

# Future demand for fertilizer from bioenergy crop production

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## Abstract

In this study an assessment is made of the future demand of fertilizers from bioenergy crop production. A representative sample of various assessments on the contribution of bioenergy is derived from literature. The projections are translated into fertilizer demand, assuming that all bioenergy is produced from dedicated woody bioenergy crops. The amount of nutrients in the harvested biomass is used as a proxy for the fertilizer demand. Results indicate that the global demand for fertilizer for bioenergy crop production is limited to 1% to 8% in 2015 and 2% to 16% in 2030 of the total global demand for fertilizers for agriculture (excluding bioenergy crop production), equal to 1 Mt, 12 Mt, 4 Mt and 26 Mt, respectively (sum of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O). Particularly during the second quarter of the 21st century the production of bioenergy crops could increase rapidly, which could result in a fertilizer demand (sum of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) of 16 Mt to 63 Mt in 2050. The technical potential for bioenergy crop production are however much larger, comparable to a technical fertilizer demand in 2050 of 108 Mt to 640 Mt.

## Introduction

Biomass has the potential to provide a renewable (green or CO<sub>2</sub> neutral) energy source, locally and readily available in large parts of the world. Modern biomass (i.e. the use of biomass for electricity generation and the production of modern fuels), from now on also referred to as bioenergy, contributes ca. 7 EJy<sup>-1</sup> (Turkenburg 2000). Estimates in literature of the future contribution from bioenergy in 2050 range between 0 to 1135 EJy<sup>-1</sup> (Hoogwijk *et al.* 2002). The largest potential comes from bioenergy crops: 0 to 1098 EJy<sup>-1</sup> (Lashof *et al.* 1990; Hall *et al.* 1993; Sorensen 1999; Fisher *et al.* 2001; Hoogwijk 2004). Other sources are residues and waste. For comparison: the global primary energy consumption in 2000 was 446 EJ (IEA 2003). In terms of land use, the 0 to 1098 EJy<sup>-1</sup> equal an area of 3.2 Gha. For comparison: the global agricultural land use is 5.0 Gha (FAO 2003).

The (potentially large) increase in the production of bioenergy crops production of dedicated bioenergy crops could have an (potentially large) impact on land use patterns and the agricultural sector in general, including the demand for fertilizers.

## Objective

The objective of this study is to calculate the future demand for fertilizers resulting from bio-energy crop production in the coming decades.

## Approach

Projections on the future contribution from bioenergy are taken to estimate the production of bioenergy crops in the coming decades. The production of bioenergy is translated into a production of biomass from dedicated bioenergy crops and into a demand for fertilizers.

## Methodology

Figure 1 shows an overview of projections on the future use of bioenergy to 2100 from 17 studies (Berndes *et al.* 2003). The projections differ from ca. 50 EJ/y to more than 400 EJ/y in 2050. This large range is a result of:

- Differences in scope. E.g. 14 of the 17 studies are either demand driven (focussing on the demand for bioenergy) or supply driven (focussing on the sources of bioenergy) and consequently ignore demand-supply interactions.
- Differences in assumptions on the complex interacting demographic, techno-economic, socio-cultural and political forces, which are poorly understood and difficult to model (Döös and Shaw 1999).

In this study, we include four studies for which data were readily available and that vary in scope and with respect to the assumptions on the forces that determine the bioenergy production potential and that include the range in projections found by Berndes et al. (2003).

Two studies focus on the implementation potential of bioenergy, i.e. the projected potential of bioenergy that realistically can be produced, including various economic and institution barriers.

- Global Energy Perspectives (1998), from now on referred to as WEC (WEC 1998). In this study the contribution of bioenergy is calculated based on various scenarios that vary on assumptions that determine the bioenergy production potential, e.g. population growth, environmental taxes, economic growth.
- SRES scenario analysis (2001), from now on referred to as IMAGE (IMAGE-team 2001). A similar approach is used as in WEC, but different scenarios are included following Special Report on Emissions Scenarios (SRES) published by the Intergovernmental Panel on Climate Change (IPCC).

Two studies focus on the technical potential of bioenergy production, i.e. the upper limit of biomass production that can be produced under certain conditions, but excluding various economic and institutional barriers.

- Potential of bioenergy production under four land use scenarios (2004), from now on referred to as HOOGWIJK (Hoogwijk *et al.* 2004). In this study the amount of land available for bioenergy crop production and the bioenergy production potential from these areas is calculated. The area land available for bioenergy crop production is limited to land not needed for food production, which is the sum of abandoned agricultural land and various types of low productive land. The calculation of the area surplus land follows the scenario approach used in IMAGE. The calculation of the bioenergy production potential on these surplus areas is based on the technical potential.
- Quickscan of bioenergy production potentials (2005), from now on referred to as SMEETS (Smeets *et al.* 2005a, b). In this study, the amount of land available for bioenergy crop production and the bioenergy production potential from these areas in 2050 is calculated. The area land available for bioenergy crop production is limited to land not needed for food production. Various levels of agricultural production efficiency are included that vary with respect to the (technical) potential to generate surplus land. In addition, the technical potential for bioenergy crop production on these surplus areas is calculated.

The four scenarios also represent the range in projections found in literature: from 52 EJ/y to 211 EJ/y in 2050 for the studies that focus on the implementation potential to 215 EJ/y to 1272 EJ/y for the studies that focus on the technical potential, see figure 1. The use of bioenergy in 2000 is set at 0, to avoid inconsistencies in base year data.

All data derived from the various studies are given in Joule (J) and converted into metric ton (t) based on a higher heating value of 19 GJ/t.

No information was available on the contribution of the various sources of biomass for energy use, such as bioenergy crops, agricultural and forestry residues and wastes. However, the largest potential comes from bioenergy crops, so we assume that the total bioenergy potential originates from bioenergy crops. Although various crops are in theory suitable as a bioenergy crop: cereals, sugar crops, oil crops, grasses (e.g. miscanthus, reed canary grass) and woody crops (e.g. poplar, willow and eucalyptus), grasses and woody crops have the best environmental end economic performance compared to other crops and are also versatile, i.e. the biomass can be converted into various liquid and solid types of (bio)energy carriers. Therefore, we assume that all bioenergy is produced from woody bioenergy crops, as also most existing studies do (including IMAGE, HOOGWIJK and SMEETS).

The fertilizer requirement is calculated based on the average nutrient content of the harvested biomass. The reason is that this avoids that soils become nutrient depleted. The average nutrient content of poplar and eucalyptus is included for all regions, which is estimated at 5.2 kg N per ton dry weight biomass, 0.5 kg P per ton dry weight biomass and 2.7 kg K per ton dry weight biomass Lodhiyal and Lodhiyal in (Jorgensen *et al.* 2001).

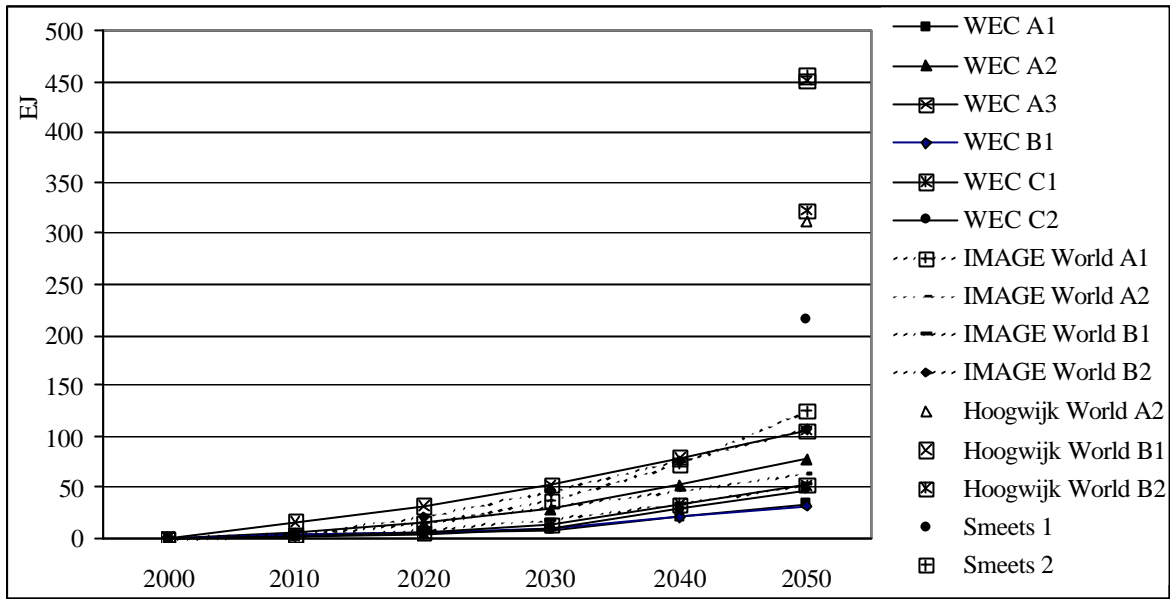


Figure 1. Increase in bioenergy supply from 2000 to 2050 projected by the four studies included (the two highest technical potentials projected by SMEETS of 1101 EJ/y and 1272 EJ/y in 2050 and the highest potential projected by HOOGWIKJ of 657 EJ/y in 2050 are excluded from figure 1).

### Results

Figure 2 shows the demand for fertilizers (N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) in the coming decades including projections of the demand for fertilizers from agriculture (excluding bioenergy crop production) by the Food Agricultural Organisation (FAO 2000). The demand for fertilizers from bioenergy crop production in 2000 is set at 0, to avoid inconsistencies in base year data.

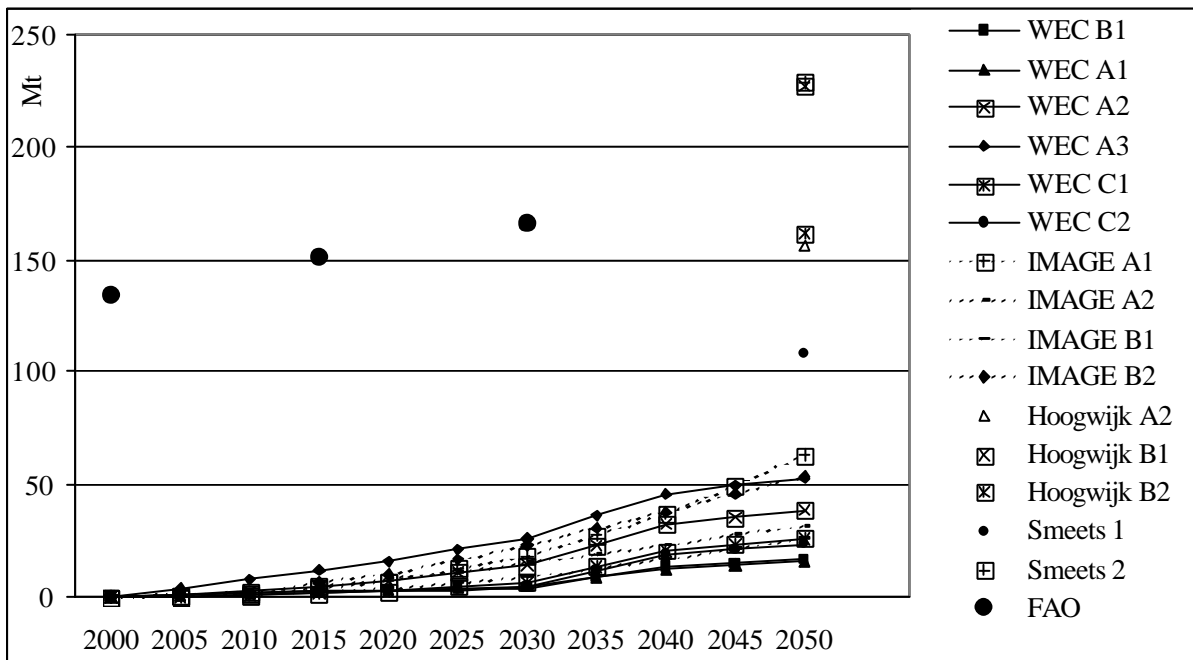


Figure 2. Increase in demand for fertilizers (N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) for bioenergy crop production between 2000 to 2050 in mega (million) tons (Mt) (the two highest technical potentials projected by SMEETS of 554 Mt/y and 640 Mt/y in 2050 and the highest potential projected by HOOGWIKJ of 330 Mt/y in 2050 are excluded from figure 2).

The results indicate that during the coming 5 to 10 year the demand for fertilizers from bioenergy crop production is limited to 24 Mt in 2015, but that during the second quarter of the 21st century and later on the demand could increase rapidly, up to 63 Mt in 2050. The technical potentials of bioenergy crop production equal a demand for fertilizers of 108 Mt/y to 640 Mt/y in 2050, dependent on the type of potential.

Table 1 shows the demand for fertilizers for bioenergy crop production as a percentage of the demand for fertilizers for agriculture (excluding bioenergy crop production) in 2015 and 2030.

Table 1. Demand for fertilizer from bioenergy crop production according to various scenarios as percentage of the demand for fertilizers for agriculture (excluding bioenergy crop production) in 2015 and 2030.

Source	Scenario	2015	2030
WEC	B1	1	2
WEC	A1	2	3
WEC	A2	3	8
WEC	A3	8	16
WEC	C1	1	4
WEC	C2	1	3
IMAGE	A1	3	11
IMAGE	A2	3	9
IMAGE	B1	2	5
IMAGE	B2	4	14

The data in table 1 indicate that there is a large uncertainty with respect to the projected demand for fertilizers in the coming decades, particularly on the longer term. The short-term demand (to 2015) for fertilizers seems limited to some 4% of the demand for fertilizers for conventional agriculture in 2015. The long-term demand (2015 and onwards) for fertilizers seems much higher due to the continued increase in bioenergy crop production, up to 16% of the demand for fertilizers for conventional agriculture in 2030.

Results are presented here at a global level, but are also available at a regional level. An Excel file with detailed regional projections can be downloaded from the International Energy Agency Task 40 'Sustainable International Bio-energy Trade' website [www.fairbiotrade.org](http://www.fairbiotrade.org).

## Discussion and conclusion

In this study, the demand for fertilizers for bioenergy crop production to 2050 is analysed. The indirect impact of bioenergy crop production on the demand for fertilizers is potentially much larger. The production of dedicated bioenergy crops is not allowed to compete with food production or result in further deforestation. Consequently, increases in the efficiency of food production are required to generate surplus agricultural land for bioenergy crop production. The potential to increase the efficiency of food production e.g. by (an increase of) the application of irrigation and by (an increase of) the application of fertilizers is considerable, as SMEETS has shown. Further research on the indirect impact of bioenergy crop production is required to analyse this impact.

## References

- Berndes, G., M. Hoogwijk and R. Van den Broek (2003). "The contribution of biomass in the future global energy supply: a review of 17 studies." *Biomass and Bioenergy* 25(1): 1-28.
- FAO (2000). Fertilizer requirements in 2015 and 2030. Food Agricultural Organisation. Rome, Italy
- FAO (2003). FAO Stat Database - Agricultural Data. <http://apps.fao.org/page/collections>., Food Agricultural Organisation. Rome, Italy.
- Fisher, G. and L. Schrattenholzer (2001). "Global bioenergy potentials through 2050." *Biomass and bioenergy* 20: 151-159.
- Hall, D. O., F. Rosillo-Calle, R. J. Williams and J. Woods (1993). Biomass for Energy: Supply prospects. *Renewable Energy: Sources for Fuels and Electricity*. T. B. Johansson, H. Kelly, A. K. N. Reddy and R. H. Williams. Washington D.C., Island Press: 593-651.
- Hoogwijk, M. (2004). On the global and regional potential of renewable energy sources. PhD thesis. Utrecht University. Utrecht, the Netherlands

- Hoogwijk, M., A. Faaij, B. De Vries and W. Turkenburg (2004). "Potential of biomass energy under four land use scenarios. Exploration of regional and global cost supply curves." *Global Environmental Change* (submitted).
- Hoogwijk, M., A. Faaij, R. Van den Broek, G. Berndes, D. Gielen and W. Turkenburg (2002). "Exploration of the ranges of the global potential of biomass for energy." *Biomass and Bioenergy* 25(2): 119-133.
- IEA (2003). *Key world energy statistics 2003*. International Energy Agency, Energy Statistics Division. Paris, France
- IMAGE-team (2001). *The IMAGE 2.2 implementation of the SRES scenarios: a comprehensive analysis of emissions, climate change and impacts in the 21st century*. National Institute for Public Health and the Environment. Bilthoven, The Netherlands
- Jorgensen, U. and K. Schelde (2001). *Energy crop water and nutrient use efficiency*. Prepared for the International Energy Agency Bioenergy Task 17 Short Rotation Crops. Danish Institute of Agricultural Sciences, Tjele, Denmark
- Lashof, D. A. and D. A. Tirpak (1990). *Policy options for stabilizing global climate*. United States Environmental Protection Agency. Hemisphere Publishing Corporation, New York, Washington, Philadelphia, U.S.A. London, U.K.
- Smeets, E., A. Faaij and I. Lewandowski (2005a). "A quickscan of global bioenergy potentials to 2050. Part A: review of existing data and studies and the development of a bottom-up methodology." in preparation.
- Smeets, E., A. Faaij and I. Lewandowski (2005b). "A quickscan of global bioenergy potentials to 2050. Part B: regional bioenergy potential and an assessment of underlying variables." in preparation.
- Sorensen, B. (1999). *Long-term scenarios for global energy demand and supply: Four global greenhouse mitigation scenarios*. Energy & Environment Group, Roskilde University. Roskilde
- Turkenburg, W. C. (2000). *Renewable energy technologies*. World Energy Assessment. J. Goldemberg. Washington, D.C., U.S.A., UNPD: 220-72.
- WEC (1998). *Global Energy Perspectives database*. Accessible via [http://www.iiasa.ac.at/cgi-bin/ecs/book\\_dyn/bookcnt.py](http://www.iiasa.ac.at/cgi-bin/ecs/book_dyn/bookcnt.py), UN World Energy Council. 2003.