and for forest residues this could be about 30 PJ.[53])

The total energy demand of the Netherlands is expected to be 2900 PJ in the year 2000 and may be 3500 PJ in 2015.[52] The potential contribution of indigenously produced biomass to the Dutch energy system will therefore be approximately 1–1.5% in 2000 and about 1.5–2.5% in 2015.

Note that biomass wastes, such as waste wood, organic domestic waste, sludge, wastes from food and beverage industry, are not included in these projections. These biomass wastes could contribute about another 50 PJ (LHV).[10]

4. DISCUSSION AND CONCLUDING REMARKS

Claims on and supply of agricultural land in the Netherlands are analyzed on the basis of policy memoranda and various studies. Future land claims are expected to come mainly from extending forestry, nature and urban areas. Those total non-agricultural land claims amount to 25 000–78 000 ha in 2000 and 59 000–192 000 ha in 2015. The range is due to the distinction between 'hard' claims (for urban development, infrastructure and indus-

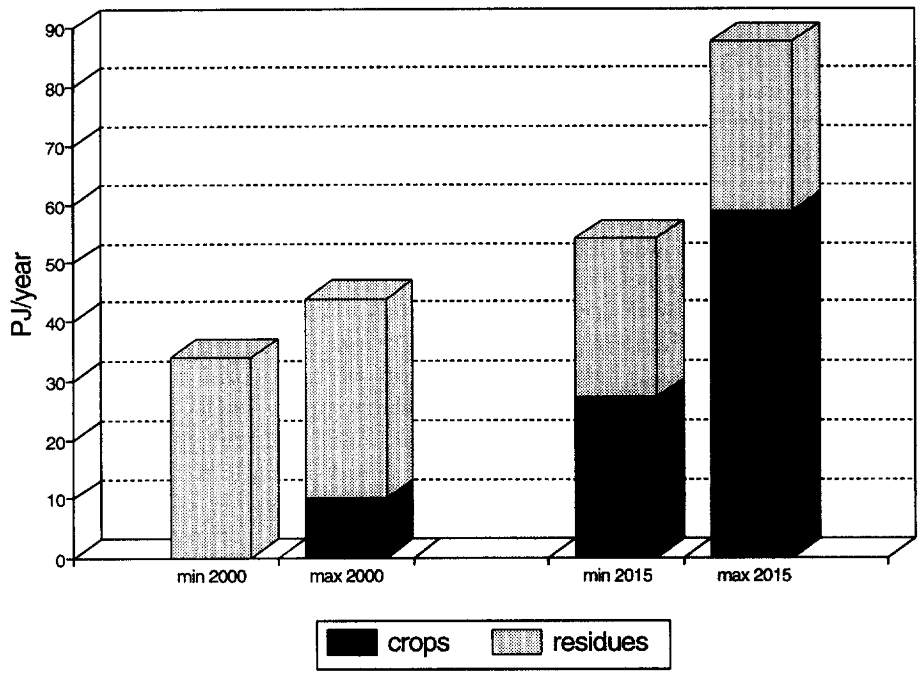

Fig. 4. Potential energy supply from biomass from both energy farming and secondary production in the Netherlands in the years 2000 and 2015.

try) and 'soft' claims (for purposes such as nature development and forestry).

The supply of agricultural land determines the potential availability of land for growing alternative crops such as energy crops. Various studies and analyses forecast a decreasing number of farms and high mobility of agricultural land. However, the growth of new alternative (and profitable) crops is not considered in these studies. We estimated the potential future surplus of agricultural land on the basis of potential increments in productivity of various agricultural sectors and on the assumption that the demand for food production per inhabitant in the Netherlands will remain stable. This resulted in a net supply of land (including both agricultural and non-agricultural claims) of 0–50 000 ha in 2000 and 110 000 and 250 000 ha in 2015. However, it is not known to what extent opposing trends, such as a shift to less intensive production methods in the agricultural sector, might increase the demand for land to produce food and fibre. Shifts to higher value products and further extensifying of agriculture might result in a reduced supply of agricultural land. Theoretically, this could reduce the land available for energy crops to fallow land, which fluctuates from year to year depending on European agricultural policy. Dominant for the developments in agriculture are a number of supra-national factors, such as the European agricultural policy, further liberalization of the world market for agricultural products and rationalization of the agricultural production in, for example, Eastern Europe.[5] The global demand for food will be a main factor in the way agriculture will develop. Visions differ in this respect between large potential surpluses of food production[54,55] and a development in which non-sustainable agricultural practices may result in an inadequate supply of food, as described by the World Watch Institute.[56,57]

Currently, in the Dutch context, biomass produced via energy farming is considerably more expensive than fossil fuels because of the relatively high cost of land and relatively high income of farmers.[58] Therefore, energy farming is not an attractive option for farmers. On the other hand, the national energy and environmental policy hopes to achieve a larger contribution of renewables to the Dutch energy system, particularly in order to reduce the emission of greenhouse gases. This policy is the basis for incentives (such as the taxing of fossil fuels and support of renewable energy) and could be a major incentive for the cultivation of energy crops, also in the Dutch context. It would be interesting to study the competitiveness of energy crops in the economic scenarios that the Agricultural Economics Institute (LEI) uses to calculate the regional balances in land use.[15] The development of new economically viable crops, which could be energy crops, may well prove to be a special factor influencing the way agriculture will proceed. Further development and support of energy crops, especially if driven by a policy that aims to diversify the energy supply and reduce CO_2 emissions, could make energy crops so attractive that they might counteract extensification of agriculture. The (indirect) environmental and economic effects that this could have need to be evaluated before we can judge whether or not such a situation is desirable.

If land is used for energy crops such as miscanthus and short rotation coppice, it could theoretically contribute 0–10 PJ in 2000 and 27–59 PJ in 2015. Secondary yields of biomass, such as that from forest and public parks, are substantial, also when expressed in yields per hectare, and can contribute a further 34 PJ in 2000, decreasing to approximately 28 PJ in 2015. Further research into the possibilities and limitations of increasing biomass harvest from recreational areas belonging to the National Ecological Network (NEN) is desirable. The production of extensively managed energy crops in buffer zones which are part of the NEN could be important. The potential and the effects of biomass harvest from nature areas should be investigated further, since the acreage concerned is substantial.

In the year 2000, the total potential contribution of both energy crops and secondary biomass yields can theoretically contribute approximately 1–1.5% to the expected primary energy demand. In 2015, this contribution can be 1.5–2.5%; this percentage takes the expected growth in energy consumption into account.

Although modest in terms of total potential contribution to the energy supply, the absolute amount of energy produced would be significant. The third energy memorandum of the Ministry of Economic Affairs, published in 1995, projected that renewables would contribute 10% of the primary energy supply of the Netherlands in 2020, which is equivalent to 270 PJ in 2020. Biomass and waste (including municipal solid waste) should contribute 120 PJ. In this projection the import of biomass from other countries is considered to be the main source.[59] However, as shown in this study, indigenous biomass production might be able to supply 50–90 PJ/yr, and in addition 50 PJ/yr could be obtained from biomass wastes. Uncertainties remain: the estimated potential depends on further productivity increments in agriculture. A shift to less intensive agricultural production or increased exports could increase the demand for agricultural land. On the other hand, further liberalization of the world market for agricultural products (most likely leading to lower price levels) and rationalization of agriculture in, for example, Eastern Europe, may result in increased availability of land that can be used for alternative crops like energy crops. Technically, the introduction of a significant amount of energy farming in the Netherlands seems possible, without leading to conflicts with other claims for agricultural land. The main bottleneck in this respect is whether energy farming will be economically attractive for farmers.

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