Internationale Konferenz
für Erneuerbare Energien, Bonn
International Conference
for Renewable Energies, Bonn

The Potentials of Renewable Energy[1]

Thematic Background Paper

January 2004

Authors:

Thomas B Johansson
International Institute for Industrial Environmental Economics, Lund University, Lund, Sweden

Kes McCormick
International Institute for Industrial Environmental Economics, Lund University, Lund, Sweden

Lena Neij
International Institute for Industrial Environmental Economics, Lund University, Lund, Sweden

Wim Turkenburg
Copernicus Institute for Sustainable Development and Innovation, Utrecht University, Utrecht, The Netherlands

---

[1] This Thematic Background Paper (TBP) draws heavily from other texts that the authors have authored or co-authored, such as the World Energy Assessment: Update of the Overview (2003), the World Energy Assessment: Energy and the Challenge of Sustainability (2000), and Energy for Sustainable Development: A Policy Agenda (2002).

Disclaimer

This is one of 12 Thematic Background Papers (TBP) that have been prepared as thematic background for the International Conference for Renewable Energies, Bonn 2004 (renewables 2004). A list of all papers can be found at the end of this document.

Internationally recognised experts have prepared all TBPs. Many people have commented on earlier versions of this document. However, the responsibility for the content remains with the authors.

Each TBP focuses on a different aspect of renewable energy and presents policy implications and recommendations. The purpose of the TBP is twofold, first to provide a substantive basis for discussions on the Conference Issue Paper (CIP) and, second, to provide some empirical facts and background information for the interested public. In building on the existing wealth of political debate and academic discourse, they point to different options and open questions on how to solve the most important problems in the field of renewable energies.

All TBP are published in the conference documents as inputs to the preparation process. They can also be found on the conference website at www.renewables2004.de.

Executive Summary

Renewable energy flows are very large in comparison with humankind's use of energy. Therefore, in principle, all our energy needs, both now and into the future, can be met by energy from renewable sources. Technologies exist that convert renewable energy flows to modern energy carriers or directly into desired energy services. Renewable energy now provides 14 percent of the world's primary energy, mostly traditional biomass, and 20 percent of electricity, mostly hydropower. Technological development during the last decade has resulted in modern renewable energy supply becoming competitive in many situations. Further technological development and industrial learning will continue to bring costs down. When environmental costs and security of supply considerations are included, renewable energy has even wider markets. With decisive efforts to speed up this dissemination, all human energy needs could be met by rerouting a small fraction of naturally occurring renewable energy flows within a century.

About the Authors:

Thomas B Johansson is Professor and Director, International Institute for Industrial Environmental Economics (IIIEE), Lund University, Sweden. He was Director of the energy and Atmosphere Programme of the United Nations Development Programme, 1994-2001, where he, *inter alia,* developed and launched the World Energy Assessment. He is since 1992 the international Co-Chair of the Working Group on Energy Strategies and Technologies of the China Council on International Cooperation for Environment and Development (CCICED). He received the Volvo Environment Prize in 2000.

Kes McCormick is a Research Associate and PhD Candidate at the International Institute for Industrial Environmental Economics (IIIEE) at Lund University, Sweden. He holds a Master of Environmental Science from Monash University, Australia and a Bachelor of Arts with Honours from Melbourne University, Australia. His research concentrates on overcoming barriers to bio energy implementation and the role of local governance

Lena Neij is Associate Professor at the International Institute for Industrial Environmental Economics (IIIEE) at Lund University, Sweden. Her research is focused on the dynamics of energy systems, methods for analysing technical change, renewable energy, energy efficiency and energy policy.

Wim C. Turkenburg (1947), trained as physicist, is professor and head of the Department on Science, Technology and Society (STS) of Utrecht University, the Netherlands. Also he is director of the Copernicus Institute for Sustainable Development and Innovation of Utrecht University and scientific director of the Utrecht Centre for Energy research (UCE). Recently he also was chairman of the Sub-Committee on Energy of the UN Committee on Energy and Natural Resources for Development (UN-CENRD) and Convening Lead Author of the chapter on Renewable Energy Technologies of the World Energy Assessment (WEA), published in 2000.

Table of Contents

1. Introduction

Renewable energy sources may be highly responsive to environmental, social and economic goals (see Box 1). Presently, renewable energy provides about 14 percent of global primary energy consumption, mostly traditional biomass, and about 20 percent of electricity, mostly large-scale hydropower. However, 'new' renewables contribute only 2 percent of the world's primary energy use. Such renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases.

Box 1: Definition of Renewable Energy

In a broad sense renewable energy sources refer to hydropower, biomass energy, solar energy, wind energy, geothermal energy, and ocean energy. The term 'new' renewables suggests a greater focus on modern and sustainable forms of renewable energy, in particular: modern biomass energy, geothermal heat and electricity, small-scale hydropower, low-temperature solar heat, wind electricity, solar photovoltaic and thermal electricity, and marine energy.

Discussions on biomass are sometimes clouded by problems of definition. The term combustible renewables and waste (CRW) includes all vegetable and animal matter used directly or converted to solid fuels, as well as biomass-derived gaseous and liquid fuels, and industrial and municipal waste converted to energy. The main biomass fuels in developing countries are firewood, charcoal, agricultural residues and dung, often referred to as traditional biomass.

Source: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP; International Energy Agency. 1998. Biomass Energy: Data, Analysis and Trends. Paris: OECD.

Natural flows of renewable resources are immense in comparison with global energy use. This holds both from a theoretical and technical perspective, however the level of their future use will primarily depend on the economic performance of technologies utilising these flows. Policies promoting the development and use of renewable energy sources and technologies can make a significant difference. Clearly, the long-term use of energy resources will likely become more an issue of the degree to which present and future societies have to balance environmental and economic trade-offs, and control greenhouse gas emissions rather than a question of resource and technology existence. Furthermore, the growing problem of the availability of (cheap) fossil fuels will amplify energy security concerns.

A rapid expansion of energy systems based on renewable energy sources will require actions to stimulate the market in this direction. This expansion can be achieved by finding ways to drive down the relative cost of new renewables in their early stages of development and commercialisation, while still taking advantage of the economic efficiencies of the marketplace. Pricing based on the full costs of conventional energy sources (including phasing out subsidies and internalising externalities) will make new renewables more competitive. However, such measures remain controversial. In any case, significant barriers stand in the way of the accelerated development of renewable technologies, which

can only be overcome by appropriate frameworks and policies.
Section 2 discusses the theoretical and technical potential of renewable energy resources and technologies, as well as current use in terms of technology options and status, and the associated environmental and social issues.

Section 3 explores the economic potentials of renewable energy with a particular focus on cost reductions and technological development.

Section 4 outlines a selection of scenarios, which have been developed to illustrate future use of energy. Some of these are based on approximately no changes in the supply mix, others recognise the possibility of increasing the share of renewable energy in the future.

Section 5 looks at the markets where renewable energy carriers might compete and make a difference, particularly in the case of developing countries. A market perspective brings into question what underlies a market, such as social conditions, demand for products and services, and consumer knowledge.

Section 6 identifies the barriers that renewable energy innovations confront all along the innovation chain (from research and development, to demonstration projects, to cost buy-down, and to widespread diffusion).

Section 7 concludes with policy recommendations that relate to many policy areas, including land use, agriculture, buildings, transportation, and urban planning.

2. Renewable Energy Resources and Technologies

The natural energy flows through the earth's ecosystem, and the geographical and technical potential of what they can produce for human needs, exceeds current energy use by many times (approximately 425 EJ in 2002). But in order to place renewable energy resources in perspective it is important to examine the long-term energy resource availability from the viewpoint of theoretical maximums, or ultimately recoverable resources (see Table 1). This is known as the theoretical potential. Admittedly, it can be argued that an analysis based on recoverable resources is irrelevant because hydrocarbon occurrences or natural flows become resources only if there is demand for them and appropriate technology has been developed for their conversion and use. The appraisal of technical potential therefore takes into account engineering and technological criteria. In any case, the picture is clear, renewable energy resources are immense and will not act as a constraint on their development.

Table 1: Global Renewable Resource Base (Exajoules a Year)

Resource	Current use[a]	Technical potential	Theoretical potential
Hydropower	10.0	50	150
Biomass energy	50.0	>250	2,900
Solar energy	0.2	>1,600	3,900,000
Wind energy	0.2	600	6,000
Geothermal energy	2.0	5,000	140,000,000
Ocean energy	-	-	7,400
TOTAL	**62.4**	**>7,500**	**>143,000,000**

a. The current use of secondary energy carriers (electricity, heat and fuels) is converted to primary energy using conversion factors involved.

Adapted from: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP.

Currently, renewable energy sources supply about 14 percent of the world's primary energy use, predominantly traditional biomass, used for cooking and heating, especially in rural areas of developing countries. Large-scale hydropower supplies about 20 percent of global electricity. Its scope for expansion is limited in the industrialised world, where it has nearly reached its economic capacity. In the developing world, considerable potential still exists, but large hydropower projects often face financial, environmental, and social constraints. It is estimated that together 'new' renewables (modern biomass energy, geothermal heat and electricity, small-scale hydropower, low-temperature solar heat, wind electricity, solar photovoltaic and thermal electricity, and marine energy) contributed about 9 EJ in 2001, or about 2 percent of the world's energy use.

It will likely be decades before 'new' renewables add up to a major fraction of total global energy use, because they currently represent only a small percentage of total energy use. Nevertheless in a few countries such as Germany, the scientific community operates in important studies with an ambitious target of 50 percent renewable energy sources by 2050.

2.1 Hydropower

Hydroelectricity is obtained by mechanical conversion of the potential energy of water in high elevations. An assessment of its energy potential requires detailed information on the local and geographical factors of runoff water (available head, flow volume per unit of time, and so on). The total theoretical potential of hydro energy is estimated at 150 Exajoules a year while the technical potential of hydroelectricity is estimated at 50 Exajoules a year (see Table 1). Because rainfall varies by region and country, hydro energy is not evenly accessible. Rainfall may also vary in time, resulting in variable annual power output.

2.1.1 Technology options and status

Hydroelectricity generation is regarded as a mature technology, unlikely to advance further. But for small-scale hydropower, there is room for further technical development and with the choice of very favourable sites, the use of existing administrative structures and existing civil works for flood-control purposes, the costs of small-scale projects could come down substantially. The installed capacity in 2001 is estimated at 690 GW for large hydro and 25 GW for small hydro.

2.1.2 Environmental and social issues

Considering the criticism of large dams, modern construction tries to include in the system design several technologies that minimise the social and ecological impacts. Some of the most important impacts are the displacement of local communities, particularly indigenous people, changes in fish amount and fish biodiversity, sedimentation, biodiversity perturbation, water quality standards, human health deterioration, and downstream impacts. The World Commission on Dams has done substantial work on this issue and elaborated a comprehensive set of recommendations for reconciling conflicting demands surrounding large dams (see Box 2). However, it is important to note that hydropower projects (not including the construction phase) produce almost no greenhouse gas emissions or air pollutants.

Box 2: Strategic Principles in the Construction of Dams

1. Gaining Public Acceptance

Wide public acceptance of key decisions is imperative for equitable and sustainable water and energy resources development.

2. Comprehensive Options Assessment

Alternatives to dams do often exist. Needs for water, food and energy should be assessed and objectives clearly defined. Furthermore assessments should involve a transparent and participatory process, applying economic, social and ecological criteria.

3. Addressing Existing Dams

Opportunities exist to improve existing dams, address remaining social issues and strengthen environmental and restoration measures.

4. Sustaining Rivers and Livelihoods

Understanding, protecting and restoring ecosystems is important to protect the welfare of all species and foster equitable human development.

5. Recognising Entitlements and Sharing Benefits

Negotiations with adversely affected communities can result in mutually agreed and legally enforceable mitigation and development provisions. However, affected people need to be among the first to benefit from the project.

6. Ensuring Compliance

Public trust and confidence requires that the governments, developers, regulators and operators meet all commitments made for the planning, implementation and operation of dams.

7. Sharing Rivers for Peace, Development and Security

Dams with a trans-boundary impact require constructive co-operation and good faith negotiation among riparian states.

Source: World Commission on Dams. 2000. Dams and Development: A New Framework for Decision-Making. London: Earth scan Publications.

2.2 Biomass energy

Biomass can be classified as plant, animal manure or municipal solid waste. Forestry plantations, natural forests, woodlands and forestry waste provide most woody biomass, while most non-woody biomass and processed waste comes from agricultural residues and agro-industrial activities (see Table 2). Sweden is probably the world leader in creating a working biomass market, which utilises biomass for energy purposes such as domestic heating with advanced heating systems and district heating. The growing contribution of biomass has been combined with increases in the number of companies that supply wood and wood products, as well as the number of parties that use biomass as an energy source. Sweden plans to increase the 25 percent share of biomass in the total primary energy supply to 40 percent by 2020.

Table 2: Types and Examples of Plant Biomass

Woody biomass	Non-woody biomass	Processed Waste	Processed fuels
• Trees • Shrubs and scrub • Bushes such as coffee and tea • Sweepings from forest floor • Bamboo • Palms	• Energy crops such as sugarcane • Cereal straw • Cotton, cassava, tobacco stems and roots • Grass • Bananas, plantains and the like • Soft stems such as pulses and potatoes • Swamp and water plants	• Cereal husks and cobs • Bagasse • Wastes from pineapple and other fruits • Nut shells, flesh and the like • Plant oil cake • Sawmill wastes • Industrial wood bark and logging wastes • Black liquor from pulp mills • Municipal Waste	• Charcoal from wood and residues • Briquette and densified biomass • Methanol and ethanol • Plant oils from palms, rape, sunflower and the like • Producer gas • Biogas

Source: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP.

Biomass resources are abundant in most parts of the world, and various commercially available conversion technologies could transform current traditional and low-tech uses of biomass to modern energy. If dedicated energy crops and advanced conversion technologies are introduced extensively, biomass could make a substantial contribution to the global energy mix. From a number of studies, the potential contribution of biomass in the long term can take a variety of estimates (see Table 3). Although most biomass is used in traditional ways (as fuel for households and small industries) and not necessarily in a sustainable manner, modern industrial-scale biomass applications have increasingly become commercially available. However, the biomass challenge is not so much an issue of availability but sustainable management, conversion, and delivery to the market in the form of modern and affordable energy services (see TBP 11).

Table 3: Estimates from the literature on the global potential of biomass energy

Source [a]	Types of residues [b]	Biomass residue potentially available (EJ y^{-1})			
		Year			
		1990	2020-2030	2050	2100
1	FR, CR, AR		31		
2[c]	FR, CR, AR, MSW		30	38	46
3	FR, MSW		90		
4					272
5	FR, CR, AR, MSW			217 - 245	
6		88			
7 [c]	FR, CR, AR, MSW		62	78	
8	FR, CR, AR		87		
A1 [d]	Energy crops			660	1118
A2 [d]	Energy crops			310	396
B1 [d]	Energy crops			449	703
B2 [d]	Energy crops			324	485

[a] 1: (Hall et al., 1993), 2: (Williams, 1995), 3: (Dessus et al., 1992), 4: (Yamamoto et al., 1999), 5: (Fischer and Schrattenholzer, 2001), 6: (Fujino et al., 1999), 7: (Johansson et al., 1993), 8: (Swisher and Wilson, 1993)

[b] FR = forest residues, CR = crop residues, AR = animal residues, MSW = municipal solid waste

[c] These studies rather estimated the potential contribution, in stead of the potential available.

[d] Scenarios from the International Panel on Climate Change (IPCC) that depict the potential of energy crops combining the possible output from abandoned agricultural land, low-productive land, and rest land.

Adapted from: Hoogwijk, M., Faaij, A., Eickhout; B., de Vries, B. & Turkenburg, W. Submitted for publication. Potential of grown biomass for energy under four land-use scenarios.

2.2.1 Technology options and status

A large variety of raw materials and treatment procedures make the use of biomass a complex system that offers a lot of options. Biomass energy conversion technologies can produce heat, electricity and fuels (solid, liquid and gas).

Solid biomass

Domestic biomass-fired heating systems are widespread, especially in colder climates. In developing countries the development and introduction of improved stoves for cooking and heating has a big impact on biomass use. Combustion of biomass to produce electricity is applied commercially in many regions. The globally installed capacity to produce electricity from biomass is estimated at 40 GW(e). Furthermore, gasification technologies can convert biomass into fuel gas with demonstration projects under way in various countries. The gas produced can be used to generate electricity but also to produce methanol or hydrogen. Small gasifiers coupled to diesel or gasoline engines are commercially available on the market.

Biogas
Anaerobic digestion of biomass has been demonstrated and applied commercially with success in many situations and for a variety of feedstocks, including organic domestic waste, organic industrial waste, manure, and sludge. Large advanced systems have been developed for wet industrial waste. In India there is widespread biogas production from animal and other wastes.

Biomass fuels
Conversion of biomass to liquid (bio-oil), gaseous and solid fractions can also be achieved by pyrolysis (heating up to 500 degrees Celsius in absence of oxygen). Bio-diesel can be obtained from oilseeds, using extraction and esterification techniques. In 2001 the world production was about 1.2 billion litres. Also, production of ethanol by fermenting sugars is a classic conversion route for sugar cane, maize, and corn on a large scale, especially in Brazil, France and the United States of America. In 2001 the world production of ethanol was estimated at 19 billion litres. Finally, hydrolysis of biomass is an option to produce liquid fuels.

2.2.2 Environmental and social issues

Biomass energy can be a carbon neutral energy source, which makes it very attractive. However, erosion is a problem related to the cultivation of many annual crops. The best-suited energy crops are perennials, with much better land cover than food crops. Increased water use caused by additional demands of new vegetation can also become a concern in some regions. Furthermore the use of pesticides can affect the quality of groundwater and surface water, which in turn impacts on plants and animals. The use of plantation biomass will result in removal of nutrients from the soil that have to be replenished in one way or another. Biomass plantations can also be criticized because the range of biological species they support is much narrower than what natural forests support. However, if plantations are established on degraded land or excess agricultural lands, the restored lands are likely to support a more diverse ecology. Finally, the collection, transport and use of biomass increase the use of vehicles and infrastructures and cause emissions to the atmosphere. A wide variety of social issues, some related to environmental factors, are barriers to a greater use of bio energy.

2.3 Solar energy

Solar energy has immense theoretical potential (see Table 1). The amount of solar radiation intercepted by the Earth is much higher than annual global energy use. Large-scale availability of solar energy depends on a region's geographic position, typical weather conditions, and land availability (see Table 4). The assessment here is made in terms of primary energy. In other words, the energy before the conversion to secondary or final energy is estimated. The amount of final energy will depend on the efficiency of the conversion device used (such as the photovoltaic cell applied).

Table 4: Annual Solar Energy Potential

Region	Minimum Exajoules	Maximum Exajoules
North America	181	7,410
Latin America and Caribbean	112	3,385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	371	9,528
Pacific Asia	41	994
South Asia	38	1,339
Centrally planned Asia	115	4,135
Pacific OECD	72	2,263
TOTAL	**1,575**	**49,837**

Note: The minimum and maximum reflect different assumptions on annual clear sky irradiance, annual average sky clearance, and available land area.

Adapted from: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP; Nakicenovic, N., Grübler, A. & McDonald, A. (eds) 1998. Global Energy Perspectives. Cambridge: Cambridge University Press.

2.3.1 Technology options and status

Solar energy is versatile and can be used to generate electricity, heat, cold, steam, light, ventilation, or hydrogen. It appears that several factors will determine the extent to which solar is utilised. These include the availability of efficient and low cost technologies, effective energy storage technologies, and high-efficiency end-use technologies.

Photovoltaics

One technique to produce electricity is the direct conversion of solar light to electricity using photovoltaic (PV) systems. The currently operating solar PV capacity is estimated at 1.1 GW(e). The major component of PV systems is the solar module, normally a number of cells connected in series. At present, crystalline silicon cells and modules are dominating the market. The conversion efficiency of these commercially available modules is 12 to 15 percent. This figure may increase to 12 to 20 percent in the year 2010 and up to 30 percent or more in the longer term. Higher efficiency may be achieved by stacking cells with different optical properties. There are many types of solar cells under development or in production. It is still too early to identify winners or losers among the PV technologies. However, there is reasonable consensus that thin-film technologies generally offer the best long-term prospects for very low production costs and an energy-pay-back-time of less than one year.

Solar thermal electricity

Solar thermal systems that produce high temperature heat can be used to generate electricity. Examples of solar thermal electricity (STE) technologies are parabolic trough systems, parabolic dish systems, and solar power towers surrounded by a large array of two-axis tracking mirrors reflecting direct solar radiation onto a receiver on top of the tower. The total installed capacity is currently about 0.4 GW(e). STE systems can be designed for solar-only applications, but also hybridised with fossil fuels to allow power production without sunlight.

Solar thermal heat
The world's low and medium temperature heat consumption, estimated at about 100 EJ a year, can at least partially be met using solar collectors. At present the total installed collector area is about 100 million square metres. The solar domestic hot water system (SDHW), having a collector area of 2 to 6 square metres and a storage capacity of 100 to 300 litres, is the most important application. The SDHW systems in Northern and Central Europe are designed to operate on a solar fraction of 50 to 65 percent. Subtropical climates generally achieve solar fractions of 80 to 100 percent. Large water heating systems find widespread use amongst others in swimming pools, hotels, hospitals, and homes for the elderly. Solar energy, using a central collector area, is also applied for district heating, covering 50 percent of the hot water production and 15 percent of the total heat demand. Heat pumps can generate high-temperature heat from a low-temperature (solar) heat source. Tens of millions of these appliances have been installed worldwide. Solar cooling, using absorption or adsorption cooling technologies, may become a feasible option as well.

Solar buildings
The application of passive solar principles in building designs contributes to the reduction of (active) energy demands for heating, cooling, lighting and ventilation. Some of these principles include: be well insulated; have a responsive, efficient heating system; face south; avoid over-hading by other buildings; and be thermally massive. Technologies involved include: low-emission double-glazed windows; low-cost opaque insulation material and high insulating buildings elements; transparent insulation material; high-efficiency ventilation heat recovery; and advanced high-efficiency lighting systems. Recent developments of building technology together with advanced, well calculated system-technology reduces the demand for heat energy by a factor 10 to 15 in comparison with houses built some 30 to 40 years ago. In such a low-energy house, renewable energies can contribute up to 100 percent of the energy demand.

2.3.2 Environmental and social issues

Solar technologies do not cause emissions during operation, but they do cause emissions during manufacturing and possibly on decommissioning (unless produced entirely by 'solar breeders'). One of the most controversial issues for PV was whether the amount of energy required to manufacture a complete system is smaller or larger than the energy produced over its lifetime. Nowadays the energy payback time of grid-connected PV systems is 3 to 9 years, and is expected to decrease to 1 to 2 years in the longer term. For stand-alone PV systems with battery storage the situation is less favourable. The energy payback time of modern Solar Home Systems is now 7 to 10 years. This may come down to roughly 6 years, of which 5 are due to the battery. This is a little sign as to what has to happen in research and development for solar energy. The availability of some of the elements in thin-film PV modules (like indium and tellurium) is also a subject of concern, although there are no short-term supply limitations. Of special concern is the acceptance of cadmium-containing PV modules, although the cadmium content of modules appears to be well within limits for safe use.

2.4 Wind energy

A region's mean wind speed and its frequency distribution have to be taken into account to calculate the amount of electricity that can be produced by wind turbines. Technical advances are expected to open new areas to development. The following assessment includes regions where the average annual wind power density exceeds 250 to 300 watts per square metre at 50 metres high (see Table 5).

Table 5: Estimated Annual Wind Energy Resources

Region	Land surface with sufficient wind conditions		Wind energy resources without land restriction	
	Percent	Thousands of km²	TWh	Exajoules
North America	41	7,876	126,000	1,512
Latin America and Caribbean	18	3,310	53,000	636
Western Europe	42	1,968	31,000	372
Eastern Europe and former Soviet Union	29	6,783	109,000	1,308
Middle East and North Africa	32	2,566	41,000	492
Sub-Saharan Africa	30	2,209	35,000	420
Pacific Asia	20	4,188	67,000	804
China	11	1,056	17,000	204
Central and South Asia	6	243	4,000	48
TOTAL[a]	**27**	**30,200**	**483,000**	**5,800**

Note: The energy equivalent is calculated based on the electricity generation potential of the referenced sources by dividing the electricity generation potential by a factor of 0.3 (a representative value for the efficiency of wind turbines, including transmission losses), resulting in a primary energy estimate.
a. Excludes China.
Adapted from: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP; World Energy Council. 1994. New Renewable Energy Resources: A Guide to the Future. London: Kogan Page Limited.

2.4.1 Technology options and status

Modern electronic components have enabled designers to control output and produce excellent power quality. These developments make wind turbines more suitable for integration with electricity infrastructure and ultimately for higher penetration. There has been gradual growth in the unit size of commercial machines, from 30 kilowatts of generating capacity in the 1970s (rotor diameter 10 metres) to 5 megawatts (110 to 120 metres diameter) and more at present. Market demands have driven the trend towards larger machines through economies of scale, less visual impacts on the landscape per unit of installed power, and expectations that offshore potential will soon be developed (see Table 6). Special offshore designs are being implemented. Modern wind turbines also have fewer components. By the end of 2002, worldwide installed capacity had topped 30,000 MW, with 22,000 MW in Europe, mainly Germany, Spain and Denmark. In fact, electricity production from grid-connected wind turbines has been growing at an impressive rate of about 30 percent per year.

Table 6: Offshore wind resources in Europe

Water depth	Up to 10km offshore	Up to 20km offshore	Up to 30km offshore
10m	551	587	596
20m	1,121	1,402	1,523
30m	1,597	2,192	2,463
40m	1,852	2,615	3,028

Note: Figures show electricity production in TWh per year.

Source: European Wind Energy Agency (EWEA) and Greenpeace. 2002. Wind Force 12: A Blueprint to Achieve 12% of the World's Electricity from Wind Power by 2020. Brussels: EWEA.

2.4.2 Environmental and social issues

Environmental and social aspects come into play in the several phases of a wind turbine project, which are building and manufacturing, normal operation, and decommissioning. Negative environmental aspects connected to the use of wind turbines are discussed as acoustic noise emission, visual impact on the landscape, impact on bird behaviour, moving shadows caused by the rotor, and electromagnetic interference with radio, television, and radar signals. In practice the noise and visual impact cause the most problems for development of wind farms.

2.5 Geothermal energy

Geothermal energy is generally defined as heat coming from the Earth. It has large theoretical potential but only a much smaller amount can be classified as resources and reserves (see Table 1). Still, even the most accessible part, classified as reserves, exceeds current annual consumption of primary energy (see Table 7). But like other renewable resources, geothermal energy is widely dispersed. Thus the technological ability to use geothermal energy, not its quantity, will determine its future share. High-temperature fields used for conventional power production (with temperatures above 150 degrees Celsius) are largely confined to areas with young volcanism, seismic, and magmatic activity. But low-temperature resources suitable for direct use can be found in most countries.

Table 7: Annual Geothermal Potential by Region

Region	Million Exajoules	Percentage
North America	26	18,9
Latin America and Caribbean	26	18,6
Western Europe	7	5,0
Eastern Europe and former Soviet Union	23	16,7
Middle East and North Africa	6	4,5
Sub-Saharan Africa	17	11,9
Pacific Asia	11	8,1
China	11	7,8
Central and South Asia	13	9,4
TOTAL	**140**	**100**

Adapted from: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP; World Energy Council. 1994. New Renewable Energy Resources: A Guide to the Future. London: Kogan Page Limited.

2.5.1 Technology options and status

Geothermal use is commonly divided into two categories: electricity production and direct application. The technology to use geothermal energy is relatively mature. The conversion efficiency of geothermal power plants is rather low, about 5 to 20 percent. In 2001 the global installed capacity was about 8 GW(e) generating 53 TWh electricity a year. Major applications can be found in the United States of America, Philippines, Italy, Mexico, Indonesia, Japan and New Zealand.

Direct application of geothermal energy can involve a wide variety of end uses, such as space heating and cooling, industry, greenhouses, fish farming, and health spas. It uses mostly existing technology and straightforward engineering. The technology, reliability, economics, and environmental acceptability of direct use of geothermal energy have been demonstrated throughout the world. Compared with electricity production from geothermal energy, direct use has several advantages, such as much higher energy efficiency. In 2001 the installed capacity for direct use was about 16 GW delivering 55 TWh heat a year.

Geothermal energy for electricity production previously had considerable economic potential only in areas where thermal water or steam is found concentrated at depths of less than 3 kilometres. This has changed recently with developments in the application of ground source heat pumps using the Earth as a heat source for heating or as a heat source sink for cooling, depending on the season. These pumps can be used basically everywhere. Important applications can be found in amongst others Switzerland and the United States of America.

2.5.2 Environmental and social issues

Geothermal fluids contain a variable quantity of gas, largely nitrogen and carbon dioxide with some hydrogen sulphide and smaller proportions of ammonia, mercury, radon, and boron. Most of the chemicals are concentrated in the disposal water, routinely re-injected into drill holes, and thus not released into the environment. The concentrations of the gases are usually not harmful. The gas emissions from low-temperature geothermal resources are normally only a fraction of the emissions from the high-temperature fields used for electricity production.

2.6 Ocean energy

Tidal energy, wave energy, and ocean thermal energy make up the types of ocean energy resources that appear most likely to move beyond speculative assumptions. The theoretical potential of each type of ocean energy is quite large, but dominated by ocean thermal energy (see Table 8). However, like other renewables, these energy resources are diffuse, which makes it difficult to use the energy. The difficulties are specific to each type of ocean energy, so technical approaches and progress differ as well.

Table 8: Annual Ocean Energy Potential

Resource category	TWh	Exajoules
Tidal energy	22,000	79
Wave energy	18,000	65
Ocean thermal energy[a]	2,000,000	7,200
TOTAL	**2,040,000**	**7,300**

a. The potential of ocean thermal energy is difficult to assess but is known to be much larger than for the other types of ocean energy. The estimate used here assumes that the potential for ocean thermal energy is two orders of magnitude higher than for tidal, wave, or salt gradient energy.

Adapted from: Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP; World Energy Council. 1994. New Renewable Energy Resources: A Guide to the Future. London: Kogan Page Limited.

2.6.1 Technology options and status

The energy of the oceans is stored partly as kinetic energy from motion of the waves and currents, and partly as thermal energy from the sun.

Tidal energy

The rise and fall of the tides creates, in effect, a low-head hydropower system. Tidal energy has been exploited in this way on a scale for centuries in the form of water mills. The one large modern version is the 240 MW(e) La Rance scheme, built in France in the 1960s, the world largest tidal barrage, using a conventional bulb turbine. A handful of smaller schemes have also been built.

Wave energy

Wave energy remains at an experimental stage, with only a few prototype systems actually working. Total grid-connected wave power is very small, consisting of several oscillating water column (OWC) devices. A new generation of larger devices is under development. Also marine currents can be used to generate electricity if the velocity of the current is high enough. The various turbine rotor options that are developed to use marine current energy generally coincide with those used for wind turbines.

Ocean thermal energy

Exploiting natural temperature differences in the sea using some form of heat engine, potentially the largest source of renewable energy of all, has been considered and discussed for the best part of a century. But the laws of thermodynamics demand as large a temperature difference as possible to deliver a technically feasible and reasonably economic system. Ocean thermal energy conversion (OTEC) requires a temperature difference of about 20 degrees Celsius, and this limits the application of this technology to a few tropical regions with very deep water. Offshore OTEC is technically difficult because the need to pipe large volumes of water from the seabed to a floating system, the huge area of heat exchanger needed, and the difficulty of transmitting power from a floating device in deep water to the shore.

2.6.2 Environmental and social issues

Offshore environmental impacts for marine energy technologies tend to be minimal. Few produce pollution while in operation. An exception is tidal barrages, where the creation of a large human-made seawater lake behind the barrage has the potential to affect fish and bird breeding and feeding. Another exception is OTEC, which may cause the release of carbon dioxide from seawater to the atmosphere. The main issues, however, tend to be conflicts with other users of the seas, for fishing, marine traffic, and leisure activities. None of the technologies discussed seems likely to cause measurable harm to fish or marine mammals.

3. Economic Potentials of Renewable Energy

Substantial cost reductions in the past few decades in combination with government policies have made a number of renewable energy technologies competitive with fossil fuel technologies in certain applications. The present status of 'new' renewables in Table 9 shows that substantial cost reductions can be achieved for most technologies. However, making these renewable energy sources competitive will require further technology development (see TBP 7) and market deployments and an increase in production capacities to mass-production levels.

Because many renewable technologies are small in scale and modular, they are good candidates for continued cost cutting. Such cost reduction can be illustrated using experience curves which describe how cost declines with cumulative production, where cumulative production is used as an approximation for the accumulated experience in producing and employing a certain technology (see Figure 1). The cost reductions illustrated by the experience curves only show the cost reduction of technologies. The cost reduction of generated heat or electricity will be larger due to additional sources of cost reduction such as technology improvements, reduced installations costs and so on. For some intermittent resources, such as wind and solar power, cost reductions of generated electricity may also level off when all 'good sites' are occupied and new technologies have to be placed in less windy or solar sites.

Wind power in coastal and other windy regions is a promising energy source (see Figure 2). Other potentially attractive options include low-temperature solar heat production, and solar electricity production in remote applications (see Figure 3). Wind and solar thermal or electric sources are intermittent, and not fully predictable. Nevertheless they can be important in rural areas where grid extension is expensive. They can also contribute to grid-connected electricity supplies in appropriate hybrid configurations. Intermittent renewables can reliably provide 10 to 30 percent of total electricity supplies in the area covered by a sufficiently strong transmission grid if operated in conjunction with hydropower or fuel-based power generation. Emerging storage possibilities (like Compressed Air Energy Storage) and new strategies for operating grids offer promise that the role of intermittent technologies can be extended much further. Alternatively, hydrogen may become the medium for storing intermittently available energy production.

Modern, distributed forms of biomass, in particular, have the potential to provide rural areas with clean forms of energy based on the use of biomass resources that have traditionally been used in inefficient, polluting ways. Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops. Its production and use currently is helping to create international bio energy markets, stimulated by policies to reduce carbon dioxide emissions. Cost reductions are also to be expected. Bio energy is, however, complex and could be differentiated into different subsystems including different resources, supply systems, conversions systems, and energy carriers. Each subsystem includes different technologies with individual learning processes for cost reductions. The development of bio energy will in some cases be based on modular technology development but in other cases be more like conventional technologies for heat and power production.

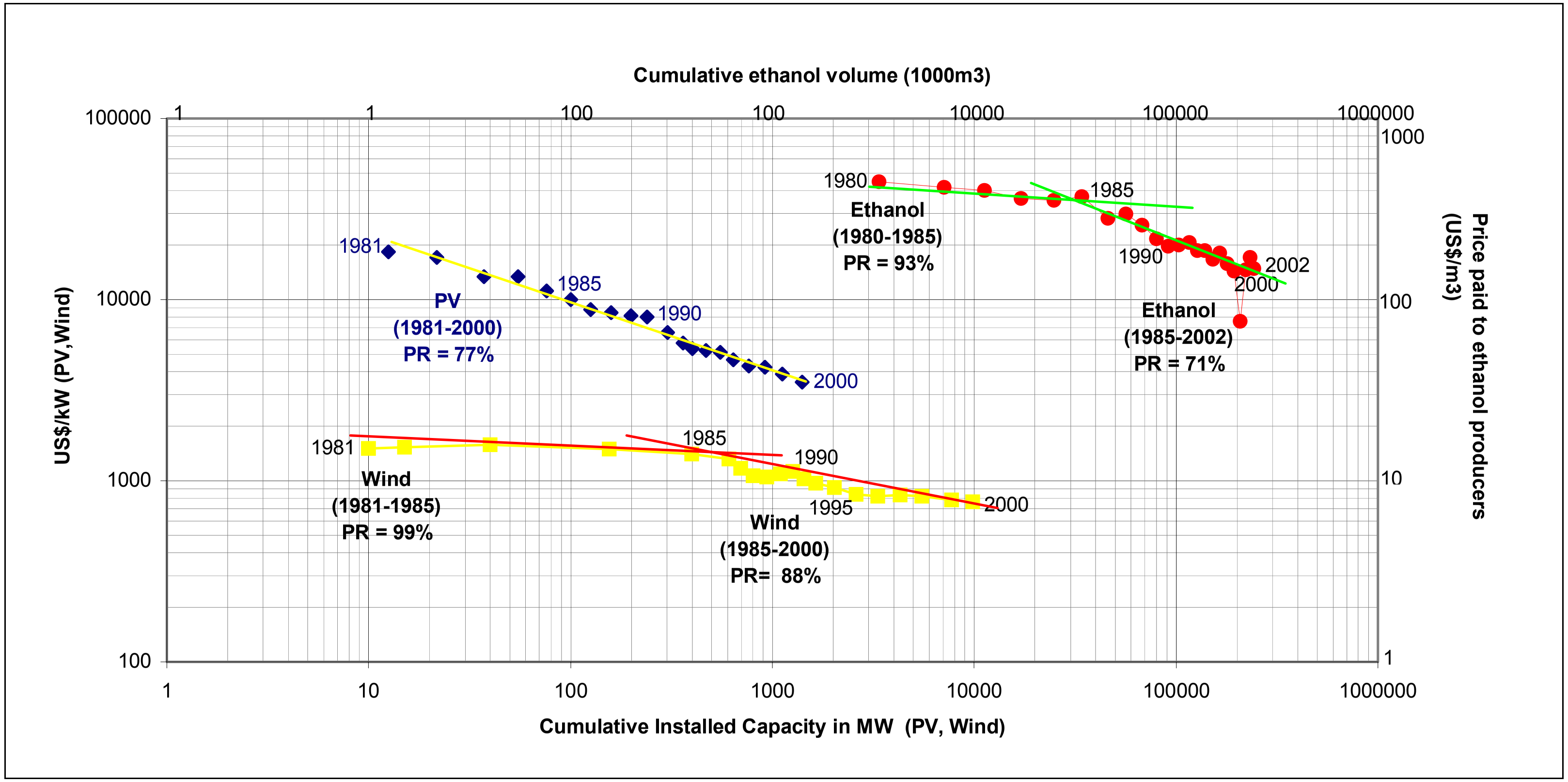
Table 9: Status of Renewable Energy Technologies for 2001

Technology	Increase in energy production in past five years (percent per year)	Operating capacity, end 2001	Capacity factor (percent)	Energy production in 2001	Turnkey investment costs (2001 U.S. dollars per kilowatt)	Current energy cost	Potential future energy cost
Biomass energy Electricity Heat [a] Ethanol Bio-diesel	~ 2.5 ~ 2 ~ 2 ~ 1	~ 40 GWe ~ 210 GWth ~ 19 bln litres ~ 1.2 bln litres	25 - 80 25 - 80	~ 170 TWh (e) ~ 730 TWh (th) ~ 450 PJ ~ 45 PJ	500 - 6,000 170 - 1,000	3 - 12 ¢/kWh 1 - 6 ¢/kWh (8 - 25 $/GJ 15 - 25 $/GJ)	4 - 10 ¢/kWh 1 - 5 ¢/kWh (6 - 10 $/GJ 10 - 15 $/GJ)
Wind electricity	~ 30	23 GWe	20 - 40	43 TWh (e)	850 - 1,700	4 - 8 ¢/kWh	3 - 10 ¢/kWh
Solar photovoltaic electricity	~ 30	1.1 GWe	6 - 20	1 TWh (e)	5,000 - 18,000	25 -160 ¢/kWh	5 or 6 - 25 ¢/kWh
Solar thermal electricity	~ 2	0.4 GWe	20 - 35	0.9 TWh (e)	2,500 - 6,000	12 - 34 ¢/kWh	4 - 20 ¢/kWh
Low-temperature solar heat	~ 10	57 GWth (95 mln m^2)	8 - 20	57 TWh (th)	300 - 1,700	2 - 25 ¢/kWh	2 - 10 ¢/kWh
Hydro energy Large Small	~ 2 ~ 3	690 GWe 25 GWe	35 - 60 20 – 90	2,600 TWh (e) 100 TWh (e)	1,000 - 3,500 700 - 8,000	2 - 10 ¢/kWh 2 - 12 ¢/kWh	2 - 10 ¢/kWh 2 - 10 ¢/kWh
Geothermal energy Electricity Heat	~ 3 ~ 10	8 GWe 16 GWth	45 - 90 20 - 70	53 TWh (e) 55 TWh (th)	800 - 3,000 200 - 2,000	2 - 10 ¢/kWh 0.5 - 5 ¢/kWh	1 or 2 - 8 ¢/kWh 0.5 - 5 ¢/kWh
Marine energy Tidal barrage Wave Tidal stream / Current OTEC	0 _ _ _	0.3 GWe exp. phase exp. phase exp. phase	20 - 30 20 - 35 25 - 40 70 - 80	0.6 TWh (e) 0 0 0	1,700 - 2,500 2,000 - 5,000 2,000 - 5,000 8,000 - 20,000	*8 - 15 ¢/kWh* 10 - 30 ¢/kWh 10 - 25 ¢/kWh 15 - 40 ¢/kWh	8 - 15 ¢/kWh 5 - 10 ¢/kWh 4 - 10 ¢/kWh 7 - 20 ¢/kWh

[a] Heat embodied in steam (or hot water in district heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

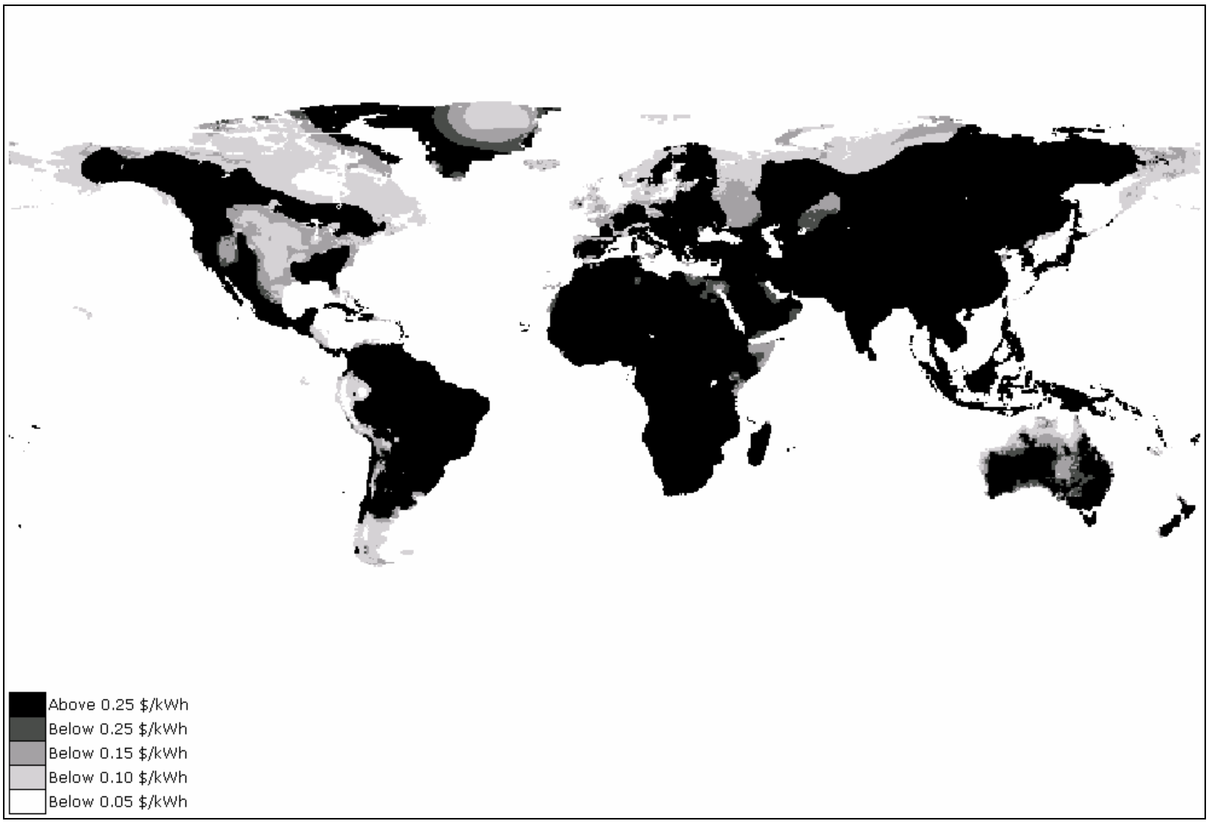
Source: Turkenburg, W. Utrecht University, The Netherlands. Unpublished.

Figure 1: Experience Curves for Photovoltaics, Windmills, and Ethanol Production



Sources: for wind turbines, L. Neij., P. Dannemand Andersen., M. Durstewitz, P. Helby, M. Hoppe-Kilpper, and P.E. Morthorst, Experience Curves: A Tool for Energy Policy Assessment (2003); for photovoltaics, V. Parente, R. Zilles, and J. Goldemberg, "Comments on Experience Curves for PV Modules," Progress in Photovoltaics: Research and Applications, John Wiley & Sons, Ltd (2002); for ethanol, J. Goldemberg, S.T. Coelho, P. M. Nastari, and O. Lucon, "Ethanol Learning Curve: The Brazilian Experience," Biomass and Energy (Submitted for publication).

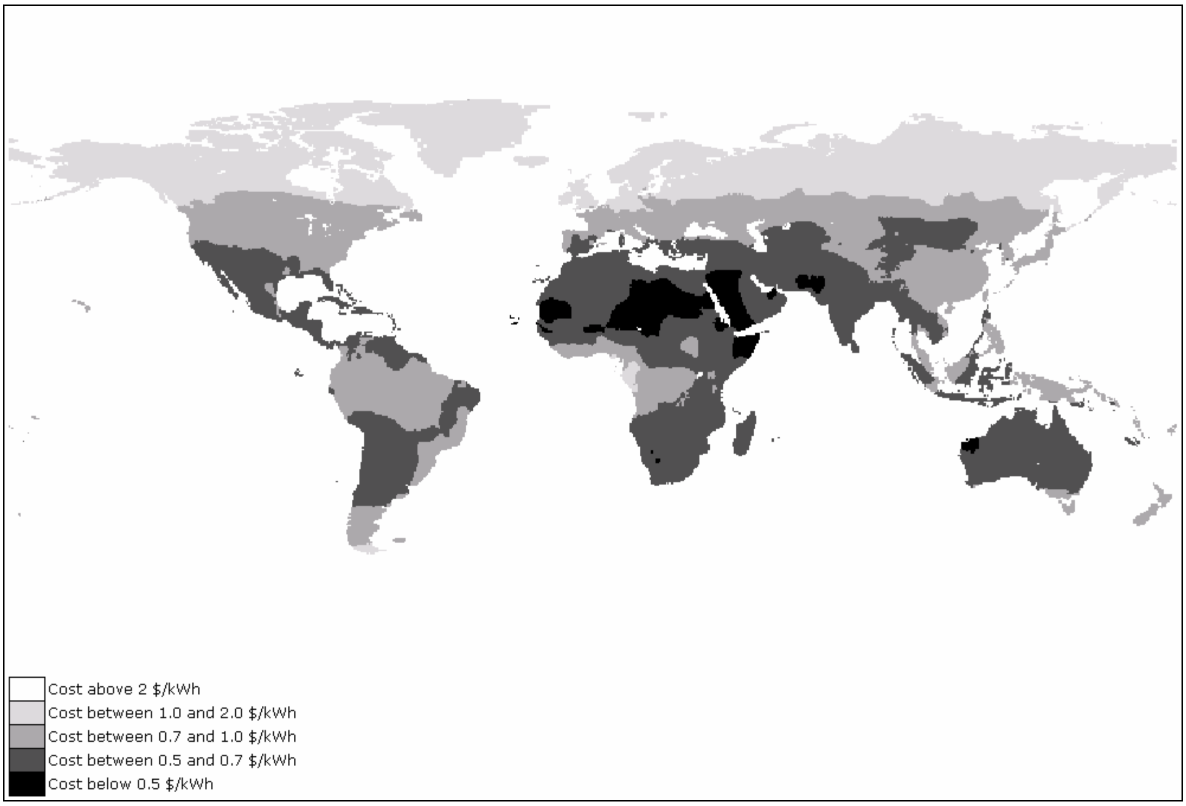
Figure 2: Geographical Distribution of Present Costs for Wind Electricity



Note: The costs of wind electricity can come down by further technology development.

Source: Hoogwijk, M., de Vries, B. & Turkenburg, W. Submitted for publication. Assessment of the global and regional geographical, technical and economic potential of onshore wind-energy.

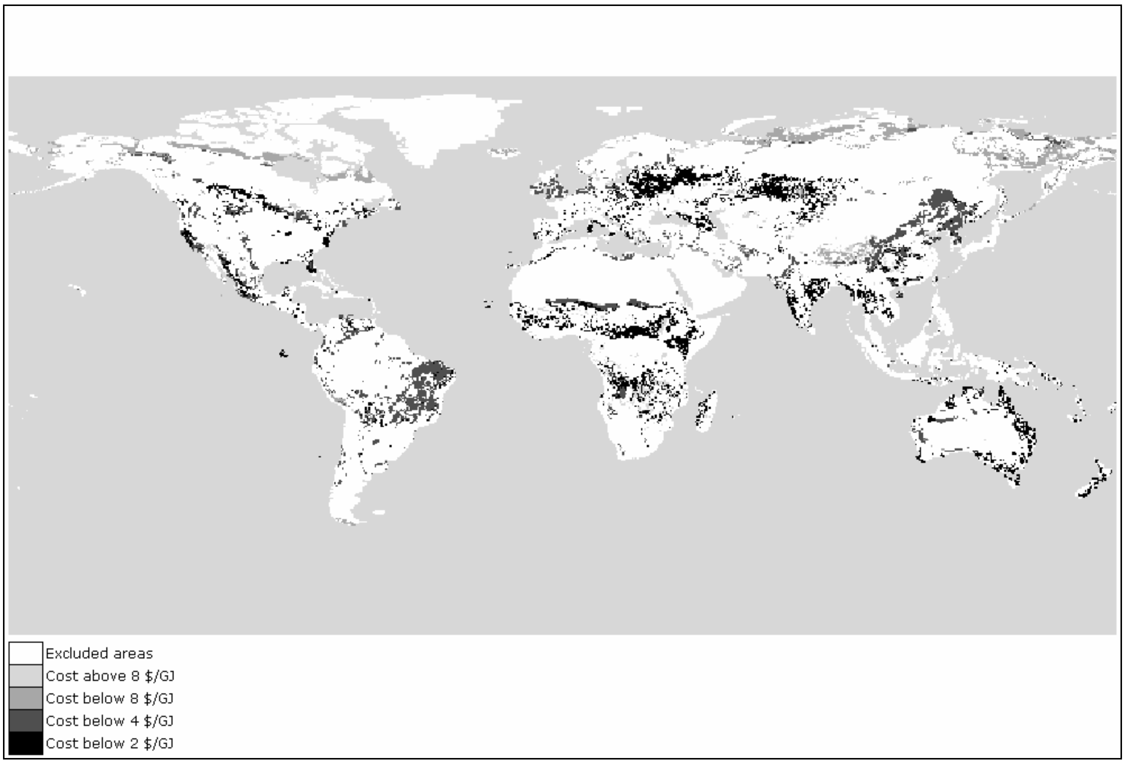
Figure 3: Geographical Distribution of Present Costs for Solar Electricity



Note: The costs of PV electricity can come down dramatically by further technology development.

Source: Hoogwijk, M., de Vries, B., Winkel, J. & Turkenburg, W. Submitted for publication. Assessment of the global and regional technical and economic potential of photovoltaic energy.

Figure 4: Geographical Distribution of Present Costs for Biomass Energy



Note: The costs of biomass energy can come down dramatically by further technology development. This image is available in greater detail that shows specific regions.

Source: Hoogwijk, M., de Vries, B., Winkel, J. & Turkenburg, W. Submitted for publication. Potential of grown biomass for energy under four land-use scenarios.

4. Scenarios for Renewable Energy

Many scenarios have been developed to illustrate future global demand and supply of energy. A review of scenarios that explore the future role of renewable energy is presented here (see Table 10). The year 2050 has been chosen for illustrative purposes, and is a frequently selected year for long-term energy scenarios in the literature. Special attention is given to several sets of scenarios: the Renewables-Intensive Global Energy Scenario (RIGES); the scenarios presented by the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council (WEC); the set of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC); and the Shell Corporation scenarios.

The figures in Table 10 show the total amount of renewable energy and the percentage of renewable energy of the total energy supply. A larger renewable energy share of total energy supply, does not necessarily mean a high quantity of renewable energy but depends on the total energy use in the scenario.

The RIGES scenario, which has been described as a renewable-intensive global energy scenario, illustrates the potential markets for renewable energy assuming that market barriers will be removed by comprehensive, and even accelerated, policy measures. In the scenario it is assumed that renewable energy technologies will capture markets whenever 1) renewable energy is no more expensive on a life-cycle cost basis than conventional alternative, and 2) the use of renewable technologies will not create significant environmental, land use, or other problems. The analysis does not consider the credits of any external benefits from renewable energy.

The results of the IIASA and WEC scenarios are a bit less optimistic than the RIGES scenario but still present a significant increase in renewable energy by 2050. Furthermore, the scenarios show a span in energy demand, total renewable and share of renewable. In the 'Ecologically driven scenario', which also describes the results of ambitious policy measures to accelerate energy efficiency and renewable energy technologies, renewable energy accounts for 40 percent of the energy demand by 2050 of which approximately 30 percent is biomass energy and 8 percent is hydropower. These scenarios, which focus on international development equity and environmental protection, are based on accelerated energy efficiency. In 2050, energy demand is assumed to be approximately 600 EJ, and the CO_2 emissions in this scenario are approximately 5 GtC per year by 2050. The scenarios describe cost reductions of new technologies according to the experience curve concept.

The IPCC scenarios have a wider span regarding the contribution of renewable energy in the future. In some scenarios the share of renewable energy is even expected to be lower than today. The scenarios, which are in all 40 and developed by 6 modelling teams, differ due to the differences in the driving forces for the scenarios, such as demographic change, social and economic development and rate and direction of technical change. Even with the same assumptions considering driving forces, the models will come up with different results. This describes the sensitivity of the scenarios not only due to assumptions made but also due to methods use. The scenarios including the highest share of renewable energy are in general the so-called A2T and B1 scenarios. These scenarios also have the lowest cumulative CO_2 emissions from 1990 until 2100. These scenarios are characterised by the introduction of clean and resource efficient technologies and for some scenarios also 'a rapid changes in economic structures towards a service and information economy with reduction in material intensity'.

The scenarios by Shell show a considerable increase in the future share of renewable energy. The first scenario presented in Table 10, 'Dynamic as usual', reflects a social shift in priority to a clean, secure and sustainable energy system and an intense competition between new and old technologies. The scenario describes a gradual shift to low carbon fuels and electricity supported by gas until 2025. The second scenario, entitled 'Spirit of coming age', illustrates a higher demand of energy to meet the energy needs developed to meet consumers' preferences of mobility, flexibility, and convenience. At the same time new energy technologies are introduced in developing as well as in developed countries making the renewable energy an important source of energy.

Table 10: Selected global energy scenarios that explore contributions of renewable energy by 2050

	Total energy demand (EJ)	Total renewable energy (EJ)	Total renewable energy (%)	Hydropower (%)	Wind power (%)	Bio-energy (%)	Other renewable sources (%)	CO2 emissions 2050 (MtC)
Renewable Energy Use 2000[1]	425	56	13	2	0.03	11	App. 0	-
RIGES[2]	512	237	46	3	-	33	10	4191
IIASA and WEC[3]	479-1040	96-308	22-40	-	-	-	-	5110-14670
IPCC[4]	642-1611	73-444	9-35	-	-	3-16	-	8500-26800
Shell[5]	852; 1217	282; 336	33; 28	5; 5	-	-	-	-

[1] Data on renewable energy use in Goldemberg (2000).

[2] Includes the RIGES scenario in Johansson et al. (1993)

[3] Includes 6 scenarios developed by IIASA and WEC in Nakicenovic et. al. (1998)

[4] Includes 40 scenarios developed by 6 modelling teams in IPCC (2000).

[5] Includes the 2 scenarios ‘Dynamics as usual’ and ‘Spirit of coming age’ in Shell International (2001).

The scenarios are generally based on assumptions of economic growth and socio-economic development. These assumptions, which may differ considerably for the various scenarios, will result in differences in energy demand. Table 11 presents the span in assumptions and resulting energy demand for the set of IPCC scenarios. The amount of renewable energy in the scenarios will depend on assumptions regarding technologies available, cost development and resources available. The share of renewables in the scenarios will depend on the total energy demand as well as on the amount of renewable energy.

Table 11: Summary of Assumptions in the IPCC scenarios 2050

	1990	Scenario A1B	Scenario A1F1	Scenario A1T	Scenario A2	Scenario B1	Scenario B2
Population (billions)	5.3	8.7	8.7 (8.3-8.7)	8.7	11.3 (9.7-11.3)	8.7 (8.6-8.7)	9.3 (9.3-9.8)
World GDP (10^{12} 1990 US$/yr)	21	164 (163-187)	181 (120-181)	187 (177-187)	82 (59-111)	136 (110-166)	110 (76-111)
Final energy intensity (MJ/US$)	16.7	6.3 (5.4-6.3)	5.5 (4.4-7.2)	4.8 (4.2-4.8)	9.5 (7.0-9.5)	4.5 (3.5-6.0)	6.0 (6.0-8.1)
Primary energy (EJ/yr)	351	1431 (1377-1601)	1347 (968-1611)	1213 (913-1213)	971 (679-1059)	813 (642-1090)	869 (679-966)

Source: International Panel on Climate Change (IPCC). 2000. Emission Scenarios. Cambridge: Cambridge University Press.

In all, the scenarios suggest that the amount of renewable energy can increase considerably until 2050, from 56 EJ to more than 400 EJ. Moreover, the share of renewable energy can increase from 14 percent to almost 50 percent. The increase in the share of renewable energy does not necessarily mean that the supply need to reach 300 to 400 EJ, but can be lower, if the total energy demand is limited by for example restricted social and economic development, improved technology development or energy efficiency measures. Even though the scenarios show a huge increase in renewable energy until 2050, a major shift to a total renewable energy system is not suggested in any of these studies by 2050; in spite of the fact that the renewable energy resources are more than sufficient. The reason for this is the large energy supply system with equipment having long life times, as well as limitations in growth rates of new systems, economic acceptance, technological turnover, and so on. The scenarios illustrate that a transition to a global energy system based on renewable energy will require significant time.

It is important to keep in mind that scenarios are thought-experiments. No likelihood of the realization of any scenario can be assigned. This is due to the important fact that policies will affect the conditions in the market place, and ongoing research and development will provide new opportunities. The introduction of renewable energy will not just take place but depend on support of technology development, market deployments and early adoption of new technologies. Such support will give rise to learning opportunities, cost reductions of new technologies, and capacity development, which will make the development and diffusion of renewable energy technologies possible. For some technologies subsidies can be used to accelerate the learning process and the process of reducing costs. This is often called to 'buy-down' the experience curves. Due to subsidies, investments will be made in relatively expensive technologies, and due to the increased number of sold and produced units, costs will go down and make the technology more competitive. Public support of different kinds will be important as incitement for market development.

The scenarios not only show the possible share of renewable energy in the future, they also describe the importance of energy efficiency, and especially end-use efficiency for the reduction of CO_2 emissions. Today, the global energy efficiency of converting primary energy to useful energy is approximately one third, which means that two thirds of primary energy is dissipated in the conversion processes, mostly as low-temperature heat. Furthermore, significant losses occur on the demand side when final energy delivers the energy service. Numerous opportunities exist for energy efficiency improvements, especially on the energy demand side. In the near future, the amount of primary energy required for a given energy services could be cost-effectively reduced by 25 to 35 percent in industrialised countries (the higher figure being achievable by more effective policies). In transitional economies, reductions of more than 40 percent will be cost-effectively achievable. And in most developing countries - which tend to have high economic growth and old capital and vehicle stocks - the cost-effective improvement potential ranges from 30 to more than 45 percent, relative to energy efficiencies achieved with existing capital stock. However, when this potential is made use of there will still remain 20 to 40 percent in 20 years time due to technological progress. Clearly, scenario analysis indicates significant opportunities by 2050, and more thereafter, for using renewable energy in the world energy system.

5. Market Development for Renewable Energy

Looking at the markets where renewable energy carriers might compete facilitates an understanding of the potential and demand for renewable energy.

The potential of markets for renewable energy and the role played by the public sector depend on the specific conditions in each country and region. Providing efficient energy-using technologies and renewable energy is a public good in many developing countries with a wide range of benefits for sustainable development. Thus governments must find an effective balance between liberalisation and directing markets towards wider social goals. It is within developing countries that much work is necessary to develop markets for renewable energy. This implies a change in focus, away from the historically dominating resource and technology assessments. Table 12 illustrates the paradigm shift that is now well underway. A market perspective brings into question what underlies a market, such as social conditions, demand for products and services, and consumer knowledge.

Table 12: Renewable Energy Paradigms

Old Paradigm	New Paradigm
Technology assessment	Market assessment
Equipment supply focus	Application, value-added, and user focus
Economic viability	Policy, financing, institutional, and social needs and solutions
Technical demonstrations	Demonstrations of business, financing, institutional and social models
Donor gifts of equipment	Donors sharing the risks and costs of building sustainable markets
Programs and intentions	Experience, results, and lessons
Cost reductions	Competitiveness on the market place

Adapted from: Martinot, E., Chaurey, A., Lew, D., Moreira, J.B. & Wamukonya, N. 2002. Renewable Energy Markets in Developing Countries. Annual Review of Energy and the Environment. 27: 309-348.

The use of renewable energy is either direct or indirect. Direct use is the immediate use of renewable energy flows to satisfy energy service needs. Examples include passive solar heating, day lighting, and solar crop drying. There are no energy markets involved here, however, policies related to other areas could advance the direct use of renewable energy, for example, building codes or other instruments in the buildings area to promote passive solar heating and day lighting. Energy services cannot be measured on a $/kWh basis, thus many comparisons of costs of local and integrated renewables with the costs of electricity generation are incorrect and misleading.

Indirect use of renewable energy refers to the generation of an energy carrier that is then applied in energy end-use equipment to provide the desired energy service. Such energy carriers include electricity, bio- or producer gas, mechanical (shaft) power, and liquid bio fuels. For some of these energy carriers there exist established markets. In other cases the use is local, e.g. small hydro or wind energy providing shaft power or isolated, stand-alone electricity use that serves niche markets, for example solar photovoltaics for illumination and communication uses.

In industrialised and transition countries and many developing countries most renewable energy use takes place through markets for heat, electricity, and fuels. Such markets increasingly exist in all developing countries, with some having national wind systems for electricity, and well developed fuel markets, while others rely more heavily on local markets and direct uses of renewable energy. The development of these energy markets thus relies on the use of a battery of incentives and regulations (see TBP 4).

In developing countries, it is useful to consider the direct end uses and look at the opportunities for renewable energy. Table 13 gives an overview of renewable energy markets in developing countries. Many of these applications encourage increased decision-making and participation from a variety of stakeholders, including the end users.

The opportunities to use renewable energy vary from one situation to another, for example urban areas of different levels of development, from rural to urban etc. There is thus not a single classification by national level of development, as most developing countries have segments of society that have well developed energy markets in combination with large segments that have extremely poor access to energy services.

Table 13: Renewable Energy Markets in Developing Countries

Application	Indicators of existing installations and markets (as of 2000)
Rural residential and community lighting, TV, radio and telephony	Over 50 million households are served by small-hydro village-scale mini-grids. 10 million households get lighting from biogas. 1.1million households have solar PV home systems or solar lanterns. 10,000 households are served by solar, wind and diesel hybrid mini-grids. There are 200k household wind generators in China.
Rural small industry, agriculture, and other productive uses	Up to 1 million water pumps are driven by wind turbines, and over 20,000 water pumps are powered by solar PV. Up to 60,000 small enterprises are powered by small-hydro village-scale mini-grids. Thousands of communities receive drinking water from solar PV powered purifiers and pumps.
Grid-based bulk power	48,000 MW installed capacity produces 130,000 GWh per year (mostly small hydro and biomass, with some geothermal and wind). More than 25 countries have regulatory frameworks for independent power producers.
Residential and commercial cooking and hot water	220 million households have more efficient biomass stoves. 10 million households have solar hot water systems. 800,000 households have solar cookers.
Transport fuels	14 billion litres per year ethanol vehicle fuel is produced from biomass. 180 million people live in countries mandating mixing of ethanol with gasoline.

Adapted from: Martinot, E., Chaurey, A., Lew, D., Moreira, J.B. & Wamukonya, N. 2002. Renewable Energy Markets in Developing Countries. Annual Review of Energy and the Environment. 27: 309-348.

5.1 Rural energy

Access to electricity opens opportunities that are taken for granted by those who enjoy continuous access. Yet 350 to 400 million households in developing countries lack access to electricity. This largely means that TV and radio are not available, lighting comes from candles and fires, telephone services are absent etc. A number of options to use renewable energy for electrification exist and the markets are growing.

Solar home systems:
These usually consist of a photovoltaic (PV) solar panel, battery, charging controller, and end uses like lighting or heating. Lanterns powered by solar energy provide lighting only. In recent years, large markets have developed, particularly in rural areas of developing countries. Installations may service single households or public buildings, like schools and health centres.

Biogas for cooking and lighting:
A biogas digester converts wastes (animal and plant) into fuels for lighting, heating, cooking, and electricity generation. Digesters can be small and serve a household or larger and provide fuels for many households. Unfortunately, market development is hampered by community and political issues, as well as some technical challenges.

Mini-grids:
Small-scale grids can provide electricity for communities with a high density. Traditionally, mini-grids have been powered by diesel generators or small hydro. However, solar PV, wind turbines, or biomass digesters, often in hybrid combinations, can replace or supplement diesel power.

Small scale wind power:
Wind power systems for a single household has been piloted in a few countries. Performance of these systems has been good, except sometimes during the summer when winds drop. Many households are therefore upgrading their systems with solar PV to complement the wind resource.

5.2 Productive uses in rural areas

The emerging uses of renewable energy are for agriculture, small industry, water pumping and cottage applications (saw mills and mechanical power). Furthermore, social services, such as education and health care can be supported by renewable energy.

Agricultural water pumping:
Water pumps driven by wind have historically played a role in rural areas. More recently, interest is growing in solar PV powered water pumps, along with biogas for water pumping in dual-fuel engines running on diesel and biogas.

Small industry:
Stand-alone energy systems can power small industries, thereby creating local jobs and opportunities. In fact, the development of mini-grids and industry go hand in hand. As small businesses grow, the economic viability of mini-grids increases. With the availability of energy, new possibilities open up.

Drinking water:
Renewable energy can power mechanical pumping and filtering (as well as ultraviolet disinfection) to provide clean drinking water. This is emerging as a potential major market in developing countries.

Crop drying:
Crop often needs to be dried for perseverance. Direct solar radiation is widely used for this purpose.

5.3 Electrical grids

Economic growth continues to drive electricity consumption, which raises concerns over how to best provide the power generation necessary for these rapidly expanding markets. Small hydro power, biomass, geothermal, and wind farms are realistic and competitive options. If environmental externalities are factored into the market prices of competing fuels, and social goals are recognised, then grid-based renewable energy becomes even more competitive.

5.4 Cooking and hot water

Direct combustion of biomass supports residential and commercial cooking and hot water in rural areas of developing countries. However, the decline in forest resources in some countries has encouraged governments to look at more efficient technologies for biomass use, as well as solar cookers. R&D for these technologies is still urgently needed. Markets are primarily found where resource constraints are appearing. Solar hot water heaters for residential and commercial uses are cost-effective in many regions. A large market exists for domestic solar hot water collectors worldwide.

5.5 Transport fuels

Biomass-derived liquid fuels can power motor vehicles in several ways. Firstly, ethanol can power specially designed vehicles that run on pure ethanol. Secondly, ethanol is mixed, for example in Brazil and the United States of America, with gasoline or diesel fuel to produce gasohol for use in ordinary vehicles. Furthermore, the commercial viability of converting sugarcane to ethanol for motor vehicles has also been demonstrated. The competitiveness of ethanol and gasohol relative to conventional gasoline has continued to improve, although the low price of oil and global automotive industry greatly affect the prospects of biomass-derived fuels, in the absence of accounting for extended costs and benefits.

6. Renewable Energy Innovations

Innovations face barriers all along the innovation chain (from research and development, to demonstration projects, to cost buy-down, to widespread diffusion). Some of these barriers reflect market imperfections; some inadequacies in the public sector domain; and some differences of view about needs, corporate priorities, relevant time horizons, and reasonable costs. The amount of public support needed to overcome such barriers will vary from one technology to the next, depending on its maturity and market potential. Direct government support is more likely to be needed for radically new technologies than for incremental advances where the private sector functions relatively effectively (see TBP 7).

Major criteria for deciding whether government should finance a particular field of energy research can be the contribution of the area to achieving a transition to a sustainable energy policy and to strengthening the competitiveness of (national) industries. It is also important that the research infrastructure in the field of interest is good enough to achieve these goals.

Interventions should aim to help the most promising energy innovations surmount bottlenecks wherever they occur in the innovation chain. Increasingly, however, this chain is viewed as a complex, interactive system requiring networks of innovation, knowledge sharing, and demand 'pull' as well as supply 'push'. Over the past couple of decades, countries have experimented with a growing number of policy instruments from target setting and procurement policies to green labelling and fiscal incentives.

Cost buy-down and widespread dissemination can be advanced through a number of policy measures. The issues and options for cost buy-down are shown in Table 14. A very effective policy option appear to be temporary subsidies, as used in Germany and Spain with very good results in terms of expanding electricity generation from renewable energy. Green certificate markets are another option now in use in many countries. The greatest impact appears to have been in the state of Texas in the United States of America. From an investors point of view the temporary subsidy would provide a better known and predictable economic situation as no assumption on the price of the green certificates have to be made. Carbon taxes have also proven effective in expanding the use of renewables, for example, a CO_2 tax in Sweden supported the shift from coal to biomass in district heating systems, contributing to biomass now providing 25 percent of Sweden's primary energy. In 2002, Brazil adopted a law to promote adoption of wind energy, photovoltaics, small-scale hydro, and biomass. The law was designed to protect the national interest where the market alone cannot. Its goal is to have these forms of energy providing approximately 10 percent of all electricity consumption, by 2010.

Table 14: Barriers and Policy Options in the Energy Innovation Chain

	Research and Development (laboratory)	Demonstration (pilot projects)	Diffusion	
			Early Deployment (technology cost buy-down)	Widespread Dissemination (overcoming institutional barriers and increasing investment)
Key Barriers	• Governments consider R&D funding problematic • Private firms cannot appropriate full benefits of their R&D investments	• Governments consider allocating funds for demonstration projects difficult • Difficult for private sector to capture benefits • Technological risks • High capital costs	• Financing for incremental cost reduction (which can be substantial) • Uncertainties relating to potential for cost reduction • Environmental and other social costs not fully internalised	• Weaknesses in investment, savings, and legal institutions and processes • Subsidies to conventional technologies and lack of competition • Prices for competing technologies exclude externalities • Weaknesses in retail supply, financing, and service • Lack of information for consumers and inertia • Environmental and other social costs not fully internalised
Policy Options to Address Barriers	• Formulating research priorities • Direct public funding • Tax incentives • Technology forcing standards • Stimulating networks and collaborative R&D partnerships	• Direct support for demonstration projects • Tax incentives • Low-cost or guaranteed loans • Temporary price guarantees for energy products of demonstration projects	• Temporary subsidies • Tax incentives • Government procurement • Voluntary agreements • Favourable pay-back tariffs • Competitive market transformation initiatives	• Phasing out subsidies to established energy technologies • Measures to promote competition • Full costing of externalities in energy prices • 'Green' labelling and marketing • Concessions and other market-aggregating mechanism • Innovative retail financing and consumer credit schemes • Clean Development Mechanism

Source: President's Council of Advisors on Science and Technology (PCAST). 1999. Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation. Washington, DC: PCAST.

7. Policy Implications and Recommendations

The degree to which there will be demand for renewable energy depends on many factors. At present, only 2 percent of the world's primary energy is 'new' renewables. One fundamental issue is that the environmental and social benefits of using renewable energy appear at the societal level, while costs have to be born by households and investors, typically without seeing the benefits reflected in market conditions. Therefore, the demand for renewable energy is strongly linked to the market situation, and can be dramatically affected by changes in market conditions (see TBP 4). Policies for renewable energy relate to many policy areas, including land use, agriculture, buildings sector, transportation, power, urban planning (see TBP 3).

Additionally, some specific areas that have to be addressed include:

- Understanding local renewable energy flows and their potential use. There is a large need to disseminate methodologies to estimate the local renewable energy flows and to create integrated (holistic) and sustainable solutions.

- Research and development to tap local renewable energy flows, for example heat pumps, buildings-integrated PV (role of net-metering), passive solar, and demand side systems (integration of efficiency improvements and renewable energy).

- Supporting all steps in the innovation chain for renewable energy technologies and systems, including: allocating a larger share of public sector funding for energy research and development to renewable energies; supporting demonstration projects, (especially for modern biomass in developing countries) perhaps as public private partnerships; and buying down the relative cost of 'new' renewables in their early stages of development and commercialisation, while still taking advantage of the economic efficiency of the marketplace. Temporary subsidies have proven to be effective.

- Setting ambitious but realistic targets and timetables; green certificates that can be traded at a national or international market combined with agreements to reduce emissions; favourable uptake prices for renewable electricity delivered to the grid; tax credits for investments in renewables; subsidies with 'sunset' clauses; and concessions for the development of renewable energy resources.

- Value of distributed generation is typically higher than central station generation, on a kWh basis. Methods and procedures for calculating the value of distributed generation needs to be improved and disseminated, especially in situations with liberalized markets without vertical integration, where benefits may not be captured by investors in generation but by distributors.

- Energy services cannot be measured on a $/kWh basis, thus many comparisons of costs of local and integrated renewables with the costs of electricity generation are incorrect and misleading.

8. References

European Wind Energy Agency (EWEA) and Greenpeace. 2002. Wind Force 12: A Blueprint to Achieve 12% of the World's Electricity from Wind Power by 2020. Brussels: EWEA.

Goldemberg, J. (ed) 2000. World Energy Assessment: Energy and the Challenge of Sustainability. New York: UNDP.

Goldemberg, J. & Johansson, T.B. (eds). Submitted for publication. World Energy Assessment: Update of Overview.

Goldemberg, J. & Johansson, T.B. (eds). 2002. Energy for Sustainable Development: A Policy Agenda. New York: UNDP.

Jaccard, M. & Mao, Y. 2002. Making Markets Work Better. In Johansson, T.B. & Goldemberg, J. (eds) Energy for Sustainable Development: A Policy Agenda. New York: UNDP.

Johansson, T.B., Kelly, H., Reddy, A.K.N. & Williams, R.H. (eds.). 1993. Renewable energy: Sources of Fuels and Electricity. Washington, DC: Island Press.

Hoogwijk, M., de Vries, B., Winkel, J. & Turkenburg, W. Submitted for publication. Assessment of the global and regional technical and economic potential of photovoltaic energy.

Hoogwijk, M., de Vries, B. & Turkenburg, W. Submitted for publication. Assessment of the global and regional geographical, technical and economic potential of onshore wind-energy.

Hoogwijk, M., Faaij, A., Eickhout; B., de Vries, B. & Turkenburg, W. Submitted for publication. Potential of grown biomass for energy under four land-use scenarios.

International Energy Agency. 1998. Biomass Energy: Data, Analysis and Trends. Paris: OECD.

International Panel on Climate Change. 2000. Emission Scenarios. Cambridge: Cambridge University Press.

International Energy Agency. 2002. Energy Balances of OECD and Non-OECD Countries 1999-2000. Paris: IEA and OECD.

Martinot, E., Chaurey, A., Lew, D., Moreira, J.B. & Wamukonya, N. 2002. Renewable Energy Markets in Developing Countries. Annual Review of Energy and the Environment. 27: 309-348.

Nakicenovic, N., Grübler, A. & McDonald, A. (eds) 1998. Global Energy Perspectives. Cambridge: Cambridge University Press.

Neij, L. 1999. Dynamics of Energy Systems: Methods of Analysing Technology Change. Lund: Lund University.

President's Council of Advisors on Science and Technology (PCAST). 1999. Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation. Washington, DC: PCAST.

Shell International. 2001. Energy needs, choices and possibilities: Scenarios to 2050. London: Shell International.

Turkenburg, W. Utrecht University, The Netherlands. Unpublished material.

World Commission on Dams. 2000. Dams and Development: A New Framework for Decision-Making. London: Earthscan Publications.

World Energy Council. 1994. New Renewable Energy Resources: A Guide to the Future. London: Kogan Page Limited.

This paper is part of a series of Thematic Background Papers (TBP):

1. **The Case for Renewable Energies** — ***José Goldemberg***, Universidade de Sao Paulo, Brazil

2. **Setting Targets for Renewable Energy** — ***Luc Werring; Joergen Henningsen***, DG TREN, European Commission

3. **National Policy Instruments**
Policy Lessons for the Advancement & Diffusion of Renewable Energy Technologies Around the World — ***Janet Sawin; Christopher Flavin***, WorldWatch Institute (WWI), USA

4. **Removing Subsidies**
Levelling the playing field for Renewable Energy Technologies — ***Jonathan Pershing***, World Resources Institute (WRI), USA

5. **Mobilising Finance for Renewable Energies** — ***Virginia Sonntag O'Brien***, Basel Agency for Sustainable Energy (BASE); ***Eric Usher***, UN Environment Programme (UNEP)

6. **Clean Development Mechanism and Joint Implementation**
New Instruments for Financing Renewable Energy Technologies — ***Axel Michaelowa***, Hamburg Institute of International Economics, (HWWA) and Perspectives, Germany

7. **Research and Development**
The Basis for wide-spread Employment of Renewable Energies — ***Joachim Luther***, Fhg-ISE Freiburg, Germany / Global Research Alliance (GRA)

8. **Capacity Development, Education and Training**
Know-how is the basic Need — ***John Christensen***, Global Network on Energy for Sustainable Development (GNESD)

9. **International Institutional Arrangements**
Bundling the Forces – but how? — ***Achim Steiner***, The World Conservation Union (IUCN)

10. **The Potentials of Renewable Energy** — ***Thomas B. Johansson***, Lund University, Sweden

11. **Traditional Biomass Energy**
Improving its Use and Moving to Modern Energy Use — ***Stephen Karekezi***, African Energy Policy Research Network (AFREPREN)

12. **Gender Equity and Renewable Energies** — ***Sheila Oparaocha***, ENERGIA

All papers are also available at the conference website: www.renewables2004.de