The contribution of biomass in the future global energy supply: a review of 17 studies

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요약

본 논문은 미래 전세계 에너지 공급에 있어서 바이오매스의 기여도에 대해 토의한것이다. 토론은 17개의 선행 연구에 기초를 두고 있다. 이들 연구들은 미래의 전세계 에너지 공급에 있어서 가능한 바이오매스 기여도에 대하여 아주 다양한 결론을 도출했다. 예를 들면 2050 년에 100 EJ/yr 미만에서 400 EJ/yr 이상까지 이다. 이러한 차이에 대한 주요한 이유는 두 가지의 결정적인 인자-에너지 곡물 생산에 대한 토지의 이용가능성과 수율 정도-가 매우 불확실하고 매우 다양한 조건들에 관련되어 있기 때문이다. 또한 미래 산림, 농임산물의 부산물들의 이용가능성에 대한 예측도 연구에 따라 다양하였다.

얼마나 바이오에너지 분야가 팽창하고 있는가에 대한 질문은 토지의 다른 이용-식품 생산, biodiversity, 토양과 자연의 보존-, 그리고 carbon sequestration 등과 상호 연관이 있다. 그러나 이들 질문은 본 연구에서 충분히 분석되지 못하였다. 따라서 바이오에너지가 에너지 분야에서 기후 변화 저감에 어느 정도 유용한 것인가는 확립하기 어려웠다. 다른 사용들과 바이오에너지 간의 상호작용에 대해 잘 정돈된 모델링이 대규모 바이오에너지의 전망에 대해서 이해를 향상시켰다.

- Overview of the reviewed studies

Table 1
The studies included in this review

	Main reference[a]
WEC[b]	WEC, New Renewable Energy Resources: World Energy Council. Kogan Page Ltd., 1994.
IIASA-WEC[c]	Nakicenovic, N., A. Grübler, and A. McDonald, Global energy perspectives: International Institute for Applied Systems Analysis/World Energy Council. Cambridge University Press, 1998.
FFES	Lazarus, M., L. Greber, J. Hall, C. Bartels, S. Bernow, E. Hansen, P. Raskin, and D. von Hippel, Towards a Fossil Free Energy Future. 1993, Stockholm Environmental Institute - Boston Center: Boston.
EDMONDS	Edmonds, J.A., M.A. Wise, R.D. Sands, R.A. Brown, and H. Kheshgi, Agriculture, land use, and commercial biomass energy: A preliminary integrated analysis of the potential role of biomass energy for reducing future greenhouse related emissions. 1996, Pacific Northwest National Laboratory.
SWISHER	Swisher, J. and D. Wilson, Renewable energy potentials. Energy, 18(5), 437–459. (1993).
USEPA	Lashof, D.A. and D.A. Tirpak, eds. Policy options for stabilizing global climate. 1990, Hemisphere Publishing Corporation: New York, Washington, Philadelphia, London.
SØRENSEN	SØrensen, B., Long-term scenarios for global energy demand and supply: Four global greenhouse mitigation scenarios. 1999, Roskilde University, Institute 2, Energy & Environment Group, Denmark.
HALL	Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods, Biomass for Energy: Supply Prospects, In: T.B. Johansson, et al., Editors. Renewable Energy: Sources for Fuels and Electricity, Washington, D.C.: Island Press, 1993 p. 593–651.
RIGES	Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams, A renewables-intensive global energy scenario (appendix to Chapter 1), In: T.B. Johansson, et al., Editors. Renewable Energy: Sources for Fuels and Electricity, Washington, D.C.: Island Press, 1993 p. 1071–1143.
LESS/BI	Williams, R.H., Variants of a low CO2-emitting energy supply system (LESS) for the world: Prepared for the IPCC Second Assessment Report Working Group IIa, Energy Supply Mitigation Options. 1995, Pacific Northwest Laboratories.
LESS/IMAGE	Leemans, R., A. van Amstel, C. Battjes, E. Kreileman, and S. Toet, The land cover and carbon cycle consequences of large-scale utilizations of biomass as an energy source. Global Environmental Change, 6(4), 335–357. (1996).
BATTJES	Battjes, J.J., Global options for biofuels from plantations according to IMAGE simulations. 1994, Interfacultaire Vakgroep Energie en Milieukunde (IVEM), Rijksuniversiteit Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands.
GLUE	Yamamoto, H., K. Yamaji, and J. Fujino, Evaluation of bioenergy resources with a global land use and energy model formulated with SD technique. Applied Energy, 63, 101–113. (1999).
FISCHER	Fischer, G. and L. Schrattenholzer, Global bioenergy potentials through 2050. Biomass and Bioenergy, 2001. 20: p. 151–159.
DESSUS	Dessus, B., B. Devin, and F. Pharabed, World Potential of Renewable Energies: Actually Accessible in the Nineties and Environmental Impact Analysis. 1992, la Huille Blanche No. 1, Paris.
SHELL	Shell International, The evolution of the world's energy system 1860–2060. 1995, Shell Center: London, U.K.
SRES/IMAGE[d]	IPCC, Special report on emission scenarios. Cambridge: Intergovernmental Panel on Climate Change. Cambridge University Press, 2000.

[a][47] is complementary to GLUE. [48] is complementary to SRES/IMAGE.

[b]WEC explores two scenarios: "Current Policies" and "Ecologically Driven" (ED). Only ED is included in this review.

[c]Six scenarios. A (3 scenarios): extensive technological improvements and high economic growth. B: less ambitious technological improvements, more intermediate economic growth. C (2 scenarios): an ecologically driven future. Substantial technological progress, international cooperation centered explicitly on environmental protection and international equity.

[d]Two IMAGE 2 simulations from the IPCC SRES scenarios were included since they were accessible within deadlines for reports that are the bases for this paper.

bioenergy demand. For example, solar and wind energy systems account for a rapidly increasing share of primary energy supply from 2030 up to 2100 in the FFES study. This relieves the demand for other non-fossil, non-nuclear primary energy supply such as bioenergy. The two ecologically driven C scenarios in the IIASA-WEC study explore widely different paths for nuclear power—and consequently different demand for other primary energy sources such as bioenergy.

Table 2
Approach, time-frame, and geographic aggregation used in the reviewed studies

	Approach	Time-frame	Geographic aggregation	Resource focused	Demand driven
WEC	Expert Judgment and per capita forecasting based on present consumption	1990–2020	9 regions		x
IIASA-WEC	Energy Economy model, six scenarios	1990–2100	11 regions		x
FFES	Energy Economy model based on Edmonds and Reilly, IPCC-based scenario with focus on fossil free energy system in 2100. Nuclear phased out by 2010	1988–2100	10 regions		x
EDMONDS	Integrated land use/energy-economy model (Edmonds and Reilly), IPCC based scenario	1995–2095	11 regions		x
SWISHER	Literature-based bottom-up calculation. Based on DESSUS and data from Hall who authored HALL	2030	20 regions	x	
USEPA	Non-integrated land use/energy-economy model based on Edmonds-Reilly	1985–2100	6 regions	x[a]	x
SØRENSEN	Bottom-up maximum limit calculation, energy-economy model	2050		x[a]	x
HALL	Literature based bottom-up calculation +expert judgment	1990	10 regions	x	
RIGES	Bottom-up energy supply construction. Biomass part based on HALL. Energy demand from somewhat adjusted high growth variant of IPCC Accelerated Policies Scenario	1985–2050	11 regions	x[a]	x
LESS/BI	Scenario extension of RIGES, using updated oil and gas resource estimates and including CO_2 sequestration	1990–2100	11 regions	x[a]	x
LESS/IMAGE	Integrated land use/energy-economy model. Energy demand from LESS/BI	1990–2100	13 regions		x
BATTJES	Integrated land use/energy-economy model + expert judgment	2050	13 regions	x	
GLUE	Land use/energy-economy model based on Edmonds-Reilly. Further bottom-up calculation of resources	1990–2100	10 regions	x	
FISCHER	Bottom-up calculation by using land use model of IIASA, with complementary data from DESSUS	1990–2050	11 regions	x	
DESSUS	Literature-based bottom-up calculation +expert judgment	1990–2020	22 regions	x	
SHELL	Not documented	2060	world		
SRES/IMAGE	Integrated land use/energy-economy model, IPCC scenario	1970–2100	13 regions		x

[a]These studies have an upper limit of biomass energy availability for their demand driven scenario, based on a resource assessment.

Resource-focused assessments took the form of inventories of potential bioenergy sources, with an evaluation of possibilities to utilize the sources for energy purposes. Food and material demand, and land-use efficiency in agriculture and forestry, determine land requirements for food and materials production—and hence availability of land for other purposes, such as energy crop production. The food and material demand and technologies for harvesting and processing biomass into

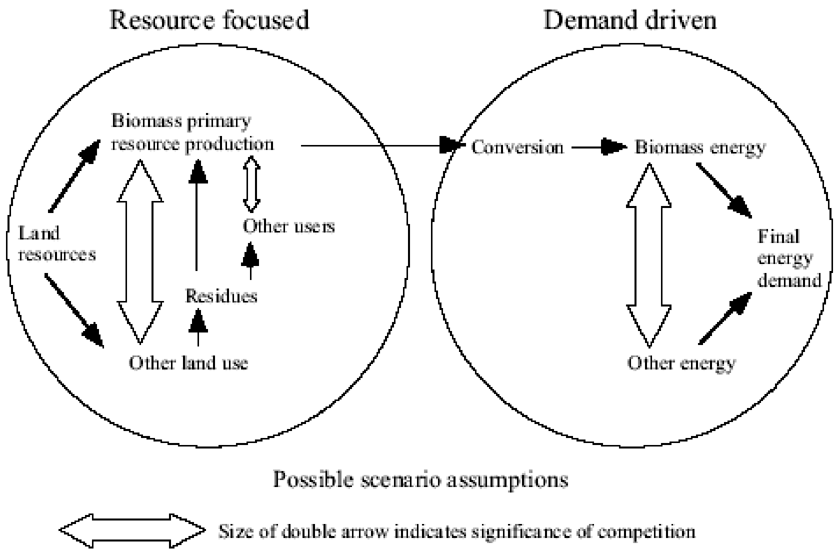

Fig. 1. The classification used in this paper. See text for a characterization of demand-driven and resource-focused studies.

- Global and regional bioenergy potentials: results of the studies

Global bioenergy supply, and relative importance of biomass in the future global primary energy supply

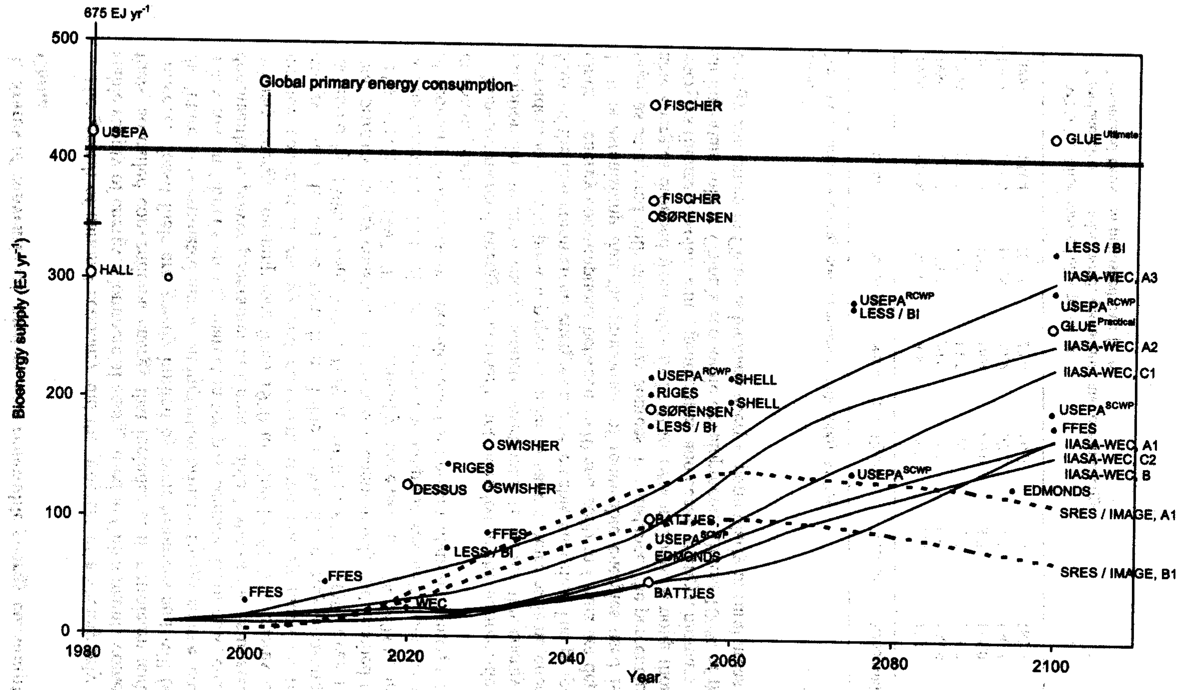

Fig. 2. Potential biomass supply for energy over time. Resource-focused studies are represented by hollow circles and demand-driven studies are represented by filled circles. USEPA and HALL, who do not refer to any specific time, are placed at the left side of the diagram. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines respectively, with scenario variant names given without brackets at the right end of each line. The present approximate global primary energy consumption is included for comparison. (The global consumption of oil, natural gas, coal, nuclear energy and hydro electricity 1999–2000 was about 365 EJ yr^{-1} [43]. Global biomass consumption for energy is estimated at 35–55 EJ yr^{-1} [44–46].)

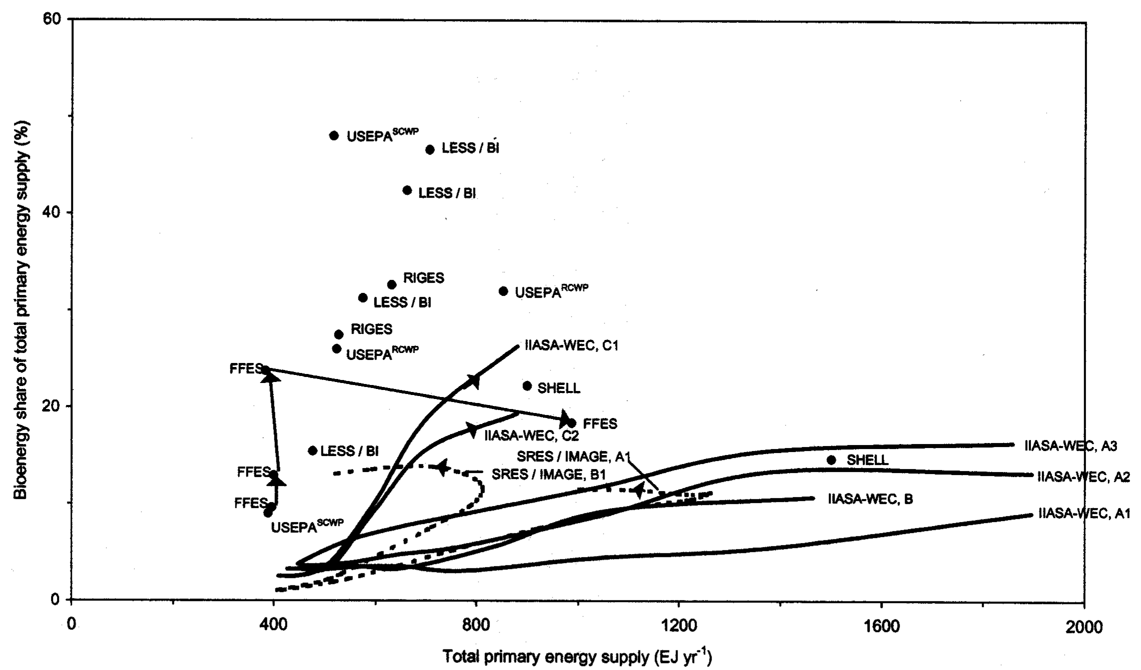

Fig. 3. Total primary energy supply, and share provided from biomass in demand-driven studies. Where no indication of development is made for a particular study, the changes over time are towards increasing total primary energy supply and bioenergy share. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines, respectively, with scenario variant names given without brackets at the right end of each line.

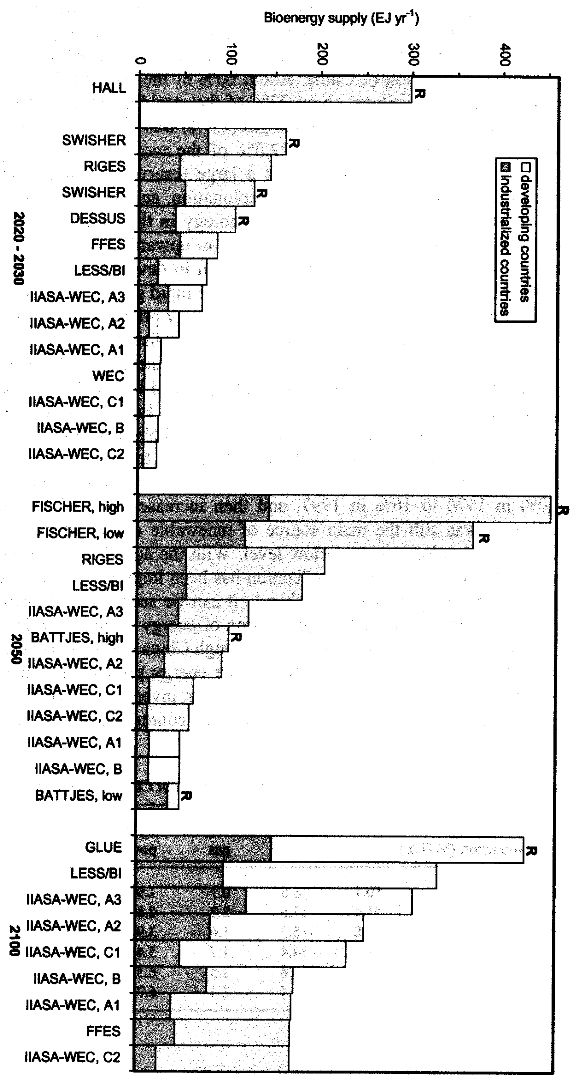

Fig. 4. Contribution of industrialized and developing regions to total bioenergy supply. Studies that are characterized as resource-focused are indicated with R. HALL does not refer to any specific time period. EDMONDS, USEPA and SHELL are not included since they only report results on the global level.

Contribution of specific biomass source to the total bioenergy supply

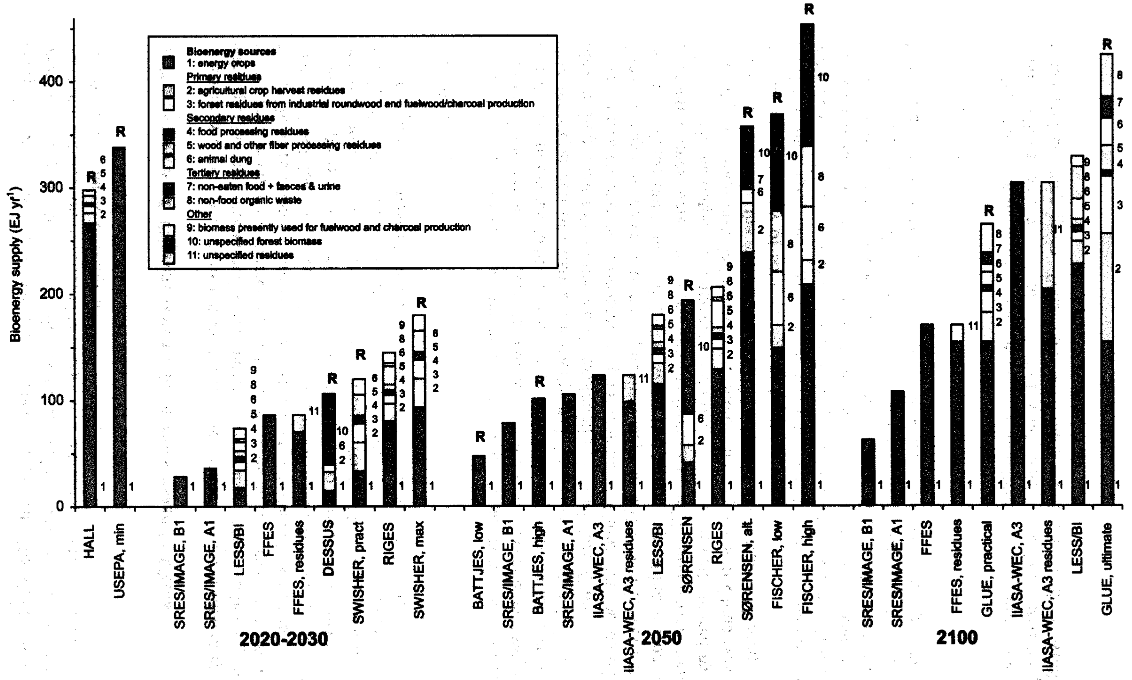

Fig. 5. The contribution of specific sources to the total bioenergy supply. The number sequence to the right of the bars corresponds to the sequence of bioenergy sources in each bar. Studies that are characterized as resource-focused are indicated with R. The IIASA-WEC study is represented by the bioenergy-intensive A3 variant. The non-specified residue potential in SWISHER is distributed between residue categories 2–6 according to HALL, since SWISHER use data from David Hall who also produced the HALL estimate.

-Discussion of approaches and results in the studies
Biomass plantations

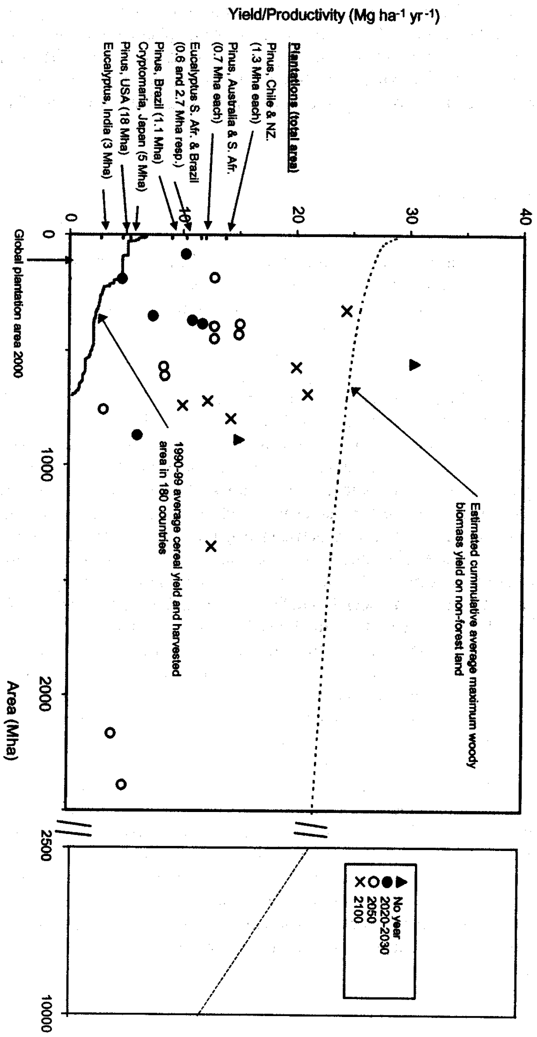

Fig. 6. Land use and yield levels in future energy crops production. Dots represent suggested plantation area and average yield levels in the studies. Lines represent suggested maximum woody biomass yield on non-forest land, and harvested area and yields in global cereal production. The global tree plantation area in 2000 is indicated on the X-axis. The average yield levels for Pinus and Eucalyptus plantations in selected countries are indicated along the Y-axis. The specific yields and plantation areas used are given for each study in Appendix A.

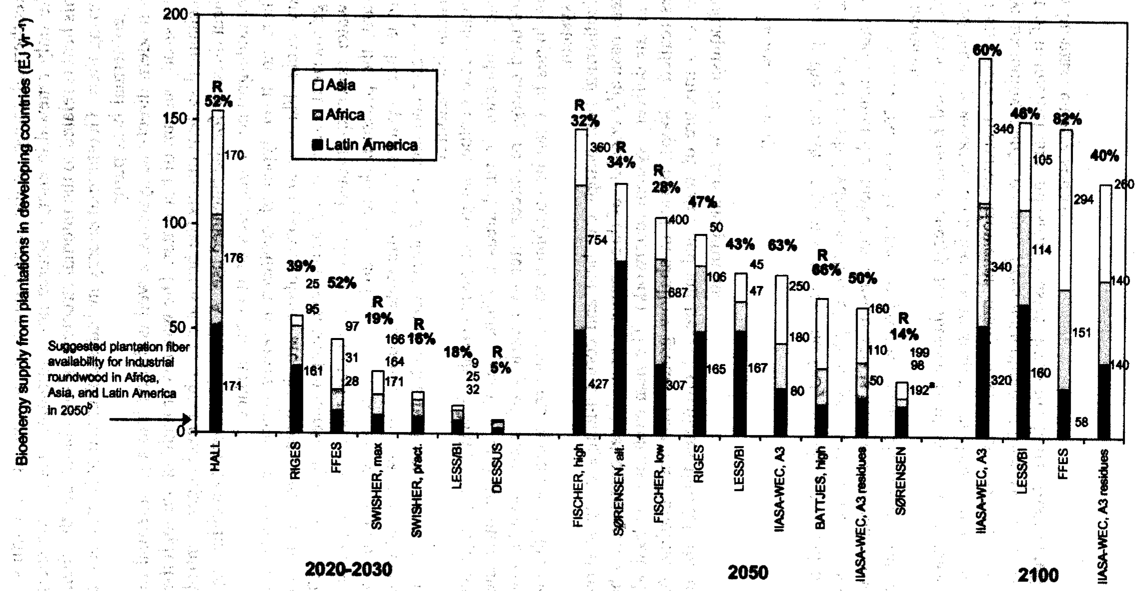

Fig. 7. The production of plantation biomass for energy in developing countries. Studies that are characterized as resource-focused are indicated with R. The percentage data above bars refer to the contribution of the plantations to the total global bioenergy supply. The numbers at the right side of bars are the plantation areas in respective region. Latin America and SE Asia "Tigers" are grouped together in SØRENSEN.

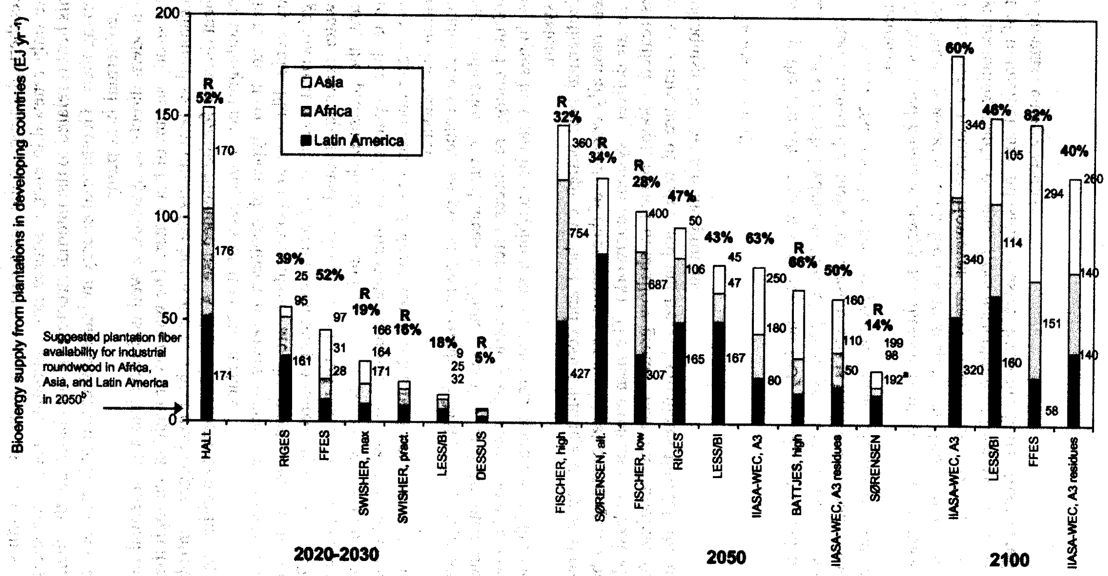

Fig. 7. The production of plantation biomass for energy in developing countries. Studies that are characterized as resource-focused are indicated with R. The percentage data above bars refer to the contribution of the plantations to the total global bioenergy supply. The numbers at the right side of bars are the plantation areas in respective region. Latin America and SE Asia "Tigers" are grouped together in SØRENSEN.

Residue generation and recoverability

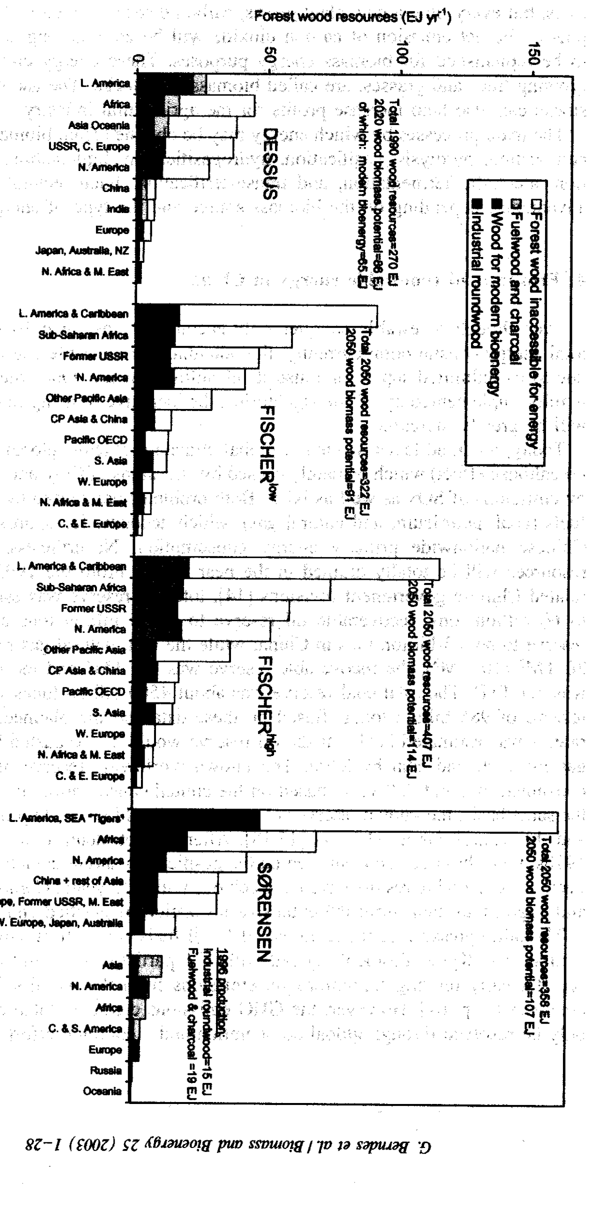

Fig. 8. The estimated bioenergy potential of forest wood. Note that the three studies use different geographic aggregation.

Interactions with other biomass and land uses
IMAGE 2 model 사용.