RENEWABLE ENERGY

A GLOBAL REVIEW OF TECHNOLOGIES, POLICIES AND MARKETS

EDITED BY

DIRK ASSMANN, ULRICH LAUMANNS AND DIETER UH

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A Global Review of Technologies, Policies and Markets

Edited by
Dirk Aßmann, Ulrich Laumanns and Dieter Uh

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Foreword

The Bonn Conference for Renewable Energies was a watershed event, bringing together a diverse range of technical and policy experts, political representatives and members of civil society who wanted to share their knowledge and discover the path to a sustainable energy future. More than 3600 participants saw how far some technologies and countries have come and how far we still have to go to reach the goal of a global economy running on clean energy.

We have also seen how far some prices can go. At the time of the conference a barrel of petroleum cost US$50, but traded a year later for up to $70 on the back of steep demand from India and China and one of the most severe natural disasters the US has ever experienced – Hurricane Katrina.

Since the conference – and hopefully in some way because of it – there is a growing acceptance that our addiction to fossil fuels makes our economies less secure and increases the likelihood that economic costs and human misery will only increase from global climate change – change that is predicted to include more frequent and more intense extreme weather events such as Katrina.

And yet for me, the most impressive part of the conference was the realization that the shift to a clean energy economy comes with enormous *opportunity* – new industries, new jobs, new wealth and greater national and international security. This shift and these opportunities can also help lift the burden of poverty from the 2 billion of our fellow citizens who survive today on less than $2 per day and must burn wood and wastes for poor and polluting energy services.

From generating clean electricity in large, offshore windfarms to small biogas digesters for a single house, the conference delegates left few stones unturned to answer the question 'Why not sustainable energy?' Some of the answers were surprising: nearly 20,000 Indian families have solar lighting because they were able to borrow money from an innovative loan programme to buy them. Some are incredibly simple: hand-cranked radios and cellphones that dramatically 'empower' local communities, and biodiesel made from local plants. And some were just impressive: the annual 30 per cent growth of the wind energy industry to 50,000 megawatts (MW) in just three decades.

Of course, some answers will only be known when the right policy meets the right technology. Getting those 'rights' together is now not just a desirable outcome, but economically imperative and environmentally urgent. For this, one outcome of the conference can help. REN21 is a global policy network designed to help rapidly expand the use of renewable energy in developing and industrial countries by bolstering the development of the best policies and decision-making at the local, national and international levels.

In these chapters I hope you find added knowledge and inspiration to continue on this necessary and intriguing path. Although we have made substantial progress, we can and must remind ourselves that sustainability is not simply a process of doing things better. It is instead a *destination* – a place where our energy demands are satisfied through resources and technology that do not leave our children and theirs with a polluted world that cannot adapt to climate change.

I hope we meet again on this exciting adventure!

Klaus Toepfer
Ex-Executive Director
United Nations Environmental Programme

List of Acronyms and Abbreviations

ADEME	Environment and Energy Management Agency (France)
AIJ	'Activities Implemented Jointly'
AIM	Alternative Investments Market (London Stock Exchange)
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
bbl	barrel (of oil)
BEDP	Bagasse Energy Development Programme (Mauritius)
BEERECL	Bulgarian Energy Efficiency and Renewable Energy Credit Line
BtL	biomass to liquids
CABEI	Central American Bank of Economic Integration
CAES	compressed air energy storage
CAREC	Central American Renewable Energy and Cleaner Production Facility
CBO	Congressional Budget Office (US)
CD	capacity development
CDM	Clean Development Mechanism (Kyoto Protocol)
CEO	chief executive officer
CER	Certified Emission Reduction
CHP	combined heat and power
CNG	compressed natural gas
CO_2	carbon dioxide
CRW	combustibles and renewable waste
DFI	development finance institution
DME	dimethyl ether
DNA	Designated National Authority
DNES	Department of Non-conventional Energy Sources (India)
DOE	Designated Operational Entity
EB	Executive Board (of the Clean Development Mechanism)
EBRD	European Bank for Reconstruction and Development
ECA	export credit agency
EGAT	Electricity Generating Authority of Thailand
EIT	economy in transition
EJ	exajoule
ERU	emission reduction unit
ESMAP	Energy Sector Management Programme (World Bank)

ETBE	ethyl tertiary-butyl ether
ETEF	Empowerment Through Energy Fund
EU	European Union
EVA	Austrian Energy Agency
FAME	fatty acid methyl ester
FI	financing institution
FSU	former Soviet Union
GATT	General Agreement on Tariffs and Trade
GDB	Global Development Bond
GEF	Global Environment Facility (United Nations Environment Programme)
GEIX	Global Energy Innovation Index
GHG	greenhouse gas
GNESD	Global Network on Energy for Sustainable Development
GREFF	Global Renewable Energy Fund of Funds
Gtoe	gigatonnes of oil equivalent
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
GVEP	Global Village Energy Partnership
GW	gigawatt
HVAC	heating, ventilation, air conditioning
HVDC	high-voltage direct current
IAEA	International Atomic Energy Agency
IBT	improved biomass technology
ICT	information and communication technologies
IEA	International Energy Agency
IET	International Emissions Trading (Kyoto Protocol)
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IPSE	Intergovernmental Panel on Sustainable Energy (proposed)
IREDA	Indian Renewable Energy Development Agency
ITDG	Intermediate Technology Development Group
IUCN	World Conservation Union
JI	Joint Implementation (Kyoto Protocol)
JREC	Johannesburg Coalition for Renewable Energy
KCJ	Kenya Ceramic Jiko
Ksh	Kenyan shilling
LAC	Latin America and the Caribbean
LDC	less developed country
LPG	liquefied petroleum gas
MBT	modern biomass energy technology
MDG	Millennium Development Goal

MMSD	Mining, Minerals and Sustainable Development Project
MNES	Ministry of Non-conventional Energy Sources (India)
MRET	Mandatory Renewable Energy Target (Australia)
MTBE	methyl tertiary-butyl ether
Mtoe	megatonnes of oil equivalent
MW	megawatt
MWe	megawatt electrical
NFFO	Non-Fossil Fuel Obligation (United Kingdom)
NGO	non-governmental organization
NO_x	oxides of nitrogen
NREA	New and Renewable Energy Agency (Egypt)
NREL	National Renewable Energy Laboratory (US)
ODA	Official Development Aid
OE	Operational Entity
OECD	Organisation for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets (United Kingdom)
OLADE	Organización Latinoamericana de Energía
OPEC	Organization of the Petroleum Exporting Countries
OPIC	Overseas Private Investment Corporation
OTEC	ocean thermal energy conversion
OWC	oscillating water column
PCF	Prototype Carbon Fund
PDD	Project Design Document
PES	public electricity supplier(s)
PPA	power purchase agreement
ppmv	parts per million by volume
PPO	pure plant oil
PRSP	Poverty Reduction Strategy Paper
PSE	producer subsidy equivalent
PTC	production tax credit
PURPA	Public Utilities Regulatory Act 1978 (US)
PV	photovoltaic(s)
R&D	research and development
RD&D	research, development and demonstration
RE	renewable energy
REC	renewable energy certificate
REEEP	Renewable Energy and Energy Efficiency Programme (REEP)
REILP	Renewable Energy and International Law Project
REN21	Renewable Energy Network for the 21st Century
RES	renewable energy source(s)
RESCO	rural energy service company
RES-E	Electricity from Renewable Energy Source
RET	renewable energy technology

RIGES	Renewables-Intensive Global Energy Scenario
RO	Renewables Obligation (England and Wales)
ROC	Renewable Obligation Certificate
ROE	return on investment
RPS	Renewables Portfolio Standard
RTE	renewable technology
SDHW	solar domestic hot water
SEFI	Sustainable Energy Finance Initiative
SEWA	Self-Employed Women's Association (India)
SHS	solar home system
SHW	solar hot water
SI	Shell International
SMEs	small and medium-size enterprises
SNG	substitute natural gas
STE	solar thermal electricity
SWERA	Solar and Wind Resource Assessment
TBE	traditional biomass energy technology
TBP	Thematic Background Paper
TREC	tradable renewable energy certificates
TWh	terawatt-hour
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAT	value added tax
WBGU	German Advisory Council on Global Change
WCD	World Commission on Dams
WEC	World Energy Council
WEHAB	Water, Energy, Health, Agriculture and Biodiversity
WSSD	World Summit for Sustainable Development
WTO	World Trade Organization

Introduction

The International Conference for Renewable Energies (Renewables 2004) that took place in Bonn, Germany, in June 2004 marked a major highlight in the growing worldwide discussion on the role of renewable energies in the future global energy mix. In many countries all over the world there is a growing awareness of the opportunities and potentials that renewable energy (RE) might have in the short and in the long term. Nevertheless, tapping these potentials needs political will and action. This will have to include the establishment of favourable framework conditions, the involvement of the finance and business sectors in order to enable investment in RE, and the development of capacities both in industrialized and in developing countries.

Taking a look at the history of energy systems, the 'renewable energy age' is not a new phenomenon. It already existed before fossil fuels were discovered and was used on an increasingly large scale in the context of industrialization. Over the subsequent decades, different types of coal were discovered; then oil was added to the mix as a very user-friendly type of energy source, especially for mobile purposes. In the 20th century, natural gas became an increasingly important source of energy for the modern economies of the world. Nuclear energy, which was introduced in the 1950s, is, in contrast, a very complex technology that requires large investments. It can therefore only be a technology option for industrialized and politically stable countries if the risks are accepted by societies.

Now, some centuries after the starting point of the fossil fuel age, the world is faced with the negative consequences of the present energy system: carbon dioxide (CO_2) concentration in the atmosphere is constantly increasing and the effects of global warming are becoming ever more evident. As the Intergovernmental Panel on Climate Change (IPCC) points out in its third Assessment Report, there is an urgent need for action in order to achieve a low-carbon global energy system.

After decades of growth in energy consumption and with the rapidly increasing energy demand in transition and developing countries, the 'mid-depletion point' of oil (and gas) resources is near. Given the relevance of energy for economic development and welfare, the following facts underline the necessity for transition of the global energy system.

One-third of humankind still lives in poverty – which also means energy poverty. Around 2 billion people have no access to modern forms of energy. The lack of a sufficient and affordable modern energy supply limits the opportunities for the poor to improve their quality of life and contributes to the increase of migration from rural areas to the cities.

The global implementation of RE technology can contribute significantly to addressing these problems. However, there are some key issues that need to be considered. Generally, the introduction of any new, innovative technology in an existing market requires some preconditions:

- There has to be a demand for the new product through an added value in terms of comfort or economic, social and environmental benefits.
- The product must be affordable in relation to income or investment.
- A structure of support for the product is necessary: information, awareness, maintenance, quality standards, improvement by research and development (R&D).

Therefore, the introduction of new technologies rests on three pillars:

1 The policy framework must be favourable, as policy not only has to consider today's markets but also needs to take into account long-term developments, as much on a national as on an international level.
2 Financing for the new technology must be available; it is therefore essential that investments are commercially attractive in order to mobilize resources from private companies and financing institutions.
3 A supporting environment is crucial, including capacities for information, awareness-raising, R&D, after-sales service and know-how on the technologies, from primary education up to universities.

This book constitutes a review of the different determining factors that drive the worldwide dissemination of renewable energy technologies. With a clear emphasis on policy and action, contributions from outstanding international experts on renewable energy combine to form a holistic picture of the current status, impacts and future potential of renewable energies. Each chapter deals with a different issue, including detailed information on social, environmental, political, economic and technological aspects.

To start with, José Goldemberg makes the case for REs by outlining their benefits and emphasizing the need to increase RE worldwide. This chapter is followed by Thomas Johansson, Kes McCormick, Lena Neij and Wim Turkenburg's contribution in which the authors demonstrate the huge potential of RE and explain the state of the art of the various renewable energy technologies. Dirk Aßmann, Niklas Sieber and Ricardo Külheim describe the situation of the transport sector and analyse the potential role of biofuels in view of high oil prices and the relevance of transport for climate change. In this sense the chapter represents a critical contribution to the debate on sustainability in the transport sector – in terms not only of renewable but also of 'conventional' options.

In Part 2 of the book, on policies, Janet Sawin and Christopher Flavin describe and compare strategies and instruments for the promotion of RE on the national policy level: feed-in tariffs versus quotas, tax relief, subsidies, loans and renewable energy portfolio standards. An increasing number of countries have developed a range of valuable experience in the utilization of these instruments, allowing the authors to give some interesting examples for best practices. Franco Fugazza and Richard Schlirf on their part reflect on the importance of a functioning and favourable regulation for the deployment of renewable energies, supporting their arguments with case studies. An important matter for concern, and not only for RE, is the subsidies for fossil fuels that impede the creation of a level playing field. Jonathan Pershing and Jim Mackenzie scrutinize the rationale for subsidies and consider its effects, outlining the need for policy reform.

With the contribution from Achim Steiner, Thomas Wälde, Adrian Bradbrook and Frederik Schutyser we touch on another key aspect of energy policy: the question of how to organize an international driving force for the promotion of renewable energies. Against the background of the proposal of an International Renewable Energy Agency (IRENA) from the World Council for Renewable Energy (WCRE), the chapter discusses the state of international cooperation and potential future developments.

The third part of the book focuses on financing aspects of RE. Virginia Sonntag-O'Brien and Eric Usher start off by describing the investment conditions in the energy sector in general, then elaborating on the specific investment conditions for RE. Their proposal on how to develop financing solutions for RE constitutes a very interesting new approach. The Kyoto Protocol opens a window of opportunity for additional investments in RE: Axel Michaelowa, Matthias Krey and Sonja Butzengeiger explore the possibilities for RE projects deriving from Joint Implementation (JI) and the Clean Development Mechanism (CDM).

Part 4 places the emphasis on developing countries. In their contribution on RE, Susan McDade, Minoru Takada and Jem Porcaro assess its benefits of for developing countries and the role of development cooperation in the promotion of RE. Stephen Karekezi, Kusum Lata and Suani Teixeira Coelho offer some insights on a very difficult and often forgotten issue: the traditional use of biomass and its corresponding challenges, such as the need to improve its use and move to modern energy. Joy Clancy, Sheila Oparaocha and Ulrike Roehr examine the impact of energy issues on gender equity. Their chapter addresses gender aspects of household energy, and reflects on how different renewable energy technologies can contribute to reduce workload and save time, particularly for women.

The final part of the book looks into the issue of capacity development for RE. Since RE technology is still relatively new and underdeveloped, the need for capacity development in this area (including training, education, awareness creation and R&D) is considerable. In his contribution, John Christensen describes the history of capacity development in the energy sector with regard to the situation both in developed and in developing countries. Carsten Agert and Joachim Luther highlight the role of R&D in improving renewable energy technologies and reducing their costs. Although some of these technologies are not competitive today, they will be in the future. We know that the cost curve of fossil fuels will rise, whereas the specific costs of renewable energy technologies are continuously declining.

Most of the chapters have been written as Thematic Background Papers in preparation for the Renewables 2004 conference. For this publication they have been updated and revised in order to reflect recent developments and provide actual data. The editors, who have all been involved in the thematic preparation of renewable 2004, would like to thank the authors and the publisher, Earthscan, for their contribution to this collection, and for the good and constructive cooperation. We hope to have compiled an interesting text for the whole 'renewable energy community' and beyond. We wish all readers new insights, new ideas and interesting further discussions.

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PART ONE

BASICS

1

The Case for Renewable Energies

José Goldemberg

Introduction

All energy used by humankind originates from one of the following sources: radiant energy emitted by the sun (solar energy and its derivates); geothermal energy from the interior of earth; tidal energy originating from the gravitational pull of the moon; and nuclear energy.

By far the largest source is solar energy, thousands of times larger than all the others and inexhaustible for as long as the sun shines (approximately 4.5 billion years). Table 1.1 compares the energy available on earth with present energy consumption and fossil fuel reserves.

Long availability is not the only criterion by which to judge an energy source. The way it is converted into forms that meet our needs, environment and health issues – at the local, regional and global level – the problem of guaranteeing

Table 1.1 *Energy available on earth*

Type of source	$\times 10^{12}$ *watts*
Solar	174,000
Geothermal	32
Tidal	3
Present world energy consumption*	12.7
Photosynthesis	40
Winds, waves, convection and currents	370
Fossil fuel reserves (mainly coal)	≈ 2000

Note: The world's average primary energy consumption (2001) is 2.1 kW per capita.
Source: Hubbert (1971)

energy security, and the overriding social issues such as the connection between energy and poverty, employment generation and gender also have to be addressed.

We will show in this chapter that the present energy system, essentially based on the use of fossil fuels (not renewable), cannot handle these problems very well and that increasing the share of renewable energies is one of the best ways of addressing them. We will specifically address the following aspects:

1 the contribution of renewable energy to mitigating climate change;
2 innovation, local markets and employment generation;
3 diversification of energy supply, energy security and prevention of conflicts over natural energy resources;
4 poverty reduction through improved energy access and gender aspects;
5 health-related impacts (local air pollution, indoor air pollution);
6 positive spill-over effects to other sectors and further benefits.

In the concluding section some recommendations will be made.

Renewable energy: some characteristics

Solar energy manifests itself as low-temperature solar heat, high-temperature solar heat, wind electricity and photovoltaics. Low-temperature solar heat is produced by the absorption of sunlight by darkened surfaces that convert it into heat, which can be used for warming water or other fluids. High-temperature solar heat can be obtained by focusing sunlight and heating fluids to a high temperature so that they can be used to generate electricity. The warming of the atmosphere by solar heating leads to turbulence manifested as wind, which can be used to generate electricity. Photovoltaics is the direct conversion of the ultraviolet component of sunlight into electricity in appropriate surfaces. These forms of energy are all, by definition, renewable.

Geothermal energy manifests itself in the form of hot water or vapour and can be used for heat or electricity production in some specific regions. It is generally considered to be a renewable energy source. Tidal energy can be used to generate electricity in some coastal areas and is also a renewable source of energy.

Hydropower is indirectly linked to sunlight, which evaporates the water in the oceans, which then precipitates on land masses as rain, and forms rivers. Dams are built on the resulting rivers to create reservoirs, which guarantee a steady supply of water for electricity generation. A large dam is a dam with a height of 15 metres or more, measured from the foundation. Small dams are smaller than that or have no storage reservoir. Usually they produce less than 10 megawatts (MW) of electricity. Large hydropower plants flooding large areas might displace people and have undesirable ecological or social impacts, so they are considered to be a non-renewable resource by some. Small hydropower plants are usually not affected by such problems.

A small part of the solar energy reaching the earth is converted by photosynthesis into biomass (organic matter). Some of this matter was buried in the distant past (hundreds of millions of years) by sedimentation and earthquakes and transformed by bacterial action into coal, oil and gas, which constitute the present fossil fuel resources (which are not renewable). Biomass is usually regarded as a renewable energy except when leading to deforestation.

Box 1.1 Biomass

Biomass can be used in two ways:

- Traditional or non-commercial biomass is unprocessed biomass-based fuels, such as crop residues, fuelwood and animal dung. Such types of biomass are used frequently for cooking and heating in many developing countries, but they are of very low efficiency. Although traditional energy sources can be used renewably, they frequently lead to deforestation. This is why programmes to develop and disseminate improved biomass stoves in many African countries, China and India are so important.
- Modern biomass is biomass produced in a sustainable way and used for electricity generation, heat production and transportation (liquid fuels). It includes wood/forest residues from reforestation and/or sustainable management, energy crops, rural (animal and agricultural) and urban residues (including solid waste and liquid effluents), excluding the traditional uses of fuelwood in inefficient and polluting conversion systems. Most of the biomass used in Organisation for Economic Co-operation and Development (OECD) countries falls in this category.

The most important energy source in many developing countries is renewable only if realistically replaced. Much biomass use in developing countries, either domestic small-scale use or large-scale use for industrial purposes, is leading to deforestation. Moreover, biomass use for cooking and heating in developing countries is a major cause of serious indoor pollution, particularly for women, small children and the elderly. On the other hand, in OECD countries most biomass used is ‘modern biomass’, from wood plantations, wood, or urban or rural residues.

The advantages of renewables

The contribution of renewable energy to mitigate climate change

The present energy system is heavily dependent on the use of fossil fuels. Worldwide, coal, oil and gas accounted for 78 per cent of primary energy consumption in 2002. Fossil fuel combustion is the prime source of carbon dioxide (CO_2) emissions, which are growing at the rate of 0.5 per cent per year. Present levels have reached 377 parts per million by volume (ppmv) (CDIAC, 2005), up from 278 ppmv at the dawn of the industrial revolution two centuries ago.

Emissions of anthropogenic greenhouse gases, mostly from the production and use of energy, are altering the atmosphere in ways that are affecting the climate. As stated in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), there is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities, and that significant climate change would result if 21st-century energy needs were met without a major reduction in the carbon emissions of the global energy system during this century. Current CO_2 emission trends, if not controlled, will lead to more than a doubling of atmospheric concentrations before 2050, relative to pre-industrial levels. Changes have already been observed in climate patterns that correspond to scientific projections based on increasing concentrations of greenhouse gases.

This is a serious challenge to sustainable development, and the main strategies to prevent it are:

- more efficient use of energy, especially at the point of end use in buildings, transportation and production processes;
- increased reliance on renewable energy sources;
- accelerated development and deployment of new and advanced energy technologies, including next-generation fossil fuel technologies that produce near-zero harmful emissions.

The relative importance of these options and the order in which they become relevant depends on the stage of development of the region as well as availability of natural resources and technology. There are, however, important differences in the energy systems of OECD countries as compared with those of developing countries, as indicated in Table 1.2.

In the OECD countries, which have reached a very high level of development, gains in energy efficiency have been the main strategy followed. In developing countries, where renewables (mainly biomass) are already very important (20.0 per cent), albeit used in inefficient ways, modernization of the way they are used seems the better strategy to follow. In these countries, energy consumption is growing 2.3 times more rapidly than in OECD countries, so

Table 1.2 *Characteristics of energy systems, 2002*

	Fossil fuels (%)	*Renewable energy (%)*	*Nuclear (%)*	*Growth rate, all sources (%/year, 1971–2000)*
OECD	83.0	5.9	11.1	1.48
Developing countries	78.1	20.0	1.9	2.81

Source: IEA (2005)

there is ample space for innovation as the energy system grows. In all cases the increased use of renewables, which are carbon-free (or neutral), will contribute to reduction in CO_2 emissions and thus mitigate climate change.

Innovations, local market and employment generation

The rapidly growing renewable energy industries and service sectors in many countries show clear evidence that the systematic promotion of such new technologies offers great opportunities for innovation, for the development of energy markets with locally or regionally oriented value chains, and thereby for the creation of new jobs with very different qualification requirements. While the development and deployment of new state-of-the-art renewable energy technologies, such as wind or photovoltaic energy, require highly skilled, knowledge-intensive workforces in industrialized countries, developing countries can, for instance, benefit economically from an increased use of improved biomass-based energy generation, both in terms of better availability of energy for productive use and through the provision of energy services as such. Examples are the widespread use of improved wood and charcoal cooking stoves in Kenya and other African countries as well as the production of ethanol – an excellent substitute for gasoline in the Otto cycle in internal combustion engines – from sugar cane in Brazil.

Generally speaking, renewable energies are important for local employment and income generation, which result from manufacturing, project development, servicing and, in the case of biomass, rural jobs for the biomass production.

Usually renewable energy devices are decentralized, are modular in size and have low operating costs in addition to involving short construction times, which means much greater flexibility in energy planning and investment. Table 1.3 provides an idea of the number of jobs per unit of energy generated from different sources.

These numbers were obtained from a variety of sources and include jobs involved in operating the generating stations as well as the jobs involved in producing and maintaining the equipment. Photovoltaic energy is usually generated (and used) in small modules of 100 watts, and the generation of 1 terawatt-hour (TWh) would require typically 10 million modules to be installed and maintained. This is the reason why a large number of jobs are created. Ethanol production involves large plantations of sugar cane, which again explains why numerous jobs are generated.

The main beneficiaries of the adoption of renewable sources of energy will be the developing countries, where biomass, and particularly fuelwood, is used widely with very inefficient and wasteful technologies for cooking and heating. In such countries the modernization of the use of biomass could bring great benefits, including – among others – a reduction in deforestation.

Table 1.3 *Direct jobs in energy production*

Sector	*Job-years/Mtoe (fuel production)*	*Job-years/terawatt-hour (fuel production + power generation)*
Petroleum[a]	396	260
Offshore oil[a]	450	265
Natural gas[a]	428	250
Coal[a]	925	370
Nuclear[b]	100	75
Wood energy[c]		733–1067
Hydro[d]		250
Minihydro[e]		120
Wind		918[(e)]–2400[(f)]
Photovoltaics		29,580–107,000[(e)]
Bioenergy (from sugar cane)		3711–22,5392

Notes:

a The staff level for operation of a 1350-megawatt (MW) nuclear power plant in the US, producing 9.45 TWh/year (or 2.138 million tonnes of oil equivalent (Mtoe)/year) at an efficiency of 38 per cent, was 500 people.

b Electric generation based on herbaceous crops (5.5 direct jobs/megawatt electrical (MWe)) and on forestry crops (8 direct jobs/MWe), utilization 7500 h/year.

c World installed capacity for wind 17,300 MW, utilization 2000 h/year and 4.8 jobs/MW.

d Including 12 different activities to construct, transport, install and service 1 MW of photovoltaics (not including economies of scale between 2 kW and 1 MW), world installed photovoltaics capacity is 800 MW.

e Utilization of 1200 h/year; 35.5 jobs/MW (including 15 different activities to manufacture, transport, install and service 1 MW of wind power).

f Ethanol industry provides 33 direct jobs/million litres in Brazil, where ethanol production in the 1992–2001 period ranged between 10.6 and 15.4 billion litres/year (LHV of ethanol 6500 kcal/kg and density 0.8 kg/litre); energy production comprised 7 Mtoe of ethanol fuel, plus 9.6 TWh/year of cogeneration (installed capacity 2000 MW, utilization of 4800 hours/year).

Sources: [a] Grassi (1996); [b] Electric Power International (1995), Grassi (1996); [c] Grassi (1996); [d] Carvalho and Szwarcz (2001); [e] Perez (2001); [f] IEA (2002b)

Diversification of energy supply, energy security and prevention of conflicts about natural resources

Maintaining energy security in today's industrialized countries comes at high, but usually hidden, costs that find expression in military and security spending. The volatile world market prices for conventional energy sources, in particular oil, pose great risks for large parts of the world's economic and political stability, with sometimes dramatic effects on energy-importing developing countries. In this context, renewable energies can help to diversify energy supply and to increase energy security. They should increase the economic benefits that result from transformations in energy trading patterns. Additionally, in the mid- and long-term perspective renewable energies prolong the availability of most fossil fuels for the satisfaction of both energy needs and numerous other non-energy needs.

The potential for conflict, sabotage, disruption of production and trade of fossil fuels and fissionable materials cannot be dismissed. As far as electricity supply is concerned, this is dramatized by recent 'blackouts' in the eastern US, the United Kingdom and Italy, probably due to accidents, which are difficult to eliminate in highly centralized production and distribution systems. As far as oil is concerned, potential threats lead to sudden transient price increases (price spikes) that cause economic problems in many countries, and disrupt global economic growth.

The present energy system found in industrialized countries is heavily dependent on fossil fuels, which are geographically concentrated in a few regions of the world. Dependence on imported fuels leaves many countries vulnerable to disruption in supply, which might pose physical hardships and an economic burden for others; the effect of fossil fuels imports on their balance of payments is unsustainable for some countries (Box 1.2).

To reduce such dependence is a high priority in many countries, particularly as regards oil imports in developing countries, which frequently spend a large fraction of their foreign currency earnings on oil imports. Just to give an example: oil imports consume half of all export earnings in Barbados, and a similar situation is widespread among oil-poor countries. To increase the share of indigenous renewable energy in their system is an important step in solving this problem.

Poverty reduction through improved energy access and gender aspects

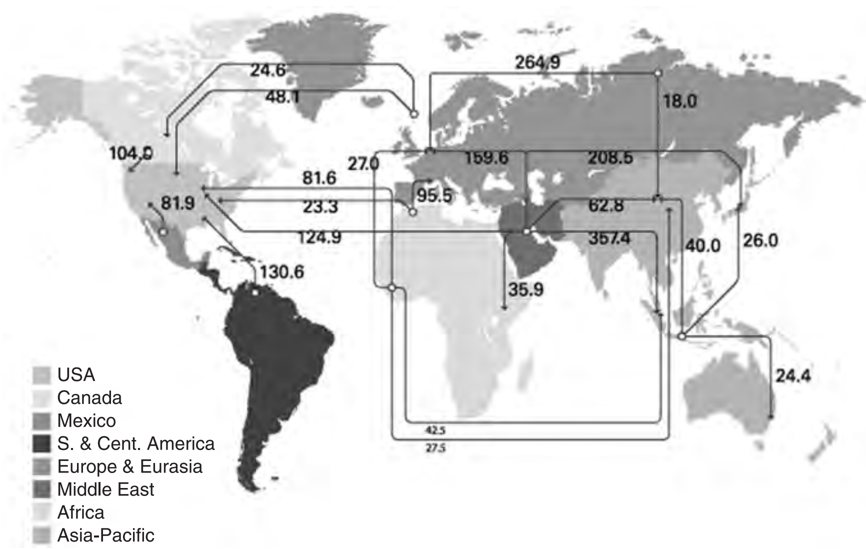
The enhanced use of renewables is closely linked to poverty reduction and elimination, since energy services can:

- improve access to pumped clean water for drinking and for cooking food to reduce hunger (95 per cent of food needs cooking);
- reduce the time spent by women and children on basic survival activities (gathering firewood, fetching water, cooking, etc.);
- provide lighting that permits home study, increases security and enables the use of educational media and communication in school; and
- reduce deforestation.

More than 2 billion people cannot access affordable energy services based on the efficient use of gaseous and liquid fuels, and on electricity, and are dependent on gathering fuelwood and fetching water. This lack of access to affordable energy constrains their opportunities for economic development and improved living standards. Women, the elderly and children suffer disproportionately because of their relative dependence on traditional fuels, and exposure to emissions from cooking is the main cause of respiratory disease in these groups. Access to electricity through transmission distribution lines is unlikely to be possible in

Box 1.2 Flow of Gulf oil supplies, 2010

Almost two-thirds of the world's oil resources are in the Middle East, mostly in the Gulf region (the Islamic Republic of Iran, Iraq, Kuwait, Qatar, Saudi Arabia and the United Arab Emirates), although these six countries now account for only 26 per cent of global crude oil supplies (IEA, 2005). They are expected to double their share to 53 per cent in 2010 (UNDP, WEC and UNDESA, 2000). All OECD countries are expected to increase their dependence on oil imports over the next few years. Their imports, 56 per cent of their requirements in 2000, are expected to rise to 76 per cent in 2020. Asia-Pacific countries' crude oil imports are expected to increase to 72 per cent of their requirements in 2005 (up from 56 per cent in 1993). The Middle East is expected to account for 92 per cent of the region's imports. The Gulf region is expected to supply 18 million barrels a day to Asia-Pacific countries in 2010.



Source: BP Global (2005)

Figure 1.1 *Major oil trade movements, 2004 (million tonnes)*

many parts of the world for a long time, so access to modern, decentralized small-scale energy technologies – particularly renewables – is an important element of successful poverty alleviation. The revenues from exported biofuels are another important element for alleviating poverty in developing countries.

Health-related impacts

The main pollutants emitted in the combustion of fossil fuels are sulphur and nitrogen oxides, carbon monoxide and suspended particulate matter. Ozone is formed in the troposphere from interaction among hydrocarbons, nitrogen oxides and sunlight. The environmental impacts of a host of energy-linked emissions – including suspended fine particles and precursors of ozone and acid deposition – contribute to local and regional air pollution and ecosystem degradation. Human health is threatened by high levels of the pollution resulting from fossil fuel combustion. At the local level, energy-related emissions from fossil fuel combustion, including in the transport sector, are major contributors to urban air pollution, which is thought to be responsible for some hundreds of thousands deaths annually around the world. At the regional level, precursors of acid deposition from fuel combustion can be precipitated thousands of kilometres from their point of origin – often crossing national boundaries. The resulting acidification is causing significant damage to natural systems, crops and human-made structures, and can, over time, alter the composition and function of entire ecosystems. Table 1.4 shows some of the consequences of the use of fossil fuels. Needless to say, renewables contribute relatively little to these emissions.

Positive spill-over effects to other sectors and further benefits

One of the problems with renewables is the fact that some of them are intermittent. This is indeed the case for photovoltaics, which requires sunshine, and for wind, which tends to be erratic in some locations. However, geothermal energy, small hydro schemes and especially biomass do not suffer from such shortcomings. In the case of photovoltaics, which is eminently suited for decentralized use in rural remote areas that cannot be reached by the electricity grid, the use of automobile or solar batteries for storage has proved to be a sensible and practical way of supplying electricity for lighting in the evenings when it is most needed, and the same applies to other uses such as for radio, television, communications and refrigeration. In the case of wind, the problem of intermittency can be solved by feeding the electricity generated into large grids, as is done in Denmark, Germany and the United Kingdom. Another

Table 1.4 *Environmental and health problems*

Insult	*Human disruption index*	*Share of the human disruption caused by fossil fuel burning (%)*
Oil added to oceans	10	44
Sulphur emissions to atmosphere	2.7	85
Nitrous oxide flow to atmosphere	0.5	12
Particulate emission to atmosphere	0.12	35
Carbon dioxide flow to atmosphere	0.05	75

Note: The human disruption index is the ratio of human-generated flow to the natural (baseline) flow.
Sources: UNDP, WEC and UNDESA (2003)

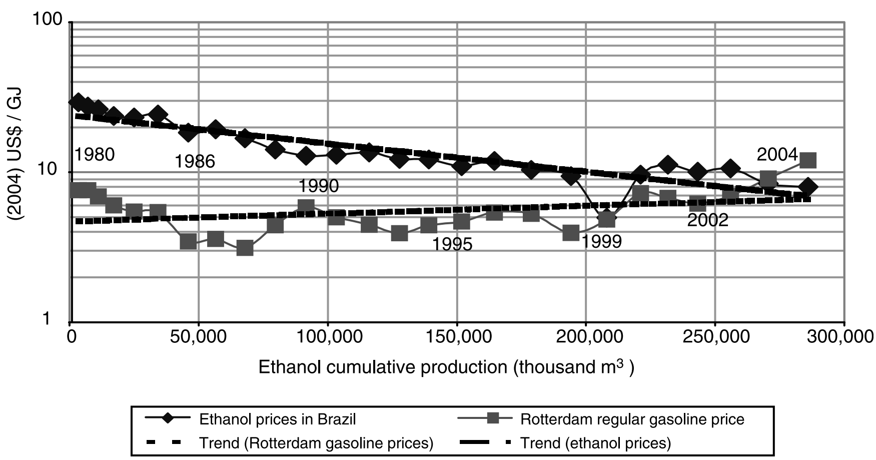
solution is the installation of hybrid systems with several sources of different energy profile.

One of the most striking successes of renewables is the ethanol programme in Brazil, where ethanol is produced from sugar cane and has replaced half the gasoline that would otherwise be consumed in the country (using roughly 4 million hectares of land). In this case, most of the energy needed for the processing of the raw material to the final product comes from the bagasse (the residue from sugar cane after the crushing process), requiring very little by way of 'external' sources of supply in the form of fossil fuels (in the agricultural part of sugar cane production). This is the reason why the energy balance for ethanol production in Brazil is 10:1 and the production of ethanol from corn in the US has an energy balance of approximately 1.5:1. The technological progress in this area, in both the agricultural and the industrial sectors, is striking and in Brazil, as well as economies of scale, has led to an impressive reduction in the costs of ethanol production. Indeed, Brazilian ethanol is presently competitive with gasoline in Rotterdam (Figure 1.2).

The Brazilian success story has led to intensive research to produce liquid fuels from cellulosic materials, a very promising area since the resource base of biomass is so widespread all over the world. Developed countries have a significant role to play in introducing biofuels into their energy systems, either directly or blended with gasoline or diesel.

Conclusions

The full potential and advantages of renewables are not clearly manifest at present because the costs of fossil fuels do not reflect their full cost. They are



Source: Goldemberg et al (2003), updated to 2005

Figure 1.2 *Prices of gasoline in Rotterdam and ethanol in Brazil* subsidized in several parts of the world, and the 'externalities' associated with them, such as additional health and environmental costs, are not considered. Removing subsidies from fossil fuels would make renewables competitive in many areas. Generally speaking, the use of renewables might benefit from bilateral and regional cooperation. After the Johannesburg World Summit for Sustainable Development (WSSD), a number of programmes to promote sustainable energy programmes in developing countries were presented to the United Nations Secretariat. Of these programmes, 23 had energy as a central focus and a further 16 would have a considerable impact on energy use. They included most prominently the DESA-led Clean Fuels and Transport Initiative; the UNDP/World Bank-led Global Village Energy Partnership (GVEP); the UNDP/LPG Association-led LPG Challenge; the EdF/ACCESS-led Alliance for Rural Energy in Africa (AREA); the EU Partnership on Energy for Poverty Eradication and Sustainable Development; and the UNEP-led Global Network on Energy for Sustainable Development (GNESD). Particularly important among them is the Johannesburg Coalition for Renewable Energy (JREC), to which more than 80 countries have adhered. The enhanced use of renewables, with its reliance on decentralized production, employment generation and reduction of environmental impacts, is a general characteristic of most of these programmes.

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2

The Potentials of Renewable Energy

Thomas B. Johansson, Kes McCormick, Lena Neij and Wim C. Turkenburg

Introduction

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 (see Box 2.1). Technologies exist that convert renewable energy flows to modern energy carriers or directly into desired energy services. Technological development during the past few decades has resulted in modern renewable energy supply becoming competitive in a number of 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 the development and dissemination of renewable energy technologies and systems, all human energy needs could be met by rerouting a small fraction of naturally occurring renewable energy flows within a century.

Although natural flows of renewable resources are immense in comparison with global energy use – from both a theoretical and a technical perspective – the level of their future use will primarily depend on the economic performance of technologies utilizing 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 probably 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.

Box 2.1 Definition of renewable energy

In a broad sense, the term ‘renewable energy sources’ refers to hydro energy, 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, these are modern biomass energy, geothermal heat and electricity, small-scale hydropower, low-temperature solar heat, wind electricity, solar photovoltaic and thermal electricity, and ocean energy (tidal, wave, current, ocean thermal, osmotic and marine biomass energy).

In 2004, renewable energy provided 17 per cent of global primary energy consumption, mostly traditional biomass, and about 19 per cent of electricity, mostly large-scale hydropower. ‘New’ renewables contributed only 2 per cent of the world’s primary energy use. However, ‘new’ renewables, often based on indigenous resources, have the potential to provide energy services with low or zero emissions of both air pollutants and greenhouse gases.

Discussions on biomass as a source of energy are sometimes clouded by problems of definition. The term ‘combustible renewables and waste’ 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 modern energy carriers. The main biomass fuels in developing countries are firewood, charcoal, agricultural residues and dung, often referred to as traditional biomass. The major challenge facing biomass is to shift towards sustainable technologies and systems while reducing costs.

Source: WEA (2004); REN21 (2005)

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 commercialization, 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 internalizing externalities) will make ‘new’ renewables more competitive. However, such measures remain controversial. In any case, barriers stand in the way of the accelerated development of renewable technologies, which can only be overcome by appropriate frameworks and policies.

This chapter comprises several sections. The first section discusses the theoretical and technical potentials of renewable energy resources and technologies with subsections on technology options and status, and the associated environmental and social issues. The second section explores the economic potentials of renewable energy, with a particular focus on cost reductions and technological development. The third section outlines a selection of scenarios that have been developed to illustrate future energy systems. The fourth section looks at the markets where renewable energy might compete and make a difference, particularly in the case of developing countries. The fifth section identifies the barriers that renewable energy innovations confront all along the innovation chain, and highlights the role played by industrialized countries in developing and disseminating novel technologies. The chapter concludes with policy implications and recommendations that relate to many sectors, including land use, agriculture, buildings, transportation and urban planning.

Renewable energy resources and technologies

The natural energy flows through the earth's ecosystem, and the theoretical and technical potential of what they can produce for human needs, exceed current energy use by many times, which in 2004 was approximately 470 exajoules (EJ) including traditional biomass (WEA, 2004; BP, 2005; REN21, 2005).[1] The long-term energy resource availability from the viewpoint of theoretical maximums is immense (see Table 2.1). 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 will not act as a constraint on their development (WEA, 2000; Boyle, 2004; Hoogwijk, 2004; IEA, 2004; WEC, 2004).

In 2004, renewable energy sources supplied about 17 per cent of the world's primary energy use, predominantly traditional biomass, used for cooking and heating, especially in rural areas of developing countries (REN21, 2005). Large-scale hydropower supplied about 16 per cent of global electricity (BP, 2005). The scope to expand large-scale hydropower is limited in the industrialized world, where it has almost reached its economic capacity. In the developing world, potential still exists, but large hydropower projects often face financial,

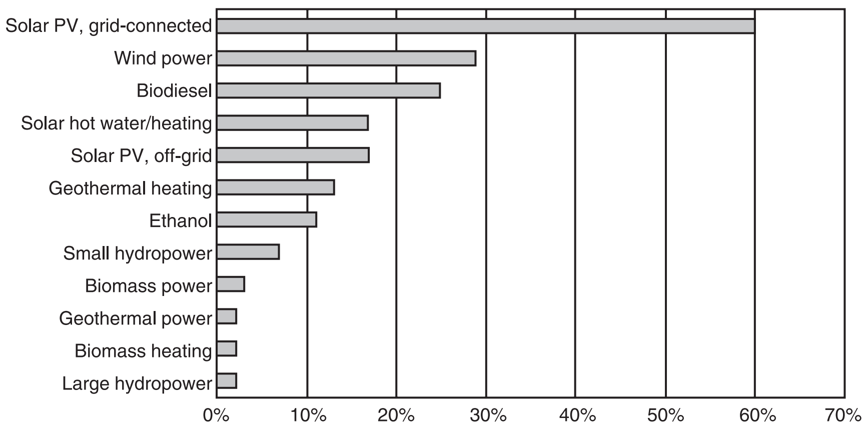
Table 2.1 *Annual global renewable energy resources*

Energy resource	*Energy use, 2001 (EJ/yr)*	*Technical potential (EJ/yr)*	*Theoretical potential (EJ/yr)*
Hydro energy	9.4	50	150
Biomass energy	45.0	>250	2900
Solar energy	0.2	> 1600	3,900,000
Wind energy	0.2	600	6000
Geothermal energy	2.1	5000	140,000,000
Ocean energy	—	—	7400
TOTAL	**~57**	**> 7500**	**>143,000,000**

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

Source: WEA (2004)

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 ocean energy) contribute about 2 per cent of the world's energy use (WEA, 2004; REN21, 2005). However, the dissemination of several 'new' renewables displays impressive growth rates (see Figure 2.1).



Source: REN21 (2005)

Figure 2.1 *Average annual growth rates of renewable energy capacity, 2000–2004*

Hydro energy

Hydropower 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. The total theoretical potential of hydro energy is estimated at 150 EJ a year and the technical potential is estimated at 50 EJ a year (WEA, 2000). 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.

Technology options and status

Large-scale hydropower generation is regarded as a mature technology, unlikely to advance further. Refurbishment of plants has shown that advanced technologies can increase the energy output at essentially unchanged water flows. 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 2004 can be estimated at 720 gigawatts (GW) for large hydro and 62 GW for small hydro (REN21, 2005).

Environmental and social issues

Considering the criticism of large dams, modern construction tries to include in the system design several technologies that minimize the social and ecological impacts. Some of the negative impacts are the displacement of local communities (particularly indigenous people), changes in fish biodiversity, sedimentation, biodiversity perturbation, water quality standards, human health deterioration, and downstream impacts (WCD, 2000a). The World Commission on Dams (WCD) has done substantial work on this issue and elaborated a comprehensive set of recommendations for reconciling conflicting demands surrounding large dams (see Box 2.2).

Box 2.2 Principles for dams and development

- *Gaining public acceptance*. Wide public acceptance of key decisions is imperative for equitable and sustainable water and energy resources development.
- *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.
- *Addressing existing dams*. Opportunities exist to improve existing dams, respond to remaining social issues, and strengthen environmental and restoration measures.
- *Sustaining rivers and livelihoods*. Understanding, protecting and restoring ecosystems is important to protect the welfare of all species and to foster equitable human development.
- *Recognizing 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.
- *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.
- *Sharing rivers for peace, development and security*. Dams with a transboundary impact require constructive cooperation and good faith negotiation among riparian states.

Source: WCD (2000a)

It is important to note that the WCD also recognizes that hydropower projects (not including the construction phase) can produce very low greenhouse gas emissions and air pollutants. However, in some cases the greenhouse gas emissions can be high and actually surpass those resulting from thermal alternatives (WCD, 2000b). It is therefore advisable to conduct full life-cycle assessments to compare available options. This includes measuring carbon flows in the natural pre-impoundment watershed and identifying how these will be altered following the construction of a dam. Quantification of these changes is complex because it requires an understanding of the carbon cycle in the whole watershed (Fearnside, 2004).

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 Box 2.3). Sweden, Finland, Denmark and Austria are world leaders in creating working biomass markets that utilize 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.

Box 2.3 Types and examples of biomass

- *Woody biomass*. Trees; shrubs and scrub; bushes such as coffee and tea; sweepings from forest floor; bamboo; and palms.
- *Non-woody biomass*. Energy crops such as sugar cane; cereal straw; cotton, cassava, tobacco stems and roots; grass; bananas, plantains and the like; soft stems such as pulses and potatoes; and swamp and water plants.
- *Processed waste*. 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; and municipal waste.
- *Processed fuels*. Charcoal from wood and residues; briquette and densified biomass; methanol and ethanol; plant oils from palm, rape, sunflower and the like; producer gas; and biogas.

Source: WEA (2000)

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. However, the potential contribution of biomass in the long term can take a variety of estimates (see Table 2.2). 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. The biomass challenge is therefore not so much an issue

Table 2.2 *Annual global biomass energy resources*

Source[a]		*Biomass type*[b]	*Biomass resources (EJ)*		
			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[c]		FR, CR, AR, MSW	62	78	
7		FR, CR, AR	87		
8[d]	A1	EC		657	1115
	A2	EC		311	395
	B1	EC		451	699
	B2	EC		322	485

Notes:

a Data from several sources, including 1: Hall et al (1993); 2: Williams (1995), 3: Dessus et al (1992); 4: Yamamoto et al (1999); 5: Fischer and Schrattenholzer (2001); 6: Johansson et al (1993b); 7: Swisher and Wilson (1993); 8: Hoogwijk et al (2005).

b FR = forest residues, CR = crop residues, AR = animal residues, MSW = municipal solid waste, EC = energy crops.

c These studies estimated the potential contribution rather than the potential available.

d These studies are based on scenarios and therefore depict several different potentials for energy crops.

of availability as one of sustainable management, conversion, and delivery to the market in the form of modern and affordable energy services (Berndes et al, 2003).

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). 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 large potential to expand. Combustion of biomass to produce electricity and heat is applied commercially in countries such as Sweden, Austria and Denmark. The globally installed capacity to produce electricity from biomass is estimated at 39 GW (REN21, 2005). 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 liquids such as diesel and methanol or gases such as substitute natural gas (SNG), dimethyl ether (DME) and hydrogen. Small gasifiers coupled to diesel or gasoline engines are commercially available on the market and applied in, for example, India and China.

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. Conversion of biomass to liquid, gaseous and solid fractions can also be achieved by pyrolysis (heating up to 500 °C in the absence of oxygen). Biodiesel can be obtained from oilseeds by using extraction and esterification techniques. In 2004 the world production was about 2.2 billion litres (REN21, 2005). 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 US. In 2004 the world production of ethanol was estimated at 31 billion litres (REN21, 2005). Finally, hydrolysis of lignocellulosic biomass is an alternative option to produce ethanol, and one that is gaining more development attention in a number of countries.

Environmental and social issues

Biomass energy can be a carbon-neutral energy source, which makes it very attractive. However, assessing the sustainability of biomass production systems often requires a full life-cycle analysis of carbon flows and greenhouse gas emissions. The ratio of carbon output to carbon input needs to be calculated taking into account all components at the farm and industrial plant levels. For example, farm inputs, such as tillage operations, fertilizers, pesticides and irrigation, can result in significant greenhouse gas emissions (SRU, 2005). Furthermore, soil carbon degradation can occur through the removal of residues or decomposable matter, which in turn depletes soils and reduces productivity (Lal, 2005).

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 could 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 crop residues and plantation biomass will result in the removal from the soil of nutrients that have to be replenished in one way or another (Lal, 2005). Ash recycling is a possible method, but the issue of soil quality and nutrients requires further research to ensure the sustainability of biomass systems (Dornburg, 2004).

Land use competition is a significant issue for the future of bioenergy, particularly energy crops. The availability of agricultural land for energy crops will be defined by population growth rates, diets (levels and types of consumption), and the intensity of farming (Hoogwijk et al, 2005). Biomass plantations will always be limited by the available land. The efficiency of land use in terms of climate mitigation and energy security is therefore an issue of importance when it comes to biomass plantations and conversion processes. For example, utilizing biomass for biofuels (especially biodiesel) is at present not as efficient from a climate change perspective as is utilizing biomass for heat and power (CONCAWE et al, 2004; Lal, 2005).

Biomass plantations can 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 process of collection, transport and use of biomass increases the use of vehicles and infrastructures, and causes emissions to the atmosphere. A wide variety of social issues, some related to environmental factors, must also be addressed to expand bioenergy.

Solar energy

Solar energy has immense theoretical potential. 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 2.3). 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 2.3 *Annual global solar energy resources*

Region	*Minimum EJ*	*Maximum EJ*
North America	181	7410
Latin America and Caribbean	112	3385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	371	9528
Pacific Asia	41	994
South Asia	38	1339
Central Asia	115	4135
Pacific OECD	72	2263
TOTAL	**1575**	**49,837**

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

Source: WEA (2000)

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 energy is utilized. These include the availability of efficient and low-cost technologies, effective energy storage technologies and high-efficiency end-use technologies. 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. The total installed capacity is currently about 0.4 GW (REN21, 2005). STE systems can be designed for solar-only applications, but also hybridized with fossil fuels to allow power production without sunlight. There are expectations that STE can begin to play a larger role in energy supply in the near future (Greenpeace and ESTIA, 2003).

Another technique to produce electricity is the direct conversion of solar light to electricity using photovoltaic (PV) systems. The cumulatively produced solar PV (off-grid and grid-connected) capacity up to the year 2004 is estimated at 4 GW (REN21, 2005). The average annual global growth rate for grid-connected solar PV is currently 60 per cent (see Figure 2.1). 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 commercially available modules is 10–17 per cent. This figure may increase to 12–20 per cent by 2010 and up to 30 per cent or more in the longer term (WEA, 2000). Very high efficiencies may be achieved by stacking cells with different optical properties. There are many types of solar cells under development or in production and 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 payback time of less than a year.

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 a hundred million square metres (WEA, 2004). The solar domestic hot water (SDHW) system is the most important application. The SDHW systems in Northern and Central Europe are designed to operate on a solar fraction of 50–65 per cent. Subtropical climates generally achieve solar fractions of 80–100 per cent (WEA, 2000). Large water heating systems find widespread use in swimming pools, hotels, hospitals and homes for the elderly, among other applications. 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.

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 having good insulation, having a responsive, efficient heating system and avoiding over-shading by other buildings. Technologies involved include low-emission double-glazed windows, low-cost opaque insulation material and high insulating building 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 reduce the demand for heat energy by a factor of 10–15 in comparison with houses built some 30–40 years ago (WEA, 2000). In such a low-energy house, renewable energies can contribute up to 100 per cent of the energy demand.

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 2–6 years, and it is expected to decrease to 1–2 years in the longer term (Alsema, 2003). For stand-alone PV systems with battery storage the situation is less favourable. The energy payback time of modern solar home systems is now 1–2 years if compared with kerosene lamps, but 10–20 years in comparison with a diesel generator set. These results are mainly determined by the batteries, with their high energy requirements and short lifetime (Alsema, 2003). 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 these modules appears to be well within limits for safe use.

Wind energy

Winds develop when solar radiation reaches the Earth, meeting clouds and uneven surfaces and creating temperature, density and pressure differences. The atmosphere circulates heat from the tropics to the poles, also creating winds (WEA, 2000). 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 up new areas to development. Furthermore, learning through experience will continue to improve the output of windfarms (see Table 2.4).

Table 2.4 *Annual global wind energy resources*

Region	*Land surface with sufficient wind conditions*		*Wind energy resources without land restrictions*	
	%	*Thousands km^2*	*TWh*	*EJ*
North America	41	7876	126,000	1512
Latin America and Caribbean	18	3310	53,000	636
Western Europe	42	1968	31,000	372
Eastern Europe and former Soviet Union	29	6783	109,000	1308
Middle East and North Africa	32	2566	41,000	492
Sub-Saharan Africa	30	2209	35,000	420
Pacific Asia	20	4188	67,000	804
China	11	1056	17,000	204
Central and South Asia	6	243	4000	48
TOTAL	**27**	**30,200**	**483,000**	**5800**

Note: The assessment includes regions where the average annual wind power density exceeds 250–300 watts per square metre at 50 metres high. The energy equivalent is calculated based on the electricity generation potential of the referenced sources by dividing the electricity generation potential by a representative value for the efficiency of wind turbines, including transmission losses, resulting in a primary energy estimate. Also, the total excludes China.

Source: WEA (2000)

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. However, wind (and solar) are intermittent energy sources, so sufficient back-up remains an important issue. There has been a gradual growth in the unit size of commercial machines, from 30 kW of generating capacity in the 1970s (rotor diameter of 10 metres) to 5 MW (rotor diameter of 110–120 metres), and more improvements are likely (WEA, 2000).

Market demands have driven the trend towards larger machines through economies of scale, less visual impact on the landscape per unit of installed power, and expectations that offshore potential will soon be greatly developed. Special offshore designs are being implemented (GWEC, 2002). Modern wind turbines also have fewer components. By the end of 2004, worldwide installed capacity had topped 48 GW, with much of the development being in Europe, mainly Germany, Spain and Denmark (REN21, 2005). In fact, electricity production from grid-connected wind turbines has been growing at an impressive rate of about 30 per cent per year (see Figure 2.1).

Large penetration of wind energy and other intermittent renewable energy technologies would become very attractive if a cheap form of large-scale electricity storage were developed. At present, there is only the virtual storage of electricity on the grid. For example, if compressed air energy storage (CAES) can be developed to become economically attractive, it could transform wind-generated electricity into a baseload power supply (WEA, 2000). In addition, there is the developing high-voltage direct current (HVDC) technology, which allows the transmission of electricity over long distances by overhead lines or submarine cables. With the HVDC system, power flow can be controlled rapidly and accurately.

Environmental and social issues

Environmental and social aspects come into play in the various phases of a wind turbine project: building and manufacturing, normal operation, and decommissioning. Negative environmental aspects connected to the use of wind turbines include acoustic noise, 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 the development of windfarms.

Geothermal energy

Geothermal energy is generally defined as heat coming from the Earth. It has a large theoretical potential but only a much smaller amount can be classified as resources and reserves. Still, even the most accessible part, classified as reserves, exceeds current annual consumption of primary energy (see Table 2.5). But as with 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 °C) are largely confined to areas with young volcanism and seismic activity. But low-temperature resources suitable for direct use can be found in most countries.

Table 2.5 *Annual global geothermal energy resources*

Region	*Millions EJ*	*%*
North America	26	18.6
Latin America and Caribbean	26	18.6
Western Europe	7	5.0
Eastern Europe and Former Soviet Union	23	16.4
Middle East and North Africa	6	4.3
Sub-Saharan Africa	17	12.2
Pacific Asia	11	7.8
China	11	7.8
Central and South Asia	13	9.3
TOTAL	**140**	**100**

Source: WEA (2000)

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, at about 5–20 per cent. In 2004 the global installed capacity for power production was 8.9 GW (REN21, 2005). Major applications can be found in the US, the 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 2004 the installed capacity for direct use (heating and heat pumps) was 28 GW (REN21, 2005).

Geothermal energy for electricity production previously had considerable economic potential only in areas where thermal water or steam is found concentrated at certain depths. 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 sink for cooling, depending on the season. These pumps can be used basically everywhere. Important applications can be found in Switzerland and the US, among others countries.

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 or electricity production.

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 2.6). 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. In a recent development the world's first

Table 2.6 *Annual global ocean energy resources*

Energy resource	*TWh*	*EJ*
Tidal energy	22,000	79
Wave energy	18,000	65
Ocean thermal energy	2,000,000	7200
TOTAL	**2,040,000**	**7344**

Note: 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 or wave energy.

Source: WEA (2000)

commercial wave farm to generate renewable electricity from ocean waves is being constructed in Portugal (Petroncini and Yemm, 2005).

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. The rise and fall of the tides creates, in effect, a low-head hydropower system. Tidal energy has been exploited in this way for centuries in the form of water mills. The largest modern scheme was built in France in the 1960s. A handful of smaller schemes have also been built. 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 OWC devices is under development. Marine currents can also 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.

Exploiting natural temperature differences in the sea by 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 °C, and this limits the application of this technology to a few tropical regions with very deep water. Offshore OTEC is technically difficult because of 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.

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.

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. However, making these renewables competitive will require further technology development and market deployment, as well as an increase in production capacities to mass-production levels (Johansson and Goldemberg, 2002; van Sark et al, 2005). The present status of 'new' renewables shows that substantial cost reductions can be achieved for most technologies (see Table 2.7).

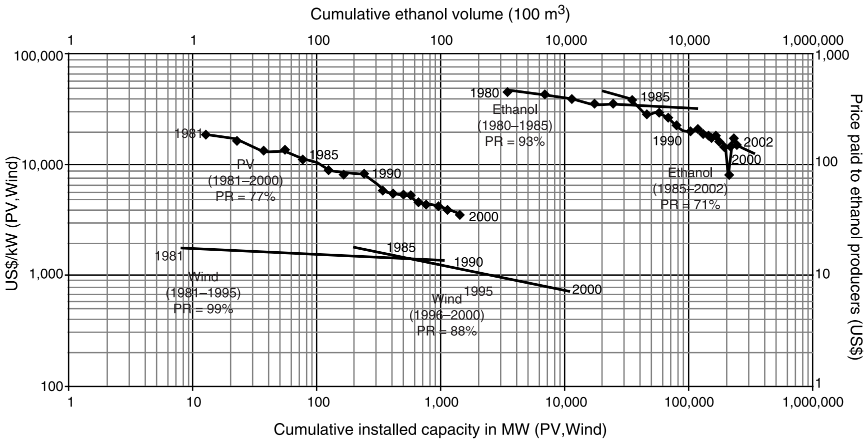
Experience curves for renewable energy

Because many renewable technologies are small in scale and modular, they are good candidates for continued cost cutting (Neij, 1997; Junginger, 2005). 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 Figures 2.2 and 2.3). Cost data are hard to find, and prices are often taken as a proxy for cost, introducing uncertainties, especially in non-competitive markets. In addition, the cost reductions illustrated by the experience curves only show the cost reduction of technologies. The cost reduction of generated heat or electricity could be larger, owing to additional sources of cost reduction such as reduced installations costs and improved availability (Neij et al, 2003). For some resources, such as hydro and wind, cost reductions of generated electricity may level off when all 'good sites' are occupied. Technologies may also mature. Furthermore, the slope of experience curves may depend on the chosen timeframe and system boundaries. The experience curves depicted here represent only a limited number of experience curves developed over recent years (see Figures 2.2 and 2.3). Experience curves have been developed for additional energy technologies, and several experience curves have been developed for one and the same technology (Junginger, 2005).

Table 2.7 *Status of renewable energy resources and technologies, 2001*

Resource and technology	*Expansion in energy production from 1997 to 2001 (%/yr)*	*Operation capacity (2001)*	*Capacity factor (%)*	*Energy production (2001)*	*Turnkey investment costs in 2001 (US$/kw)*	*Current energy cost*	*Potential energy cost*
Biomass energy							
Electricity	~2.5	~40 GWe	25–80	~170 TWh (e)	500–6000	3–12 ¢/kWh	4–10 ¢/kWh
Heat	~2	~210 GWth	25–80	~730 TWh (th)	170–1000	1–6 ¢/kWh	1–5 ¢/kWh
Ethanol	~2	~19 bln litres		~450 PJ		(8–25 $/GJ)	(6–10 $/GJ)
Biodiesel	~1	~1.2 bln litres		~45 PJ		(15–25 $/GJ)	(10–15 $/GJ)
Wind energy							
Electricity	~30	23 GWe	20–40	43 TWh (e)	850–1700	4–12¢/kWh	3–10 ¢/kWh
Solar energy							
Photovoltaic electricity	~30	1.1 GWe	6–20	1 TWh (e)	5000–18,000	25–160 ¢/kWh	5 or 6–25 ¢/kWh
Thermal electricity	~2	0.4 GWe	20–35	0.9 TWh (e)	2500–6000	12–34 ¢/kWh	4–20 ¢/kWh
Heat	~10	57 GWth	8–20	57 TWh (th)	300–1700	2–25 ¢/kWh	2–10 ¢/kWh
Hydro energy							
Large	~2	690 GWe	35–60	2,600 TWh (e)	1000–3500	2–10 ¢/kWh	2–10 ¢/kWh
Small	~3	25 GWe	20–90	100 TWh (e)	700–8000	2–12 ¢/kWh	2–10 ¢/kWh
Geothermal energy							
Electricity	~3	8 GWe	45–90	53 TWh (e)	800–3000	2–10 ¢/kWh	1 or 2–8 ¢/kWh
Heat	~10	16 GWth	20–70	55 TWh (th)	200–2000	0.5–5 ¢/kWh	0.5–5 ¢/kWh
Ocean energy							
Tidal barrage	0	0.3 GWe	20–30	0.6 TWh (e)	1700–2500	8–15 ¢/kWh	8–15 ¢/kWh
Wave	—	—	20–35	0	2000–5000	10–30 ¢/kWh	5–10 ¢/kWh
Tidal stream	—	—	25–40	0	2000–5000	10–25 ¢/kWh	4–10 ¢/kWh
OTEC	—	—	70–80	0	8000–20,000	15–40 ¢/kWh	7–20 ¢/kWh

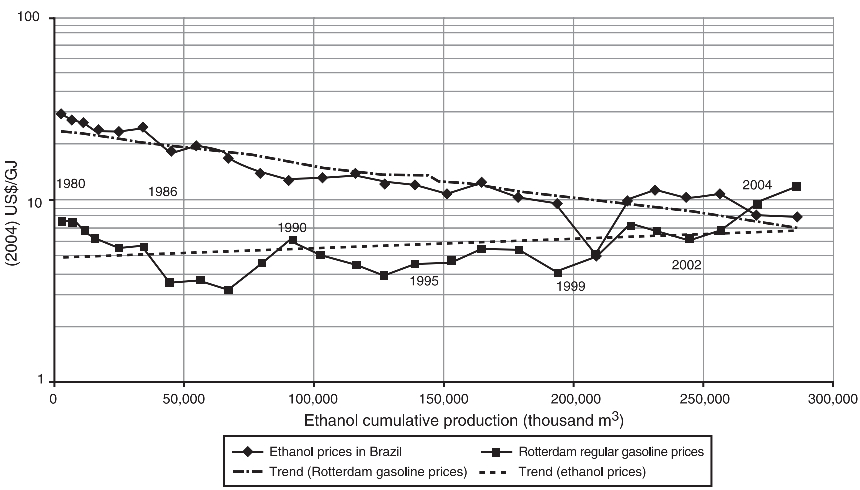
Source: WEA (2004)



Note: Data from several sources, including wind turbines produced in Denmark (Neij et al, 2003), photovoltaics worldwide (Parente et al, 2002), and ethanol produced in Brazil (Goldemberg et al, 2004). Costs are expressed in year 2000 prices.

Source: WEA (2004)

Figure 2.2 *Experience curves for photovoltaics, wind turbines and ethanol production*



Source: Coelho (2005)

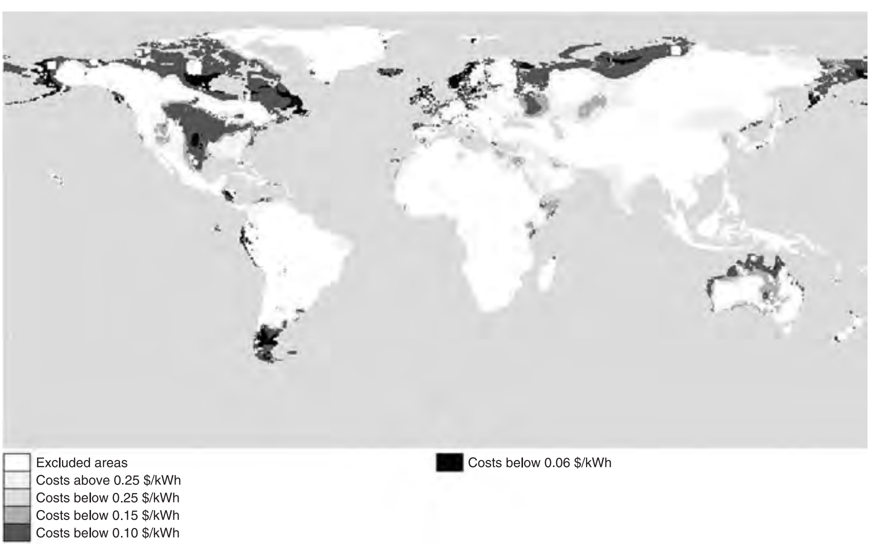
Figure 2.3 *Experience curves for ethanol and gasoline*

Present costs for renewable energy

Wind power in coastal and other windy regions is a promising energy source (see Figure 2.4). Other potentially attractive options include low-temperature solar heat production, and solar electricity production in remote applications (see

Figure 2.5). 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 electricity supplies in regions covered by a sufficiently strong transmission grid if operated in conjunction with hydropower or fuel-based power generation (Hoogwijk, 2004). Emerging storage possibilities and new strategies for operating grids offer promising indications that the role of intermittent technologies can be extended much further. Alternatively, hydrogen may become the medium for storing intermittently available energy production.

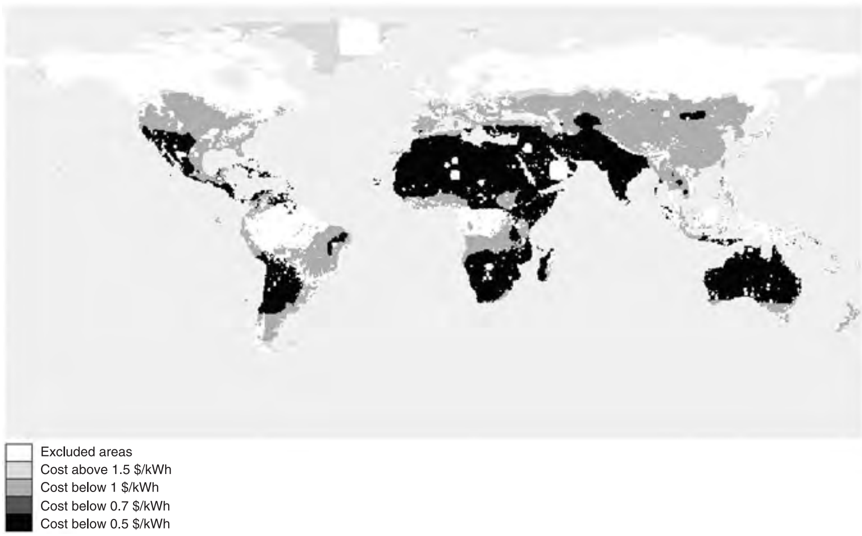
Modern, distributed forms of biomass, in particular, have the potential to provide rural areas with clean forms of energy based on biomass resources that have traditionally been used in inefficient, polluting ways (see Figure 2.6). Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops. In the US, cellulosic biofuels could be cheaper than fossil fuel gasoline and diesel (NDRC, 2004). Biomass production and use currently is helping to create international bioenergy markets, stimulated by policies to reduce carbon dioxide emissions. Bioenergy is complex and may be differentiated into different subsystems including different resources, supply systems, conversions systems, and energy carriers (Hoogwijk, 2004). Each



Note: The costs of wind electricity may come down as a result of further technological development.

Source: Hoogwijk (2004)

Figure 2.4 *Geographical distribution of present costs for wind energy*



Note: The costs of solar electricity may come down as a result of further technological development.

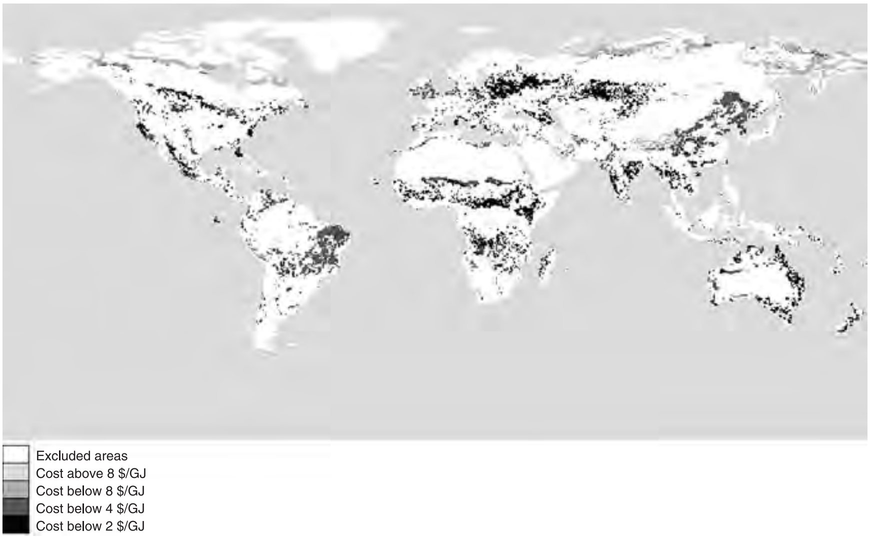
Source: Hoogwijk (2004)

Figure 2.5 *Geographical distribution of present costs for solar energy*

subsystem includes different technologies with individual learning processes for cost reductions. The development of bioenergy will in some cases be based on modular technology development but in other cases be more like conventional technologies for heat and power production.

Scenarios for renewable energy

Many scenarios have been developed to illustrate future global demand and supply of energy (see Table 2.8). The year 2050 has been chosen for illustrative purposes, which in the literature is a frequently selected year for long-term energy scenarios. 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 scenarios defined by Shell International (SI). It is important to note that a larger renewable energy share of total energy supply does not necessarily mean a high quantity of renewable energy, because it depends on the total energy use in the scenario.



Note: The costs of biomass electricity may come down as a result of further technology development.
Source: Hoogwijk (2004)

Figure 2.6 *Geographical distribution of present costs for biomass energy*

Table 2.8 *Scenarios for renewable energy, 2050*

	Total energy demand and supply (EJ)	*Total renewable energy (EJ)*	*Total renewable energy (%)*
RIGES[a]	512	237	46
IIASA and WEC[b]	479–1040	96–308	22–40
IPCC[c]	642–1611	73–444	9–35
SI[d]	852 or 1217	282 or 336	33 or 28

Notes:
a Johansson et al (1993b)
b Nakicenovic et al (1998)
c IPCC (2000)
d SI (2001)

Description of scenarios

The RIGES scenario, which involves an intensive introduction of renewables, illustrates the potential markets for renewable energy assuming that market barriers will be removed by comprehensive, and even accelerated, policy measures (Johansson et al, 1993b). In the scenario it is assumed that renewable energy technologies will capture markets whenever renewable energy is no more expensive on a life-cycle cost basis than conventional alternatives, and 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 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 renewables and share of renewables. 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 per cent of the energy demand by 2050, of which approximately 30 per cent is biomass energy and 8 per cent is hydropower (Nakicenovic et al, 1998). The scenarios describe cost reductions of new technologies according to the experience curve concept.

The IPCC scenarios published in 2000 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 40 scenarios involve a range of driving forces, such as demographic change, social and economic development, and rate and direction of technical change (IPCC, 2000). Even with the same assumptions on driving forces, the models come up with different results. This indicates the sensitivity of the scenarios not only to assumptions made but also to the methods used. The scenarios including the highest share of renewable energy have the lowest cumulative CO_2 emissions from 1990 until 2100. These scenarios are characterized by the introduction of clean and resource efficient technologies, and for some scenarios also rapid changes in economic structures towards a service and information economy with reduction in material intensity.

The energy scenarios by SI published in 2001 show a considerable increase in the future share of renewable energy. The 'Dynamic as Usual' scenario 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 'Spirit of Coming Age' scenario illustrates a higher demand of energy to meet the energy needs related to consumer preferences for mobility, flexibility and convenience (SI, 2001). At the same time, new energy technologies are introduced in developing countries as well as in industrialized countries, making renewable energy an important source of energy.

Comparison of scenarios

The scenarios are generally based on assumptions of economic growth, socio-economic development, future energy efficiencies and policy approaches. These assumptions, which may differ considerably for the various scenarios, result in differences in energy demand. The amount of renewable energy in the scenarios depends on assumptions regarding technologies available, the competitiveness of technologies, cost developments and resources available.

In all, the scenarios suggest that the amount of renewable energy can increase considerably until 2050, from 73 EJ to more than 400 EJ. The share of renewable energy in 2050 may range from 9 per cent to almost 50 per cent. An increasing share of renewable energy does not necessarily mean that the supply needs to reach 300–400 EJ; it can be lower, if the total energy demand is limited by restricted social and economic development, improved technology development or energy efficiency measures. Even though most scenarios show a huge increase in renewable energy until 2050, a major shift to a total renewable energy system by that date is not suggested in any of these studies, in spite of the fact that the renewable energy resources are more than sufficient. The reason for this is that energy supply systems have long lifetimes, as well as limitations in growth rates of new systems, economic acceptance and technological turnover, apart from other lock-in features of present energy systems. 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 marketplace, and ongoing research and development will provide new opportunities. The introduction of renewable energy will not just take place; it will depend on the support of technology development, market deployment 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. This is often called 'buying 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.

The scenarios not only show the possible share of renewable energy in the future, but 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 demand side. When renewable energy is applied in decentralized systems, energy efficiency improvement can be an important strategy to reduce the investment costs of these systems. Clearly, scenario analysis indicates significant opportunities by 2050, and more thereafter, for using renewable energy in the world energy system.

Market development for renewable energy

Looking at the markets where renewable energy carriers might compete facilitates an understanding of the demand for renewable energy. The potential markets for renewable energy and the role played by the public sector to develop these markets depend on 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 liberalization 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. A market perspective brings into question what underlies a market, such as social conditions, demand for products and services, and consumer knowledge (UNDP, 2005).

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 often 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 dollar per kilowatt-hour basis; thus, many comparisons of costs of local and integrated renewables with the costs of, for example, electricity generation by conventional power plants are incorrect and misleading.

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

In industrialized 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 nationwide 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. In developing countries it is useful to consider the direct end-uses and look at the opportunities for renewable energy to expand (see Box 2.4). Many of these applications encourage increased decision-making and participation from a variety of stakeholders, including the end-users (UNDP, 2005).

Box 2.4 Renewable energy markets in developing countries

- *Rural residential and community lighting, television, radio and telephony*. Over 50 million households are served by small hydro village-scale mini-grids; 10 million households get lighting from biogas; over 1 million households have solar PV home systems or solar lanterns; and 10,000 households are served by solar, wind and diesel hybrid mini-grids.
- *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; and thousands of communities receive drinking water from solar PV-powered purifiers and pumps.
- *Residential and commercial cooking and hot water*. A total of 220 million households have more efficient biomass stoves; 10 million households have solar hot water systems; and 800,000 households have solar cookers.
- *Transport fuels*. A total of 14 billion litres per year of ethanol vehicle fuel is produced from biomass; and 180 million people live in countries mandating the mixing of ethanol with gasoline.

Source: Martinot et al (2002)

Lighting, television, radio and telephony

Access to electricity opens up opportunities that are taken for granted by those who enjoy continuous access. Yet 350–400 million households in developing countries lack access to electricity. This largely means that television and radio are not available, lighting comes from candles and fires, and telephone services are absent (Martinot et al, 2002). A number of options to use renewable energy for electrification exist and the markets are growing. Solar home systems usually consist of a PV solar panel, battery, charging controller and end-uses such as 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, such as schools and health centres.

A biogas digester can convert 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. 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. Wind power–battery systems for a single household have 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.

Industry, water pumping and drinking water

The emerging uses of renewable energy are for agriculture, small industry, water pumping and cottage applications (sawmills and mechanical power). Furthermore, social services, such as education and health care can be supported by renewable energy. 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 engines run on diesel and biogas. Stand-alone energy systems can power small industries, thereby creating local jobs and opportunities. In fact, the development of mini-grids and industry goes hand in hand. As small businesses grow, the economic viability of mini-grids increases. With the availability of energy, new possibilities open up. Renewable energy can also 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.

Cooking and heating water

Direct combustion of biomass supports residential and commercial cooking as well as 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. Research and development 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 (Martinot et al, 2002).

Transport

Biomass-derived liquid fuels can power motor vehicles in several ways. First, ethanol can power specially designed vehicles that run on pure ethanol. Second, ethanol is mixed, in for example Brazil and the US, with gasoline or diesel fuel to produce gasohol for use in ordinary vehicles. Furthermore, the commercial viability of converting sugar cane 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 global energy and automotive industries greatly affect the prospects of biomass-derived fuels, in the absence of accounting for external costs and benefits.

Renewable energy innovations

Technological innovation is critical to the reshaping of energy systems in ways that encourage sustainable development (Johansson et al, 1993a). However, the development and diffusion of sustainable and affordable renewable energy technologies is not occurring fast enough or widely enough (Turkenburg, 2002). The challenge of stimulating novel technologies is primarily one for industrialized countries, which have the technical and economic resources for sustained research and development, and for the dissemination of renewable energy technologies. Without effective policy it is unlikely that new technologies can overcome barriers and penetrate the market to any significant extent (see Table 2.9).

Key barriers

Innovations face barriers all along the innovation chain (from research and development over demonstration projects and cost buy-down to widespread diffusion). Some of these barriers reflect market imperfections; some inadequacies in the public sector domain; and some differences of views 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 (PCAST, 1999). Direct government support is more likely to be needed for entirely new technologies than for incremental advances, where the private sector functions relatively effectively.

Major criteria for deciding whether government should finance a particular field of energy research can be the contribution of that area to achieving a transition to a sustainable energy future 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 at helping 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’ (Turkenburg, 2002). Over the past couple of decades, industrialized countries have experimented with a growing number of policy instruments from target setting and procurement policies to green labelling and fiscal incentives.

Policy options

Cost buy-down and widespread dissemination can be advanced through a number of policy measures. A very effective policy option appears to be use of temporary subsidies, as tried in Germany and Spain with very good results in terms of

Table 2.9 *Key barriers and policy options for renewable energy in industrialized countries*

	Research and development	*Demonstration*	*Diffusion*	
			Early deployment	*Widespread dissemination*
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 internalized	• 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 internalized
Policy options	• 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 payback 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 mechanisms • Innovative retail financing and consumer credit schemes

Source: PCAST (1999)

expanding electricity generation from renewable energy. Green certificate markets are another option now in use in many countries. From an investor's 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 has 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 the fact that biomass now provides 25 per cent of Sweden's primary energy. In 2002, Brazil adopted a law to promote adoption of wind energy, PV, small-scale hydro and biomass. The law was designed to protect the national interest where the market alone cannot.

Dealing with imperfections in innovation systems may require government actions on a number of fronts, including making sure that there is enough funding for new knowledge creation; improving linkages in the system; helping actors to find one another; shaping strong user–supplier links; being patient in the process of adjusting the institutional set-up; taking note of the need for variety and consistency in the applied policies; and stimulating prime movers (PCAST, 1999; Turkenburg, 2002). It is indeed a challenging task to identify the most important barriers and what policy options are capable of negating or overcoming the barriers.

Policy implications and recommendations

The degree to which there will be demand for renewable energy depends on many factors. At present, only 2 per cent of the world's primary energy is 'new' renewables (WEA, 2004; REN21, 2005). One fundamental issue is that the environmental and social benefits of using renewable energy appear at the societal level, while costs have to be borne 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. Policies for renewable energy relate to many sectors, including land use, agriculture, buildings, transportation and urban planning. Some specific areas that have to be addressed include the following:

- Understanding local renewable energy flows and their potential use. There is a pressing need to disseminate methodologies to estimate the local renewable energy flows and to create integrated (holistic) and sustainable solutions. Furthermore, continued research and development is required on local renewable energy technologies, such as heat pumps, building-integrated PV, 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 energy; 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 commercialization, while still taking advantage of the economic efficiency of the marketplace.

- Setting ambitious but realistic targets and timetables in combination with effective policies, such as the use of 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.
- Methods and procedures for calculating the value of distributed generation need 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 dollar per kilowatt-hour basis; thus, many comparisons of costs of local and integrated renewables with the costs of electricity generation are incorrect and misleading.

Notes

1 Global energy consumption in 2004 was 470 EJ, based on statistics from BP (2005) and calculations by REN21 (2005). The primary energy value of hydroelectricity generation (and nuclear) was calculated by defining the equivalent amount of fossil fuel required to generate the same volume of electricity in a thermal power station, assuming a conversion efficiency of 38 per cent. Hydropower was therefore 634 Mtoe in 2004, or 6.2 per cent of global primary commercial energy. It is common to see hydropower as 2.4 per cent of global primary commercial energy in other studies. From the work by BP (2005) and REN21 (2005), the total world primary energy in 2004 was 10,224 Mtoe (commercial) + 1010 Mtoe (traditional) = 11,234 Mtoe. If 1 Mtoe = 41.9 PJ then the result is 470 EJ.

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