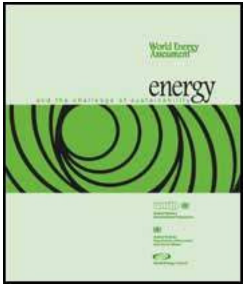


World Energy Assessment - Energy and the Challenge of Sustainability (UNDESA - UNDP - WEA - WEC, 2000, 517 p.)

PART V. FURTHER INFORMATION AND REFERENCE MATERIAL

Annexes

Annex A: Energy units, conversion factors, and abbreviations

TABLE A1. ENERGY CONVERSIONS*

To:	Terajoule (TJ)	Gigacalorie (Gcal)	Megatonne oil (equiv)	Million British thermal units	Gigawatt-hour (GWh)

			(Mtoe)	(Mbtu)	
From:	**Multiply by:**				
Terajoule (TJ)	1	238.8	2.388×10^{-5}	947.8	0.2778
Megatonne oil (equiv) (Mtoe)	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11,630
Million British thermal units (Mbtu)	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
Gigawatt-hour (GWh)	3.6	860	8.6×10^{-5}	3,412	1

*** IEA figures. Additional conversion figures available at http://www.iea.org/stat.htm**

TABLE A2. UNIT PREFIXES

k	kilo (10^{3})
M	mega (10^{6})
G	giga (10^{9})
T	tera (10^{12})
P	peta (10^{15})
E	exa (10^{18})

TABLE A3. ASSUMED EFFICIENCY IN ELECTRICITY GENERATION (FOR CALCULATING

PRIMARY ENERGY)

Type of power	Assumed efficiency
Nuclear power	. 33
Hydroelectric	1.00
Wind and solar	1.00
Geothermal	.10

TABLE A4. UNIT ABBREVIATIONS

EJ	Exajoule
GJ	Gigajoule
Gtoe	Giga tonnes oil equivalent
GWe	Giga Watt electricity
GWth	Giga Watt thermal
ha	Hectare
km^2	Square kilometre
kWh	Kilo Watt hour
Mtoe	Million tonnes oil equivalent
MWe	Mega Watt electricity
PJ	Petajoule
t	Tonne
TWh	Tera Watt hour

Annex B: Data consistency

Energy is defined as the ability to do work and is measured in joules (J), where 1 joule is the work done when a force of 1 newton (N) is applied through a distance of 1 metre. (A newton is the unit of force that, acting on a mass of one kilogram, increases its velocity by one metre per second every second along the direction in which it acts.) Power is the rate at which energy is transferred and is commonly measured in watts (W), where 1 watt is 1 joule per second. Newton, joule, and watt are defined in the International System of Units. Other units used to measure energy are tonnes of oil equivalent (toe; 1 toe equals 41.87×10^9 J) and barrels of oil equivalent (boe; 1 boe equals 5.71×10^9 J), used by the oil industry; tonnes of coal equivalent (tce; 1 tce equals 29.31×10^9 J), used by the coal industry; and kilowatt-hour (kWh; 1 kWh equals 3.6×10^6 J), used to measure electricity. See also annex A, which provides conversion factors for energy units.)

Studies on national, regional, and global energy issues use a variety of technical terms for various types of energy. The same terminology may reflect different meanings or be used for different boundary conditions. Similarly, a particular form of energy may be defined differently. For example, when referring to total primary energy use, most studies mean *commercial energy* - that is, energy that is traded in the marketplace and exchanged at the going market price. Although non-commercial energy is often the primary energy supply in many developing countries, it is usually ignored. Non-commercial energy includes wood, agricultural residues, and dung, which are collected by the user or the extended family without involving any financial transaction. Because there are no records and a lack of data on actual use, most energy statistics do not report non-commercial energy use. Estimates of global non-commercial energy use range from 23-35 exajoules a year. In contrast, wood and other biomass sold in the marketplace is reported as solids (often lumped together with coal) and becomes part of commercial energy.

Traditional energy **is another term closely related to non-commercial energy. This term generally refers to biomass used in traditional ways - that is, in the simplest cooking stoves and fireplaces - and is often meant as a proxy for inefficient energy conversion with substantial indoor and local air pollution. But traditional does not always mean non-commercial: wood burned in a kitchen stove may have been bought commercially and be reflected in commercial data. Estimates of biomass used in traditional ways range from 28-48 exajoules per year.**

The term *modern* (or *new*) *renewables* is used to distinguish between traditional renewables used directly with low conversion technology and renewables using capital-intensive high-tech energy conversion such as solar, wind, geothermal, biomass, or ocean energy to produce state-of-the-art fuels and energy services.

Another issue concerns the heating value of chemical fuels assumed in statistics and analyses. The difference between the higher heating value (HHV) and the lower heating value (LHV) is that the higher heating value includes the energy of condensation of the water vapour contained in the combustion products. The difference for coal and oil is about 5 percent and for natural gas 10 percent. Most energy production and use are reported on the basis of the lower heating value.

Yet another source of inconsistency comes from different conversion factors to the primary energy equivalent of electricity generated by hydropower, nuclear, wind, solar, and geothermal energy. In the past, non-combustion-based electricity sources were converted to their primary equivalents by applying a universal conversion efficiency of 38.5 percent. More recently, hydropower, solar, and wind electricity in OECD statistics are converted with a factor of 100 percent, nuclear electricity with 33 percent, and geothermal with 10 percent.

The quality of data differs considerably between regions. Statistical bureaus in developing

countries often lack the resources of their counterparts in industrialised countries, or data are simply not collected. Countries of the former Soviet Union used to have different classifications for sectoral energy use. Data reported by different government institutions in the same country can differ greatly, often reflecting specific priorities.

The composition of regions also varies in statistical compendiums and energy studies. At times, North America is composed of Canada and the United States - but it might also include Mexico. Except where otherwise noted, the following countries joined the Organisation for Economic Co-operation and Development (OECD) in 1961: Australia (1971), Austria, Belgium, Canada, the Czech Republic (1995), Denmark, Finland (1969), France, Germany, Greece, Hungary (1996), Iceland, Ireland, Italy, Japan (1964), Korea (1996), Luxembourg, Mexico (1994), the Netherlands, New Zealand (1973), Norway, Poland (1996), Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. Depending on when the data was collected, OECD data may or may not include the Czech Republic, Hungary, the Republic of Korea, Mexico, or Poland.

Finally, a word on the efficiency of energy conversion. Energy efficiency is a measure of the energy used in providing a particular energy service and is defined as the ratio of the desired (usable) energy output to the energy input. For example, for an electric motor this is the ratio of the shaft power to the energy (electricity) input. Or in the case of a natural gas furnace for space heating, energy efficiency is the ratio of heat energy supplied to the home to the energy of the natural gas entering the furnace. Because energy is conserved (the first law of thermodynamics), the difference between the energy entering a device and the desirable output is dissipated to the environment in the form of heat. Thus energy is not consumed but conserved. What is consumed is its quality to do useful work (as described by the second law of thermodynamics).

What this means is that a 90 percent efficient gas furnace for space heating has limited potential for further efficiency improvements. While this is correct for the furnace, it is not

the case for delivering space heat. For example, a heat pump operating on electricity extracts heat from a local environment - outdoor air, indoor exhaust air, groundwater - and may deliver three units of heat for one unit of electrical energy to the building, for a coefficient of performance of 3. Not accounted for in this example, however, are the energy losses during electricity generation. Assuming a modern gas-fired combined cycle power plant with 50 percent efficiency, the overall coefficient of performance is 1.5 - still significantly higher than the gas furnace heating system.

Annex C: Energy trends

TABLE C.1. PRIMARY ENERGY USE PER CAPITA BY REGION, 1971-97

Region	1971 (gigajoules)	1980 (gigajoules)	1985 (gigajoules)	1990 (gigajoules)	1997 (gigajoules)	Change, 1990-97 (percent)	Chang 1971- (perce
North America	266	276	258	263	272	3.7	2.4
Latin America	36	42	39	40	47	15.4	27.7
OECD Europe[a]	118	134	134	137	141	3.3	19.9
Non-OECD Europe[b]	76	108	112	108	84	-21.8	10.6
Former Soviet Union	135	178	192	195	129	-33.9	-4.2

Middle East	35	61	72	77	95	23.9	175.9
Africa	23	26	27	27	27	0.1	17.1
China	20	25	28	32	38	18.8	93.6
Asia[c]	15	17	19	21	26	18.9	66.3
Pacific OECD[d]	94	113	117	142	174	23.2	85.1
World total	**62**	**69**	**69**	**70**	**70**	**-0.1**	**12.5**
Memorandum items							
OECD countries	161	177	173	181	194	7.0	20.4
Transition economies	124	165	177	180	121	-32.4	-2.0
Developing countries	20	25	27	29	34	16.0	66.2

a. Includes Czech Republic, Hungary, and Poland. b. Excludes the former Soviet Union. c. Excludes China. d. Includes Republic of Korea.

Source: IEA, 1999a.

TABLE C.2. ELECTRICITY USE PER CAPITA BY REGION, 1980-96 (KILOWATT-HOURS)

Region	1980	1985	1990	1996
North America	8,986	9,359	20,509	11,330
OECD	5,686	6,277	7,177	8,053

East Asia	243	314	426	624
South Asia	116	157	228	313
Sub-Saharan Africa	444	440	448	439
Middle East	485	781	925	1,166
China	253	331	450	687
Transition economies	2,925	3,553	3,823	2,788
Least developed countries[a]	74	66	60	83
World	**1,576**	**1,741**	**1,927**	**2,027**

a. As defined by the United Nations.

Source: World Bank, 1999.

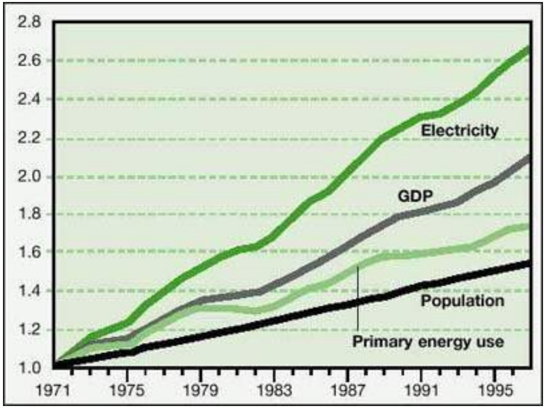
TABLE C.3. ELECTRICITY DISTRIBUTION LOSSES BY REGION, 1980-96 (PERCENT)

Region	**1980**	**1985**	**1990**	**1996**
North America	6.9	6.8	7.0	7.6
OECD	7.6	6.8	7.2	6.4
East Asia	8.4	8.8	8.2	10.1
South Asia	19.4	19.1	18.8	18.7
Sub-Saharan Africa	9.2	8.6	8.8	9.6
Transition economies	8.4	8.9	8.4	11.0
Least developed countries[a]	11.0	15.8	20.3	20.9
World	**8.3**	**8.0**	**8.3**	**8.5**

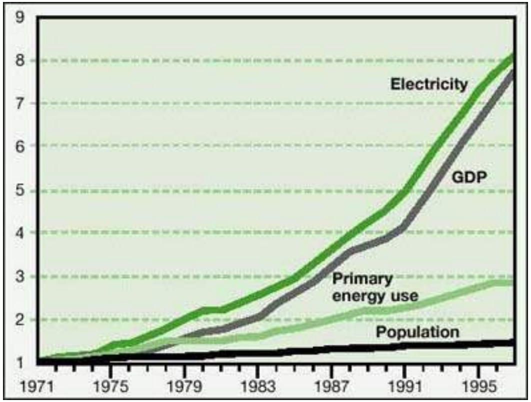
a. As defined by the United Nations.

Source: World Bank, 1999.

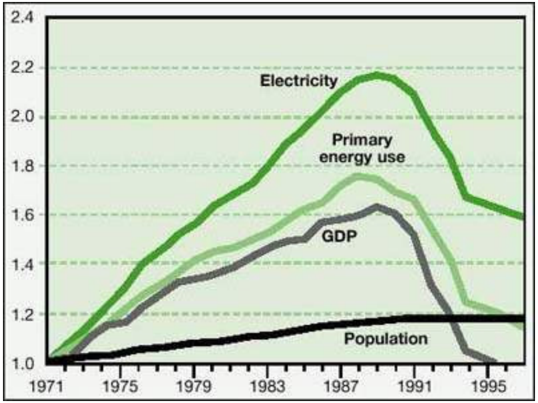
FIGURE C.1. CHANGES IN GDP, POPULATION, PRIMARY ENERGY USE, AND ELECTRICITY USE BY REGION, 1971-97 (INDEX: 1971=1)



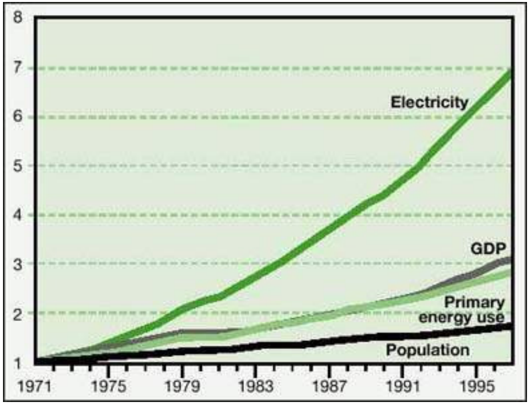
World



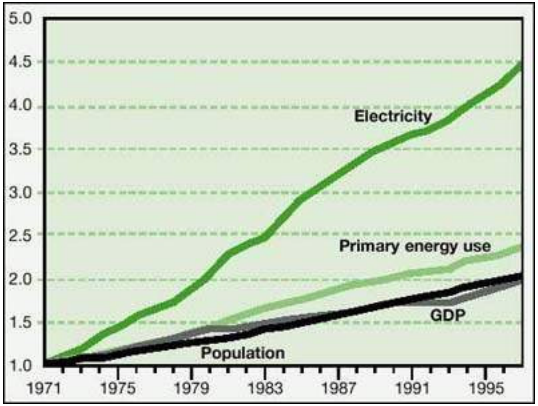
China



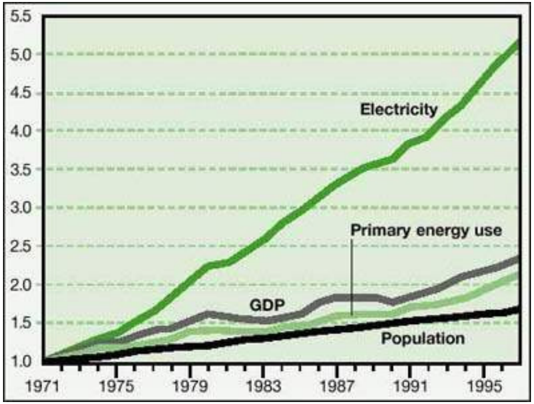
Economies in transition



Developing countries



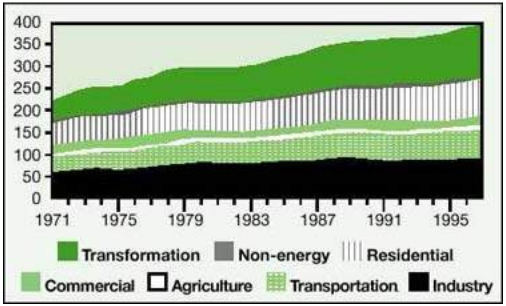
Africa



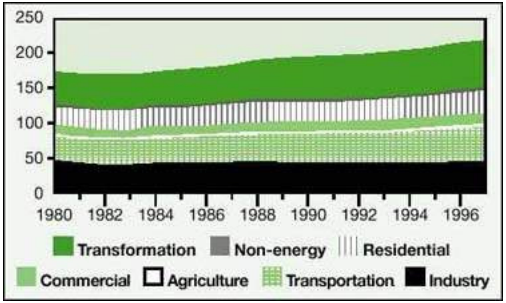
Latin America

Source: IEA, 1999a.

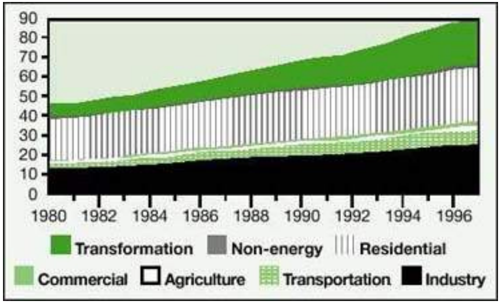
FIGURE C.2. ENERGY USE BY SECTOR IN SELECTED REGIONS, 1980-97 (EXAJOULES)



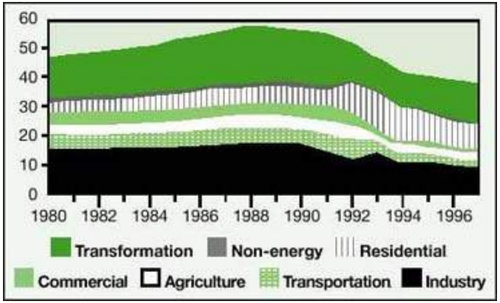
World



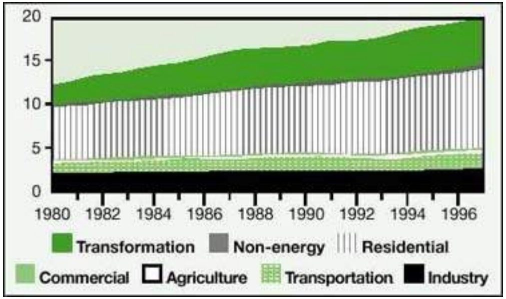
OECD



Total Asia



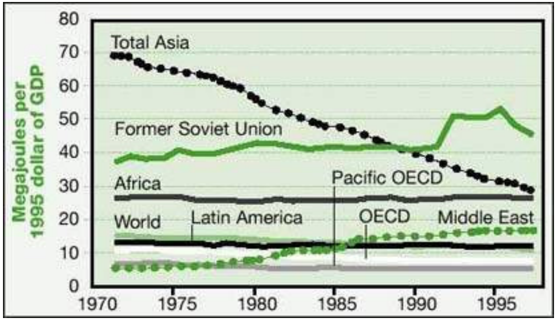
Former Soviet Union



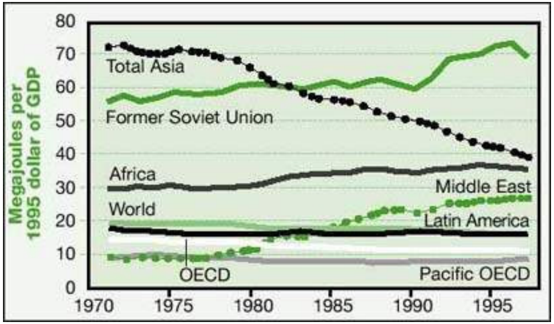
Africa

Source: IEA, 1999a.

FIGURE C.3. DEVELOPMENT OF PRIMARY AND FINAL ENERGY INTENSITIES BY REGION, 1971-1997



Final energy intensities



Primary energy intensities

Source: IEA, 1999a.

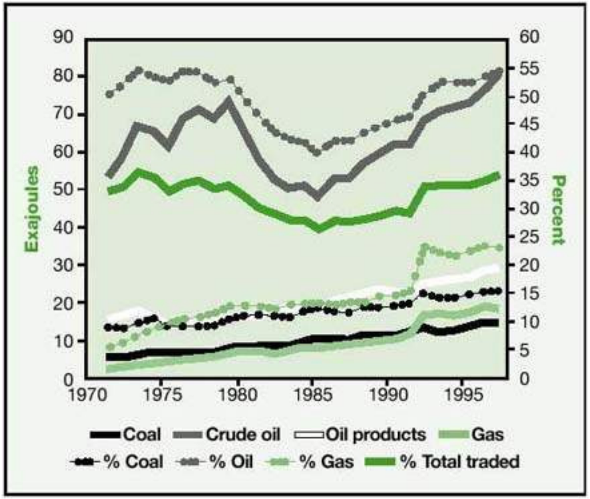
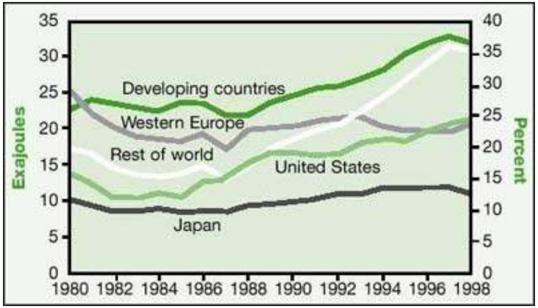


FIGURE C.4. GLOBAL TRADE IN CRUDE OIL, OIL PRODUCTS, COAL, AND NATURAL GAS, IN ABSOLUTE AND RELATIVE TERMS

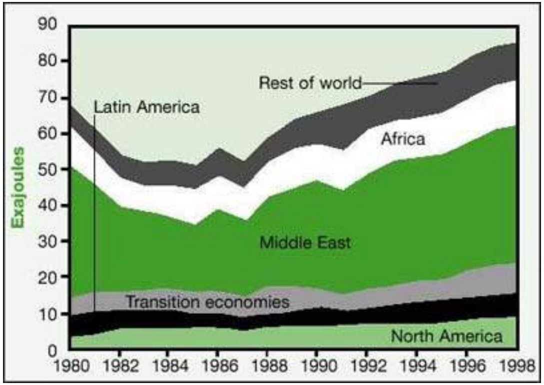
Note: Total traded shows share of total specific fuel use that is traded, that is total traded energy/primary energy.

Source: BP, 1999, IEA, 1999a, World Bank, 1999.

FIGURE C.5. MAJOR OIL IMPORTERS AND EXPORTERS, 1980-98



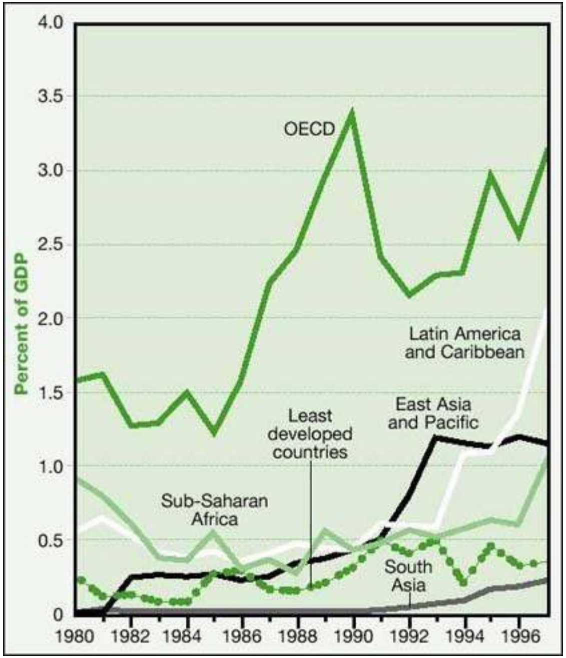
Importers



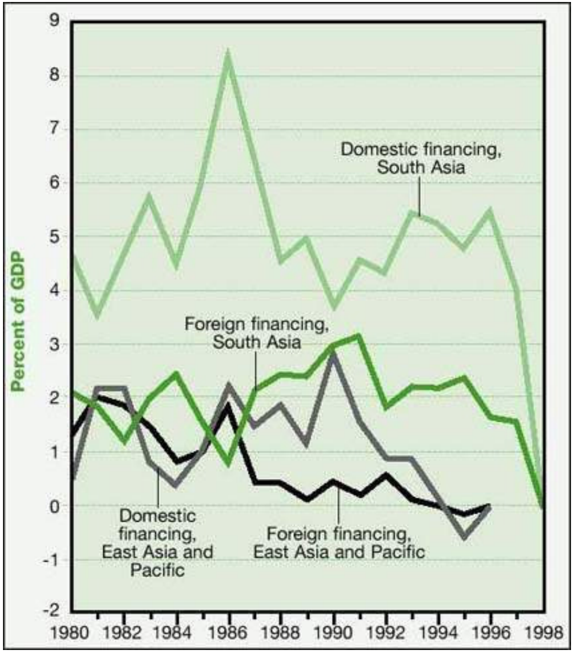
Exporters

Source: BP, 1999.

FIGURE C.6. GROSS FOREIGN DIRECT INVESTMENT AND DOMESTIC AND FOREIGN FINANCING BY REGION, 1980-97



Gross foreign direct investment



Domestic and foreign financing

Source: World Bank, 1999.

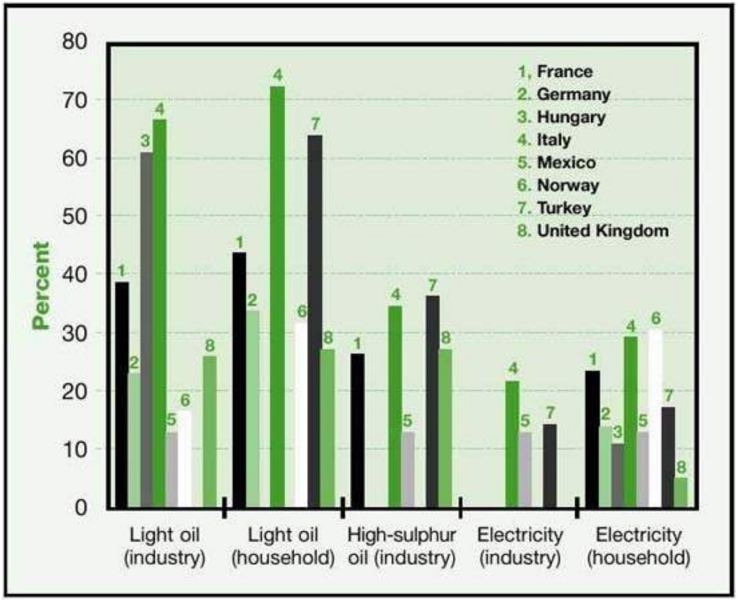
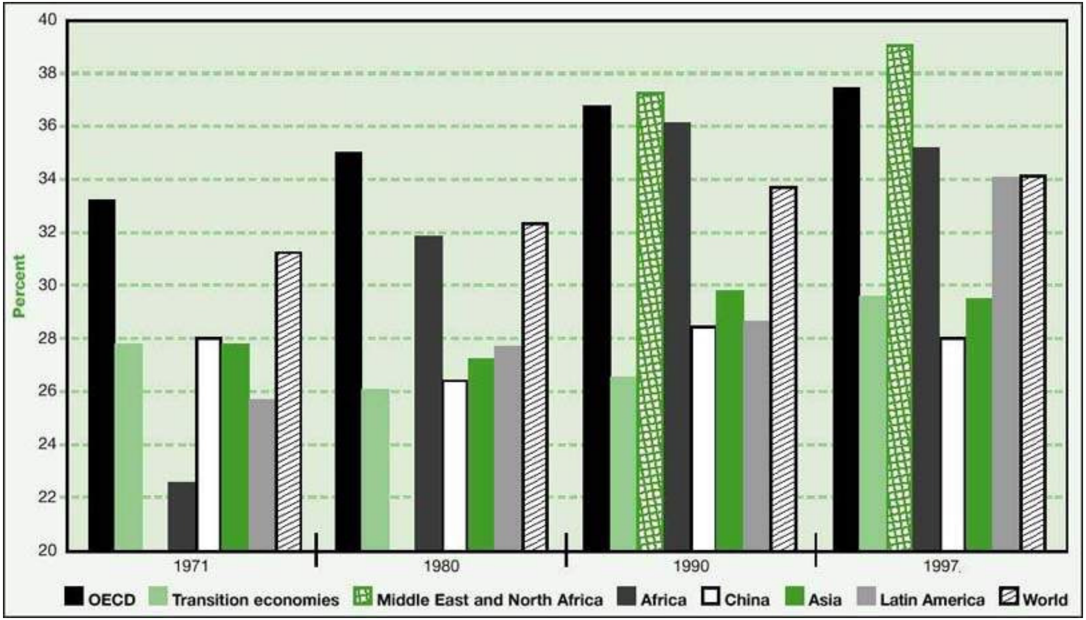


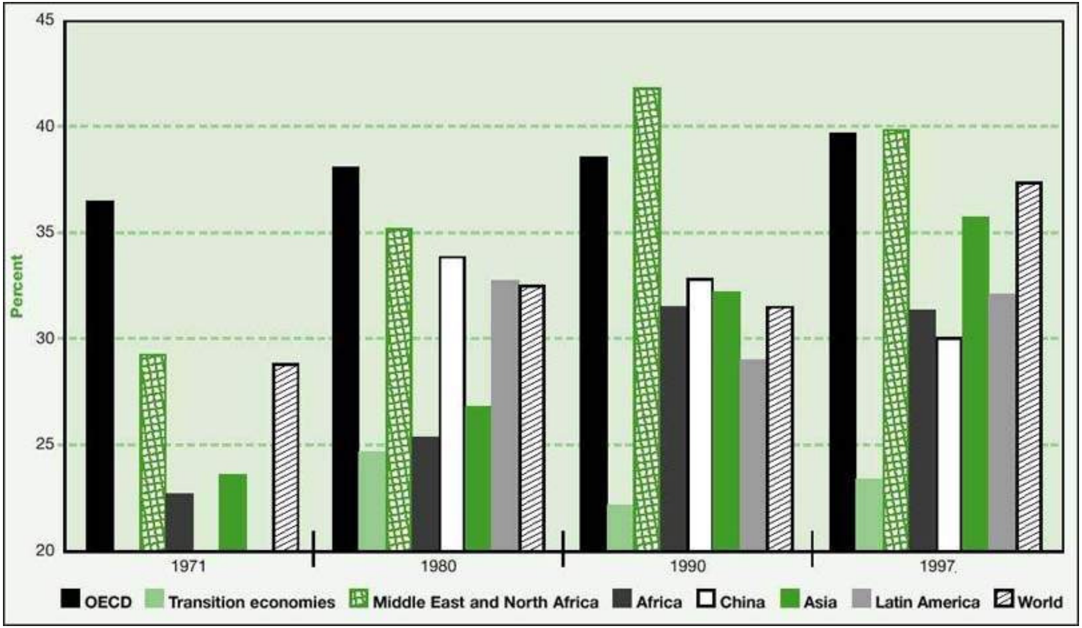
FIGURE C.7. ENERGY TAXES IN SELECTED COUNTRIES, 1998

Source: IEA, 1999b.

FIGURE C.8. EFFICIENCY OF COAL-FUELLED AND NATURAL GAS - FUELLED ELECTRICITY GENERATION BY REGION, 1971-97


40
38
36
34
32
30
28
26
24
22
20
Percent
1971
1980
1990
1997
OECD
Transition economies
Middle East and North Africa
Africa
China
Asia
Latin America
World

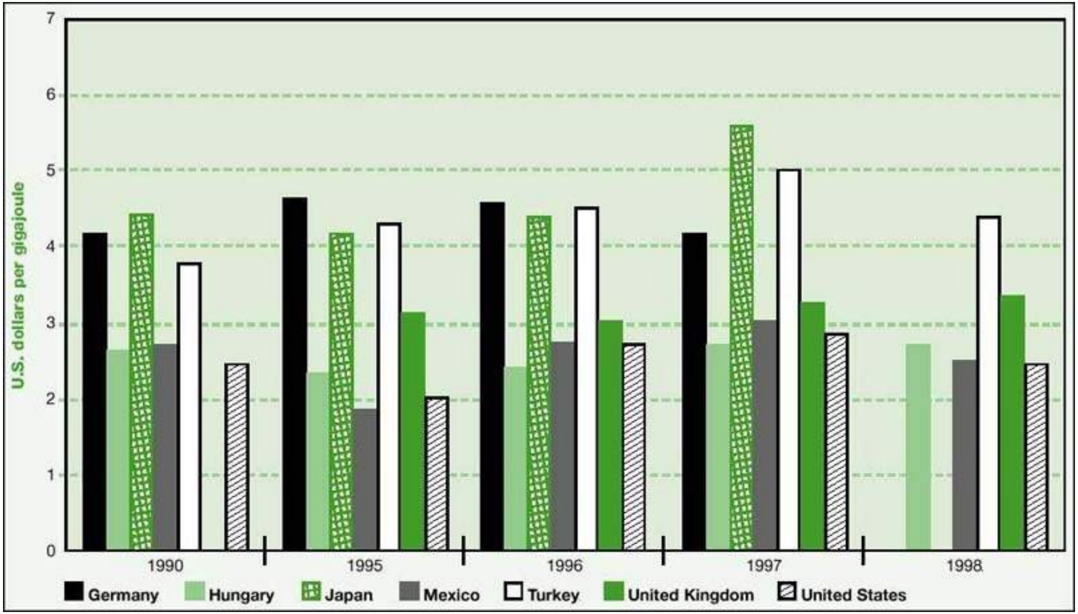
Coal



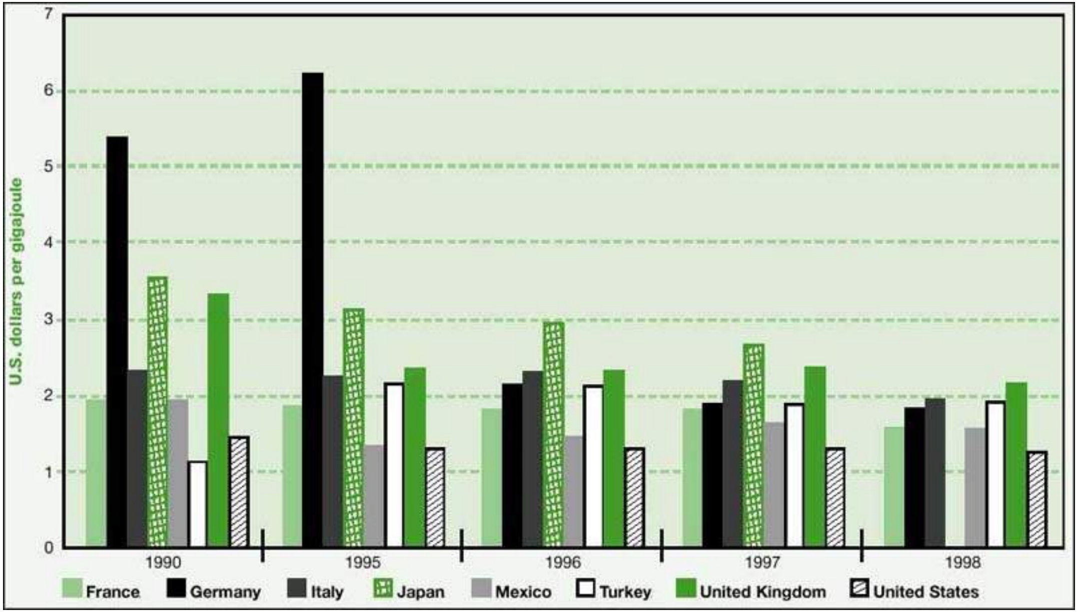
Natural gas

Source: Adapted from IEA, 1999a.

FIGURE C.9. NATURAL GAS AND STEAM COAL PRICES FOR ELECTRICITY GENERATION BY REGION, 1990-98

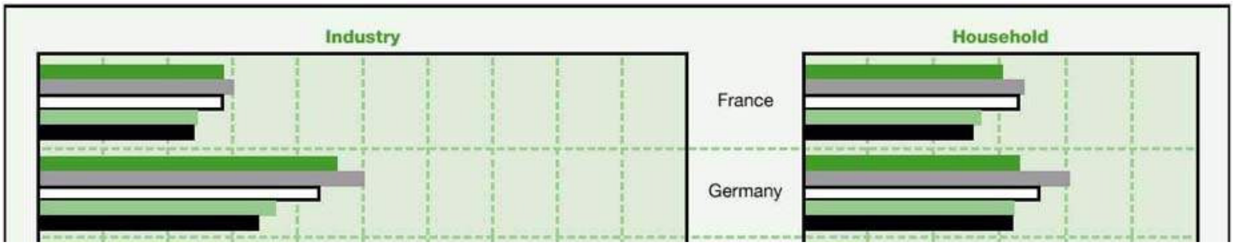

U.S. dollars per gigajoule
7
6
5
4
3
2
1
0
1990
1995
1996
1997
1998
Germany
Hungary
Japan
Mexico
Turkey
United Kingdom
United States

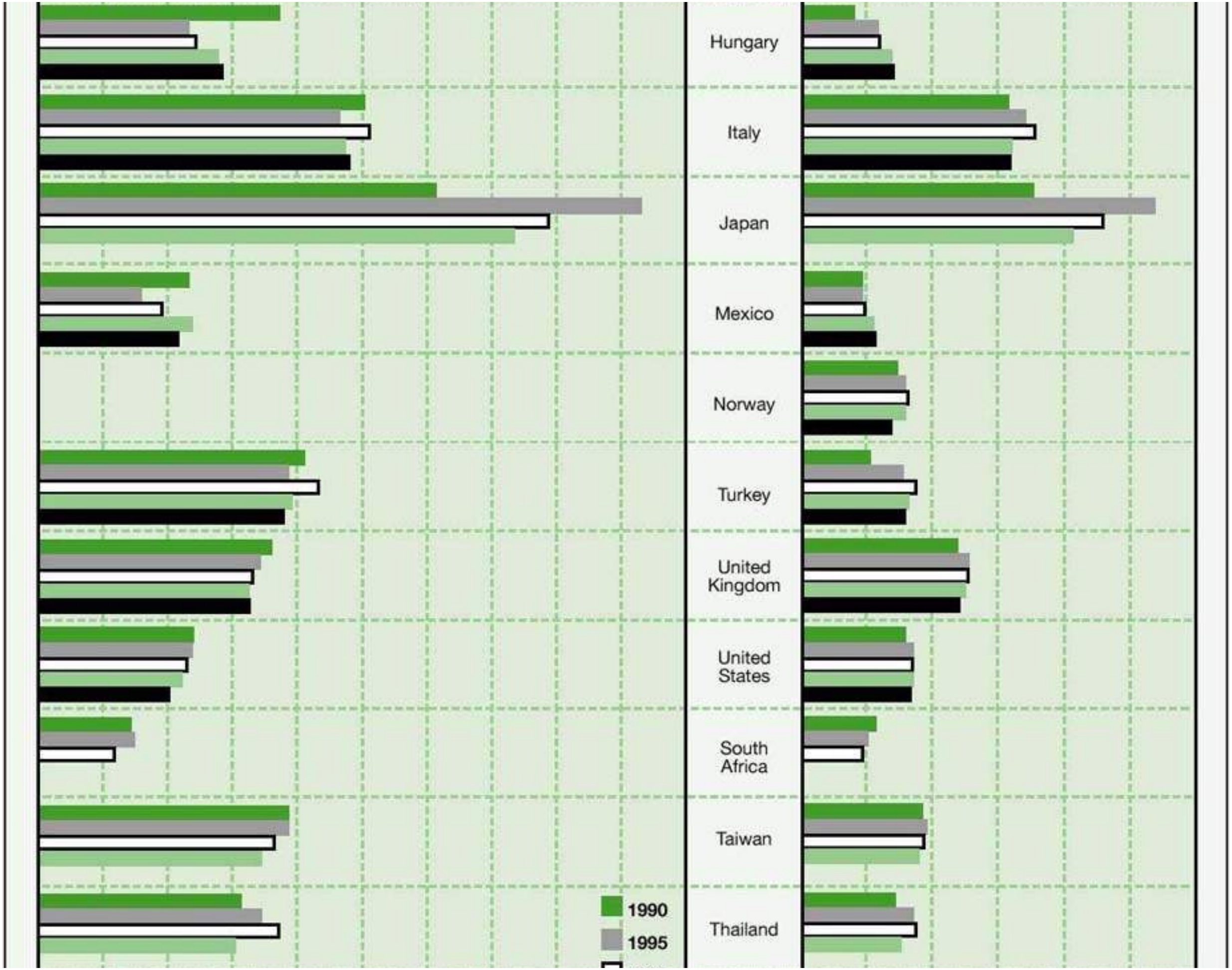
Natural gas



Steam coal

Source: IEA, 1999b.




Hungary
Italy
Japan
Mexico
Norway
Turkey
United Kingdom
United States
South Africa
Taiwan
Thailand
1990
1995

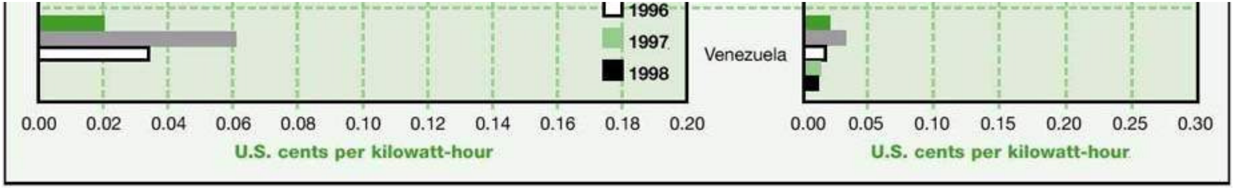
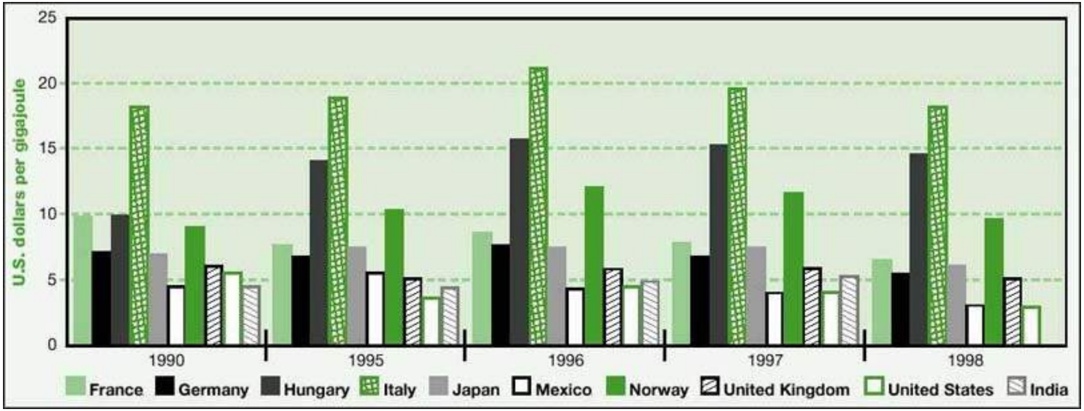


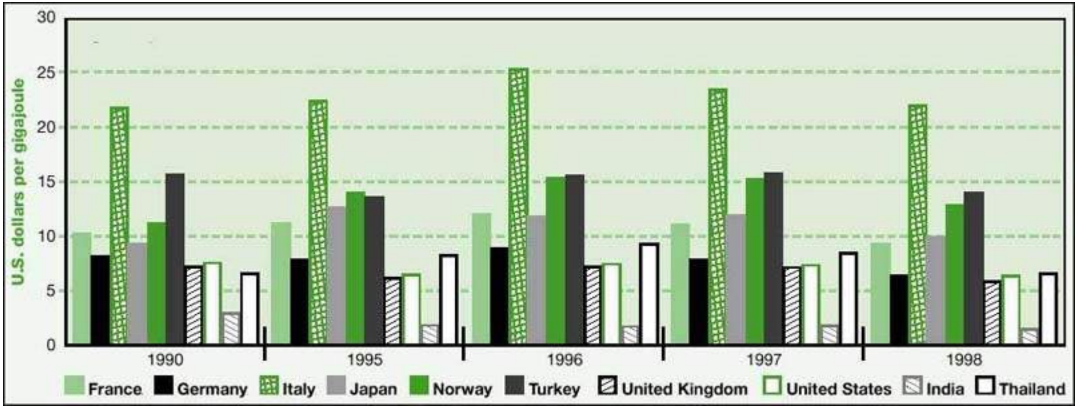
FIGURE C.10. ELECTRICITY PICES IN SELECTED COUNTRIES, 1990-98

Source: IEA, 1999b.

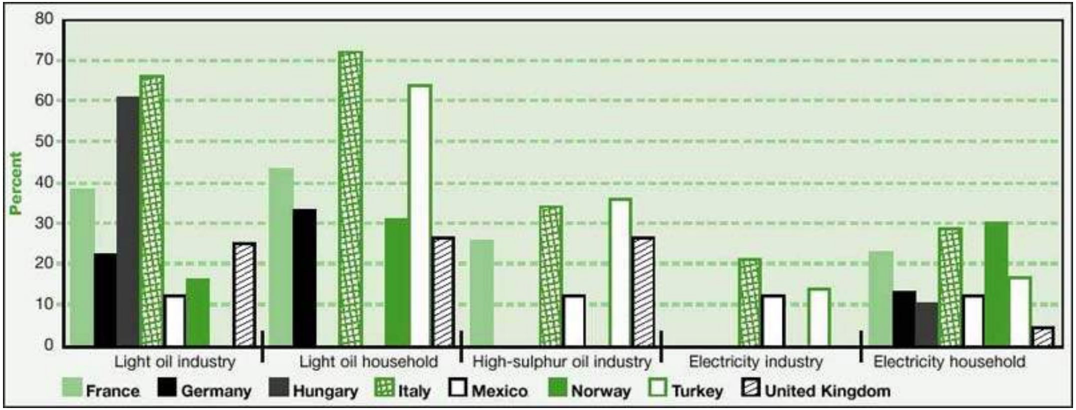
FIGURE C.11. OIL PRODUCT PRICES IN SELECTED COUNTRIES, 1990-98



Light oil prices for industry



Light oil prices for household



Taxes on different fuels

Source: IEA, 1999b.

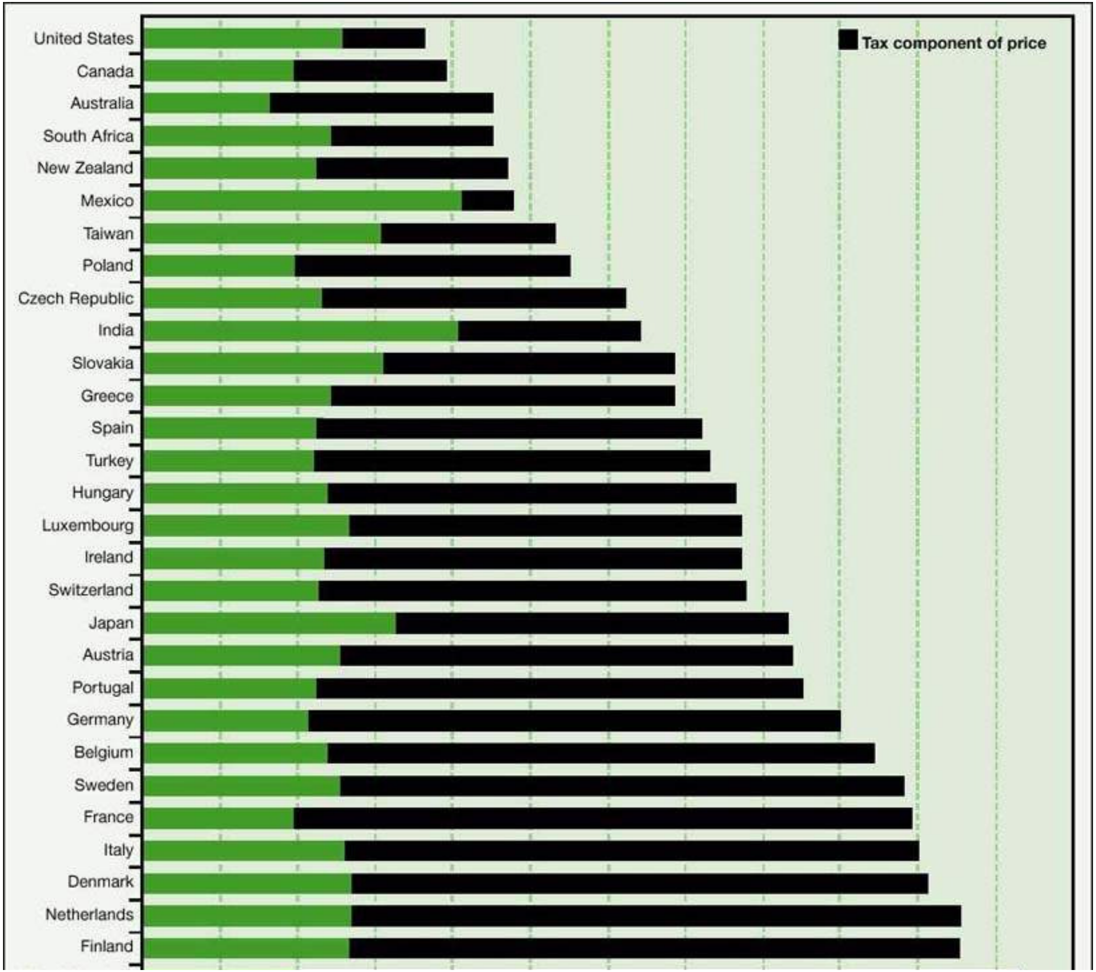

Tax component of price
United States
Canada
Australia
South Africa
New Zealand
Mexico
Taiwan
Poland
Czech Republic
India
Slovakia
Greece
Spain
Turkey
Hungary
Luxembourg
Ireland
Switzerland
Japan
Austria
Portugal
Germany
Belgium
Sweden
France
Italy
Denmark
Netherlands
Finland

FIGURE C.12. UNLEADED GASOLINE PRICES IN SELECTED COUNTRIES, 1998

Source: IEA, 1999b.

References

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IEA (International Energy Agency). 1999a. *Energy Balances.* Organisation for Economic Co-operation and Development. Paris.

IEA (International Energy Agency). 1999b. *Energy Prices and Taxes.* Quarterly statistics (second quarter). Organisation for Economic Co-operation and Development. Paris.

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Annex D: Carbon emissions

The fossil energy used in 1998 contained about 6.5 gigatonnes of carbon, down slightly from 1997. The slight reduction was caused by the economic crisis in East Asia, which curbed energy use in this fast-growing region, and China's closure of inefficient and coal-intensive heavy industry enterprises. All this carbon essentially ends up in the atmosphere in the form of carbon dioxide, the inevitable by-product of any combustion process involving hydrocarbon fuels.

The energy sector emitted about 2.8 gigatonnes of carbon during the extraction and

conversion of primary energy to fuels and electricity, and during transmission and distribution to final use. The rest, about 3.7 gigatonnes of carbon, was emitted at the point of end use. Included are 0.4 gigatonnes of carbon embodied in durable hydrocarbon-based materials and products such as plastics, asphalt, lubricants, and pharmaceuticals. Although these materials do not necessarily contribute to carbon emissions in the year they are statistically accounted for as energy or non-energy use, most materials manufactured from hydrocarbons are eventually oxidised to carbon dioxide.

Carbon is also released from the combustion of biomass. Annual net emissions from biomass conversion are difficult to determine and depend on the extent to which the biomass use is truly renewable. The information presented here assumes that biomass-based energy services are renewable and so do not result in net additions to atmospheric concentrations of carbon dioxide.

Box D.1 reports the range of carbon emission factors found in the literature and the IPCC factors used to calculate the past and current carbon emissions shown in figure D.1. Global carbon emissions effectively doubled between 1965 and 1998, corresponding to an average increase of 2.1 percent a year - not surprisingly, a mirror image of the fossil fuel - dominated global energy use. Since 1990 the average rate of increase has slowed to 0.7 percent a year, not because of carbon emission mitigation efforts but because of the economic collapse of the former Soviet Union and the financial crisis in East Asia. Although figure D.1 clearly identifies industrialised countries as the main source of carbon emissions, it also shows the growing emissions from developing countries.

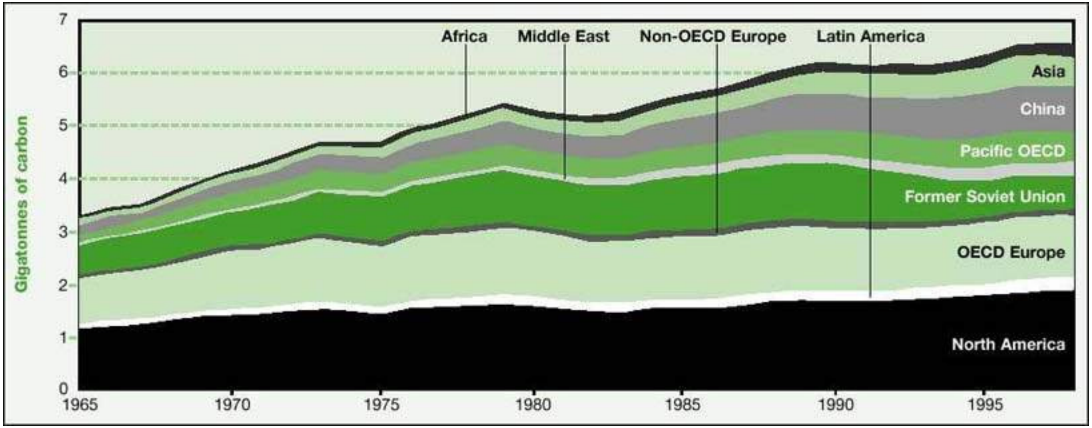

FIGURE D.1. CARBON EMISSIONS BY REGION, 1965-98

Source: Calculated from BP, 1999 data using carbon emission factors of IPCC, 1996.

BOX D.1. CARBON DIOXIDE EMISSION FACTORS

Carbon dioxide emissions are measured in units of elemental carbon. For example, in 1998 global carbon dioxide emissions were 6.5 gigatonnes (billion tonnes) of carbon. In the literature carbon dioxide emissions are often reported as the mass of the carbon dioxide molecules (1 kilogram of carbon corresponds to 3.67 kilograms of carbon dioxide).

Carbon emission factors for some primary energy sources (kilograms of carbon per gigajoule)

Source	Heating value	OECD and IPCC, 1995	Literature range
Wood	HHV		26.8 - 28.4
	LHV		28.1 - 29.9

Peat	HHV		30.3
	LHV	28.9	
Coal (bituminous)	HHV		23.9 - 24.5
	LHV	25.8	25.1 - 25.8
Crude oil	HHV		19.0 - 20.3
	LHV	20.0	20.0 - 21.4
Natural gas	HHV		13.6 - 14.0
	LHV	15.3	15.0 - 15.4
Note: HHV is the higher heating value, LHV is the lower heating value. The difference is that the higher heating value includes the energy of condensation of the water vapour contained in the combustion products (see annex A). *Source: IPCC, 1996.*			

The carbon intensity (carbon per unit of primary energy) of the global energy system fell by 0.3 percent a year in the 20th century because of substitutions of oil and gas for coal, the expansion of hydropower, and the introduction of nuclear power. Figure D.2 shows carbon intensities for 1971-97. The drop in the carbon intensity of the energy system and the decline in the energy intensity of economic production have reduced the carbon intensity of GDP by 1 percent a year. Carbon emissions per capita have not changed much since 1971. In 1997 the average carbon intensity was 16.3 grams of carbon per megajoule, the carbon intensity per unit of economic activity was 258 grams of carbon per 1995 U.S. dollar, and carbon emissions per capita were 1.15 tonnes.

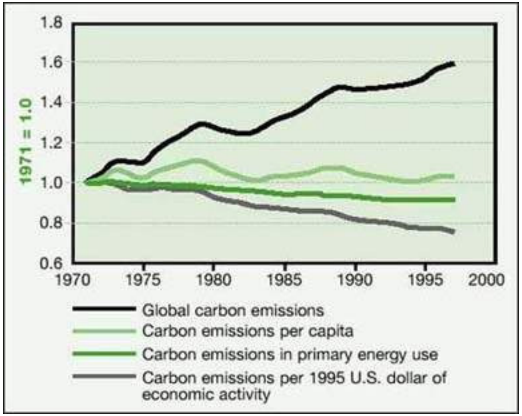

FIGURE D.2. GLOBAL CARBON EMISSIONS, CARBON EMISSIONS PER CAPITA, AND DECARBONISATION OF THE ENERGY SYSTEM AND OF ECONOMIC PRODUCTION, 1971-97

Source: IEA, 1999.

Regional carbon emissions per capita vary considerably around the average of 1.15 tonnes. In 1997 the average North American emitted 4.70 tonnes of carbon, while the average African emitted just 0.28 tonnes - 6 percent of the North American's emissions (table D.1).

TABLE D.1. CARBON EMISSIONS PER CAPITA BY REGION, 1975-97 (TONNES OF CARBON)

Region	1975	1980	1985	1990	1995	1997
North America[a]	4.84	4.96	4.54	4.54	4.55	4.70
OECD Europe	2.42	2.59	2.41	2.35	2.26	2.29
Pacific OECD[b]	2.06	2.19	2.14	2.52	2.86	3.02

Pacific OECD[b]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Non-OECD Europe	1.71	2.05	2.10	1.99	1.45	1.44
Former Soviet Union	3.16	3.47	3.53	3.50	2.36	2.15
Latin America	0.53	0.57	0.50	0.53	0.57	0.63
Middle East	0.78	1.13	1.34	1.41	1.62	1.73
Asia[c]	0.15	0.18	0.20	0.25	0.31	0.34
China	0.35	0.42	0.50	0.59	0.72	0.73
Africa	0.21	0.25	0.29	0.28	0.28	0.28
World	1.14	1.21	1.16	1.17	1.13	1.15

a. Includes Mexico. b. Includes the Republic of Korea. c. Excludes China.

Source: Calculated from IEA, 1999 energy data and IPCC carbon emission factors (see box D.1).

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Editorial board - Brief biographies of Editorial Board members

Dennis Anderson is a Professor and the Director of the Imperial College Centre of Energy Policy and Technology, London, and a visiting Professor at the University College, London. Anderson holds degrees in economics from the London School of Economics (1967) and in engineering from the University of Manchester (1963). He is a Research Associate at the Oxford University Centre for the Study of African Economies and a Member of St. Antony's College. A former Senior Economist for the World Bank and Chief Economist for Shell, Anderson has published several works on rural energy and development, economic and environmental interactions, and climate change technology. His current research interests include economic and environmental interactions, energy pricing and regulation, and development policy.

Safiatou Franciose Ba-N'Daw is a former Minister of Economic Infrastructure in the Ministry of Energy of Cte d'Ivoire. She holds an M.Sc. in Economic Sciences from the University of Abidjan, studied statistics at Georgetown University, Washington, D.C., and received an MBA from Harvard University. She is also a Certified Public Accountant. Ba-N'Daw has worked as Financial Analyst for the World Bank, and has extensive experience in the development of small and medium-sized businesses in Hungary, Turkey and Tunisia. She has served as Senior Financial Specialist with the Central Bank of Pakistan and the Government of Pakistan on the development of financial institutions in that country. She also worked on financial issues in Sri Lanka until her promotion to the Ministry of Energy.

John W. Baker, Chairman of the World Energy Council from 1995-98, currently serves as the Deputy Chairman of Celltech Group, a pharmaceuticals company, and is a non-executive director for several other companies. He is also a member of the Education

Standards Task Force and the Welfare to Work Task Force for the British Government. An arts graduate of Oxford University, he spent ten years dealing with transport policy and finance, and another decade in the field of urban renewal and public housing. In 1979 he moved into the energy sector to become the Corporate Managing Director of the Central Electricity Generating Board, and later led the management of the UK electricity privatisation and restructuring programme. He was Chief Executive Officer of National Power since its establishment in 1990, then serving as its Chairman from 1995 to 1997.

JoAnne DiSano is the Director of the Division for Sustainable Development for the UN Department of Economic and Social Affairs. DiSano has a degree in psychology and sociology from the University of Windsor, Ontario, and a Masters of Education from Wayne State University (U.S.). Before joining the United Nations, she held several senior management positions with the Government of Canada, culminating in her work with the Department of Arts, Sport, the Environment, Tourism and Territories, where she served as the First Assistant Secretary, Environment and Conservation Policy Division, and as Deputy Executive Director, Environment Strategies Directorate. From 1996 to 1998, DiSano was the Deputy Head of the Environment Protection Group of that department. She has also held positions with the Canadian Employment and Immigration Commission and the Treasury Board in Ottawa.

Gerald Doucet is the Secretary General of the World Energy Council, a position he has held since September 1998. A graduate of Ottawa University, with a Masters in Economics from Carlton University, Doucet worked for the Government of Canada in various economic and policy roles from 1967-1981. He then joined the Retail Council of Canada as Senior Vice President, and in 1988 he became the Agent General for Ontario in Europe for the Province of Ontario. From 1992 to 1994 he served as President and a Founding Director of the Europe-Canada Development Association, and from 1994-98 as President and CEO of the Canadian Gas Association.

Emad El-Sharkawi is chairman of the Egyptian National Committee of the World Energy Council, vice-chair of WEC's executive assembly for Africa, general coordinator for UN-financed energy projects in Egypt, and advisor to numerous energy organizations and commissions. He has a post-graduate diploma in electrical power engineering from King's College, University of Durham, and a Ph.D. in electrical power systems from the University of Manchester. After supervising engineering projects in Egypt early in his career, he taught and led research on electrical power systems and energy at universities in Iraq. Returning to Egypt, El-Sharkawi joined the Ministry of Electricity and Energy and later the Nuclear Power Plants Authority as Manager of Technical Affairs (1977-78). Since that time he has supervised many renewable energy programmes in Egypt and served as a member of the country's specialised councils on energies. In 1986 he was named Chairman of the Board of Directors for the Egyptian Electricity Authority. El-Sharkawi has co-authored many papers on energy and systems planning, and his efforts in the field of energy led to his election to the Royal Swedish Academy for Engineering Sciences.

Jos Goldemberg is a member of the Brazilian Academy of Sciences and the Third World Academy of Sciences. Trained in physics at the University of Saskatchewan (Canada) and the University of Illinois, Goldemberg holds a Ph.D. in Physical Sciences from the University of So Paulo. During his long academic career, he has taught at the University of So Paulo (where he also served as Rector from 1986-89), Stanford University, and the University of Paris (Orsay). He was a Visiting Professor at Princeton University in 1993-94, at the International Academy of the Environment in Geneva in 1995, and at Stanford University in 1996-97. He served the Federal Government in Brazil as Secretary of State of Science and Technology in 1990-91, Minister of Education in 1991-92, and Acting Secretary of State of the Environment in 1992. The author of several books and technical papers, Goldemberg is an internationally respected expert on nuclear physics, the environment, and energy. In 1991 Goldemberg was the co-winner of the Mitchell Prize for Sustainable Development, and in 1994 he was honoured with the establishment of the Jos Goldemberg Chair in Atmospheric Physics at Tel Aviv University. In 2000, he was awarded

the Volvo Environmental Prize, along with three of his colleagues on the World Energy Assessment.

John P. Holdren is the Teresa and John Heinz Professor of Environmental Policy and Director of the Program on Science, Technology, and Public Policy in the John F. Kennedy School of Government, and a Professor of Environmental Science and Public Policy in the Department of Earth and Planetary Sciences at Harvard University. Trained in engineering and plasma physics at MIT and Stanford, from 1973-96 Holdren co-founded and co-led the interdisciplinary graduate programme in energy and resources at the University of California, Berkeley. He is a member of the President's Committee of Advisors on Science and Technology (PCAST) and has chaired PCAST panels on protection of nuclear bomb materials, the U.S. fusion-energy R&D program, U.S. energy R&D strategy for the climate-change challenge, and international cooperation on energy. He is also a member of the U.S. National Academy of Sciences (NAS) and National Academy of Engineering (NAE), Chairman of the NAS Committee on International Security and Arms Control, and Chairman of the NAS/NAE Committee on U.S.-India Cooperation on Energy.

Michael Jefferson runs a consulting firm, Global Energy and Environment Consultants, in the United Kingdom. A graduate of the Universities of Oxford and the London School of Economics, Jefferson has worked extensively in the private sector, from merchant banking to head of oil supply strategy and planning for Europe at the Royal Dutch/Shell Group of Companies. In 1990 Jefferson was seconded to the World Energy Council (WEC) as Deputy Secretary General, and he later became director of studies and policy development for WEC. He is the author of numerous books and articles related to energy and climate change, including *Energy for Tomorrow's World* (written for a WEC commission in 1993). He was a lead author and contributing author for the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report, a member of the drafting team for the IPCC's Synthesis Report, and an IPCC peer review editor for the Third Assessment Report. He is technical coordinator and lead consultant to the G8 Renewable Energy Task Force. He also

participated in the UNDP report, *Energy after Rio,* written in 1997.

Eberhard Jochem is the Senior Scientist at the Fraunhofer Institute of Systems and Innovation Research (Karlsruhe, Germany) and Co-director of the Centre for Energy Policy and Economics (Zurich, Switzerland). Jochem holds degrees in chemical engineering (Aachen, 1967) and economics (Munich, 1971), and a Ph.D. in technical chemistry (Munich, 1971). He was a research fellow at Munich University and Harvard University. As an internationally acknowledged expert in systems analysis, technical and socioeconomic research, and policy evaluation, Jochem is a member of several national and international scientific organizations and advisory committees, including the IPCC Bureau and the Enqute Commission on "Sustainable Energy, Liberalization, and Globalization" of the German Parliament. He presented lectures at the universities in Karlsruhe and Kassel until 1999 and since then in Zurich and Lausanne, Switzerland. He is a member of the Editorial Advisory Board of *Energy Environment* and *Climate Policy.*

Thomas B. Johansson, who is on leave from the University of Lund in Sweden, is the Director of the Energy and Atmosphere Programme of the Bureau for Development Policy of UNDP. Johansson, who holds a Ph.D. in nuclear physics from the Lund Institute of Technology, is International Co-Chairman of the Working Group on Energy Strategies and Technologies of the China Council for International Cooperation on Environment and Development. He has served as Convening Lead Author, Energy Supply Mitigation Options (Working Group IIA of the Intergovernmental Panel on Climate Change); Vice-Chairman, UN Committee on New and Renewable Sources of Energy and on Energy for Development; Chairman, UN Solar Energy Group for Environment and Development; and Director of Vattenfall, the Swedish State Power Board. He is has authored or co-authored numerous books and articles including *Energy after Rio; Renewable Energy: Sources for Fuels and Electricity; Electricity-Efficient End Use and New Generation Technologies and their Planning Implications;* and *Energy for a Sustainable World.* Along with three other members of the editorial board, he was awarded the Volvo Environment Prize in 2000.

Hisham Khatib, an engineer and economist, serves as honorary Vice Chairman of the World Energy Council, as a member of the Roster of Experts for the Global Environment Facility's Scientific and Advisory Panel, and as the Advisory Editor to the *Utilities Policy* and *Energy Policy* journals (U.K.) and the *Natural Resources Forum* (U.S.). Khatib received an M.Sc. from the University of Birmingham, and a Ph.D. in electrical engineering from the University of London, where he also received a B.Sc. in economics. Khatib has more than 40 years' experience in matters relating to electricity, energy, water, and environmental issues. He has consulted to the United Nations, UNDP, UNEP, Global Environment Facility, UNIDO, World Bank, Arab Fund, Islamic Development Bank, and many other regional and international development agencies. Khatib also served as Minister of Planning, Minister of Water and Irrigation, and Minister of Energy and Mineral Resources for the government of Jordan. He is the author of two books, *Economics of Reliability in Electrical Power Systems* and *Financial and Economic Evaluation of Projects,* and of more than 100 articles and papers. In 1998 he was honoured with the "Achievement Medal" of the Institution of Electrical Engineers.

Kui-Nang Mak has been chief of the Energy and Transport Branch of the Division for Sustainable Development, UN Department of Economic and Social Affairs (DESA) since 1990. He holds a M.Sc. in electrical engineering from the University of Illinois, where he has completed all requirements except dissertation for a Ph.D. in electrical engineering; an I.E. degree in industrial economics and management from Columbia University and a Certificate from the Executive Programme on Climate Change and Development from Harvard University. He has worked for the United Nations since 1975, acting as an Economic Affairs Officer specializing in energy for DESA from 1978 to 1990. He is the author of several papers and reports on global energy issues, particularly on international cooperation and financing. His professional affiliations include serving as a member of the Sub-Committee on International Practices, Institute of Electrical and Electronics Engineers; a member of the Committee on Cleaner Fossil Fuel Systems of the World Energy Council; and an advisor for the China Coal Preparation Association.

Nebojsa Nakicenovic is the Project Leader of the Transitions to New Technologies Project at the International Institute for Applied Systems Analysis (IIASA). He is also the Convening Lead Author of the Special Report on Emissions Scenarios by the Intergovernmental Panel on Climate Change, and Guest Professor at the Technical University of Graz. Nakicenovic holds bachelor's and master's degrees in economics and computer science from Princeton University and the University of Vienna, where he completed his Ph.D. He also received an *honoris causa* Ph.D degree in engineering from the Russian Academy of Sciences. Before joining IIASA, Nakicenovic worked with the Research Centre (Karlsruhe, Germany) in the field of nuclear materials accountability. He is the author or co-author of many scientific papers and books on the dynamics of technological and social change, economic restructuring, mitigation of anthropogenic impacts on the environment, and response strategies to global change. Nakicenovic has been Associate Editor of the *International Journal on Technological Forecasting and Social Change* and of the *International Journal on Energy,* and he serves as an advisor to many groups, including the United Nations Commission on Sustainable Development. Currently, his research focuses on the diffusion of new technologies and their interactions with the environment.

Anca Popescu is the Director of the Institute of Power Studies and Design in Romania. Popescu holds a B.Sc. in electrical engineering and a Ph.D. University in high-voltage technique from the Bucharest Polytechnic. An expert in energy policy, integrated resources planning, and power sector development and investment planning, she has served as a scientific and technical expert to the UN Framework Convention on Climate Change and was the Chief Scientific Investigator on the role of nuclear power plants in greenhouse gas emission reductions in Romania in a study sponsored by the International Atomic Energy Agency. The author of numerous papers on energy planning, policy, and development, Popescu has also served as a guest lecturer at Bucharest Polytechnic University and at the National Electricity Company Training Centre.

Amulya Reddy was President of the International Energy Initiative until April 2000. Reddy received his Ph.D. in applied physical chemistry from the University of London in 1958. From 1970-91 he was a professor at the Indian Institute of Science, in Bangalore, India, and was a visiting Senior Research Scientist at the Center for Energy and Environmental Studies at Princeton University in 1984. From 1990-93, Reddy was a member of the Scientific and Technical Advisory Panel of the Global Environment Facility. He has also been a member of the Energy Research Group of the International Development Research Centre in Canada; the Economic and Planning Council, Government of Karnataka; and a member of the Panel of Eminent Persons on Power for the Minister of Power, India. He is the author of more than 250 papers, and co-author and editor of several books on energy, rural technology, and science and technology policy. Reddy was awarded the Volvo Environmental Prize for 2000, along with three other members of the World Energy Assessment editorial board.

Hans-Holger Rogner is the Head of the Planning and Economic Studies Section in the Department of Nuclear Energy in the International Atomic Energy Agency. He holds an industrial engineering degree and a Ph.D. in energy economics from the Technical University of Karlsruhe. He specialised in applying systems analysis to long-term energy demand and supply issues and in identifying technologically and economically feasible paths to sustainable energy systems. At the International Atomic Energy Agency, Rogner's activities focus on sustainable energy development and technology change. He contributes to UN efforts targeted at Agenda 21, including combating climate change.

Kirk R. Smith is Professor of Environment Health Sciences, Associate Director for International Programs at the Center for Occupational and Environment Health, and Deputy Director of the Institute for Global Health at the University of California, Berkeley. Smith holds a Ph.D. and M.P.H. in biomedical and environmental health sciences from Berkeley. He has been a Senior Fellow at the East-West Center's Program on Environment (Honolulu), and was the founding head of the East-West Center's Energy Program (1978-

1985). Smith is the author of more than 200 articles and 7 books, sits on the boards of 7 international scientific journals, and is advisor to the governments of several developing countries on environment. He is also a member of the India-U.S. Academies of Science Energy/Environment Program and of the World Health Organisation's Comparative Risk Assessment and Air Quality Guidelines committees. In 1997, he was elected to the US National Academy of Sciences.

Wim C. Turkenburg is Professor and Head of the Department of Science, Technology, and Society at Utrecht University. He is also a member of the Council on Housing, Physical Planning, and Environment of the Netherlands, Vice Chairperson of the UN Committee on Energy and Natural Resources for Development (UN-CENRD), and Chairperson of the Subcommittee on Energy of the UN-CENRD. He studied physics, mathematics, and astronomy at Leiden University and the University of Amsterdam, and received his Ph.D. in science and mathematics from the University of Amsterdam in 1971. Turkenburg is an expert on energy, the environment, and systema analysis. He is author or co-author of many articles on renewables (wind energy, photovoltaics, biomass energy), energy efficiency improvement, cleaner use of fossil fuels (decarbonization technologies), and energy and climate change. He has been member of a number of national and international boards, committees and working groups on energy, energy research, and energy and environmental policy development, serving inter alia the International Solar Energy Society, the World Energy Council, the Intergovernmental Panel on Climate Change, and the Government of the Netherlands.

Francisco Lopez Viray is the Secretary of Energy in the Philippines, and chairs its subsidiary agencies, including the National Power Corporation, the Philippine National Oil Company, and the National Electrification Administration. Viray holds an M.Sc. in electrical engineering from the University of the Philippines and a Ph.D. in engineering from West Virginia University. His extensive career has included advisory and research positions on a number of energy and power planning projects. A specialist in the areas of power system

engineering, computer applications in engineering and energy planning and management, Viray has received several citations and awards, including the ASEAN Achievement Award in Engineering, and the Outstanding Professional in Electrical Engineering from the Professional Regulation Committee of the Philippines.

Robert H. Williams is a Senior Research Scientist at Princeton University's Center for Energy and Environmental Studies, with a Ph.D. in physics from the University of California, Berkeley (1967). He served on two panels of the President's Committee of Advisors on Science and Technology: the Energy R&D Panel (1997), as chair of its Renewable Energy Task Force; and the International Energy Research, Development, Demonstration, and Deployment Panel (1999), as chair of its Energy Supply Task Force. Since 1993 he has been a member of the Working Group on Energy Strategies and Technologies of the China Council for International Cooperation on Environment and Development. He was a member of the Scientific and Technical Advisory Panel for the Global Environment Facility and chaired its Climate and Energy Working Group (1995-1998). He has written many articles and coauthored several books on a wide range of energy topics. He is recipient of the American Physical Society's Leo Szilard Award for Physics in the Public Interest (1988), the U.S. Department of Energy's Sadi Carnot Award (1991) for his work on energy efficiency, and a MacArthur Foundation Prize (1993). In 2000, along with three other members of the World Energy Assessment editorial board, he received the Volvo Environmental Prize.

Glossary - Selected terminology

Acid deposition: fallout of substances from the atmosphere (through rain, snow, fog or dry particles) that have the potential to increase the acidity of the receptor medium. They are primarily the result of the discharge of gaseous sulphur oxides and nitrogen oxides from the burning of coal and oil e.g. in electricity generation, smelting industries and transport. "Acid rain" is the result of the combination of these gases in the air with vapor. Acidifying

deposition can be responsible for acidification of lakes, rivers and groundwater, with resulting damage to fish and other components of aquatic ecosystems, and for damage to forests and other harmful effects on plants. (Note: precipitation is naturally acid as a result of the absorption of carbon dioxide from the atmosphere.)

Agenda 21: a comprehensive plan of action to be taken globally, nationally and locally in every area in which human impacts on the environment. It was adopted by more than 175 governments at the UN Conference on Environment and Development in 1992 (also known as the Rio Earth Summit).

Animate energy: energy derived from human or animal power.

Anthropogenic emissions: the share of emissions attributed to human activities.

API degree: the American Petroleum Institute has adopted a scale of measurement for the specific gravity of crude oils and petroleum products that is expressed in degrees.

Biofuels: fuels obtained as a product of biomass conversion (such as alcohol or gasohol).

Biomass: organic, non-fossil material oil of biological origin, a part of which constitutes an exploitable energy resource. Although the different forms of energy from biomass are always considered as renewable, it must be noted that their rates of renewability are different. These rates depend on the seasonal or daily cycles of solar flux, the vagaries of climate, agricultural techniques or cycles of plant growth, and may be affected by intensive exploitation.

Biogas: a gas composed principally of a mixture of methane and carbon dioxide produced by anaerobic digestion of biomass.

Breeder reactor: a reactor which produces a fissile substance identical to the one it

consumes and in greater quantity than the one it has consumed, that is, it has a conversion ratio greater than unity.

Business-as-usual: the projected future state of energy and economic variables in the event that current technological, economic, political, and social trends persist.

Capacity building: developing skills and capabilities for technology innovation and deployment in the relevant government, private-sector, academic, and civil institutions.

Carbon sequestration: the capture and secure storage of carbon that would otherwise be emitted or remain in the atmosphere, either by (1) diverting carbon from reaching the atmosphere; or (2) removing carbon already in the atmosphere. Examples of the first type are trapping the CO_2 in power plant flue gases, and capturing CO_2 during the production of decarbonised fuels. The common approach to the second type is to increase or enhance carbon sinks.

Carbon tax: a levy exacted by a government on the use of carbon-containing fuel for the purpose of influencing human behavior (specifically economic behavior) to use less fossil fuels (and thus limit greenhouse gas emissions).

Carbon sinks: places where CO_2 can be absorbed, such as forests, oceans and soil.

Clean Development Mechanism (CDM): is one of four 'flexibility' mechanisms adopted in the Kyoto Protocol to the UN Framework Convention on Climate Change. It is a cooperative arrangement through which certified greenhouse gas emission reductions accruing from sustainable development projects in developing countries can help industrialized countries meet part of their reduction commitments as specified in Annex B of the Protocol.

Cogeneration: see combined heat and power

Combined cycle plant: electricity generating plant comprising a gas-turbine generator unit, whose exhaust gases are fed to a waste-heat boiler, which may or may not have a supplementary burner, and the steam raised by the boiler is used to drive a steam-turbine generator.

Combined heat and power (CHP) station: also referred to as a cogeneration plant. A thermal power station in which all the steam generated in the boilers passes to turbo-generators for electricity generation, but designed so that steam may be extracted at points on the turbine and/or from the turbine exhaust as back-pressure steam and used to supply heat, typically for industrial processes or district heating.

Commercial energy: energy that is subject to a commercial transaction and that can thus be accounted for. This contrasts to non-commercial energy, which is not subject to a commercial exchange, and thus difficult to account for in energy balances. The term non-commercial energy thus is technically distinct from traditional energy, but in practice they are often used interchangeably.

Commission on Sustainable Development (CSD): was created in December 1992 to ensure effective follow-up of the United Nations Conference on Environment and Development, to monitor and report on implementation of the agreements at the local, national, regional and international levels.

Compressed natural gas (CNG): natural gas stored under pressure in cylinders and used as fuel for automotive engines.

Cost buy-down: the process of paying the difference in unit cost (price) between an innovative energy technology and a conventional energy technology in order to increase sales volume, thus stimulating cost reductions through manufacturing scale-up and economies of learning throughout the production, distribution, deployment, use, and maintenance cycle.

Developing countries: generally used in this report to refer to the countries that are members of the Group of 77 Countries and China.

Digester: a tank designed for the anaerobic fermentation of biomass.

Dimethyl ether (DME): an oxygenated fuel that can be produced from any carbonaceous feedstock by a process that begins with syngas production.

Discount rate: the annual rate at which the effects of future events are reduced so as to be comparable to the effect of present events.

Economies in transition: national economies that are moving from a period of heavy government control toward lessened intervention, increased privatization, and greater use of competition.

Energy innovation chain: the linked process by which an energy-supply or energy-end-use technology moves from its conception in theory and the laboratory to its feasibility testing through demonstration projects, small-scale implementation and finally large-scale deployment.

Energy intensity: ratio between the consumption of energy to a given quantity, usually refers to the amount of primary or final energy consumed per unit of gross domestic or national product.

Energy efficiency: the amount of utility or energy service provided by a unit of energy *(U/E),* which can be used as a measure of energy efficiency in end-use applications. An increase in energy efficiency enables consumers to enjoy an increase in utility or energy service for the same amount of energy consumed or to enjoy the same utility of energy services with reduced energy consumption, *U = (U/E) E.* The usual situation is one in which an increase in energy efficiency *(U/E)* boosts both energy use and the utility

derived from each unit of energy consumed.

Energy payback/time: the time of exploitation of an energy installation, necessary for recuperating all the energy consumed in its construction and operation during the projected lifespan of the installation.

Energy sector restructuring and reform: encouraging market competition in energy supply (often by transfer of ownership from the public to the private sector), while removing subsidies and other distortions in energy pricing and preserving public benefits.

Energy services: the utility of energy is often referred to by engineers as *energy services,* although that term can be confusing since units vary between applications and sometimes are not defined at all. For example, lumens is a natural unit in lighting services, and Thomas Edison proposed charging for lumens rather than kilowatt hours when electricity was first used for lighting; for practical reasons he eventually settled on charging by the kilowatt hour instead. James Watt charged for his steam engines not by their motive power, but by the difference in the costs of fuel he and his customers saved when they substituted his engine for their old one. However, when the utility or 'services' provided by energy are felt through a hot shower, chilled drinks, refrigerated food, a comfortably warm or cool house, increased transport miles, or labour saved in washing and ironing or in producing an innumerable array of industrial goods and services, it is only practicable to charge for energy in energy units.

Environmental taxes (ecotaxes): levies on products or services collected to account for environmental impacts associated with them.

Ethanol (ethyl alcohol): alcohol produced by the fermentation of glucose. The glucose may be derived from sugary plants such as sugar cane and beets or from starchy and cellulosic materials by hydrolysis. The ethanol may be concentrated by distillation, and can be blended with petroleum products to produce motor fuel.

Exergy: the maximum amount of energy that can be converted into any other form or energy under given thermodynamic conditions; also known as availability of work potential.

Externalities: benefits or costs resulting as an unintended byproduct of an economic activity that accrue to someone other than the parties involved in the activity. While energy is an economic 'good' that sustains growth and development and human well-being, there are by-products of energy production and use that have an undesirable effect on the environment (economic 'bads'). Most of these are emissions from the combustion of fossil fuels.

Final energy: is the energy transported and distributed to the point of final use. Examples include gasoline at the service station, electricity at the socket, or fuelwood in the barn. The next energy transformation is the conversion of final energy in end-use devices, such as appliances, machines, and vehicles, into useful energy, such as work and heat. Useful energy is measured at the crankshaft of an automobile engine or an industrial electric motor, by the heat of a household radiator or an industrial boiler, or by the luminosity of a light bulb. The application of useful energy provides energy services, such as a moving vehicle, a warm room, process heat, or illumination.

Foreign direct investment (FDI): is net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. Gross foreign direct investment is the sum of the absolute values of inflows and outflows of foreign direct investment recorded in the balance of payments financial account. It includes equity capital, reinvestment of earnings, other long-term capital, and short-term capital. Note that this indicator differs from the standard measure of foreign direct investment, which captures only inward investment.

Fuel cells: devices that enable chemical energy to be converted directly into electrical energy without the intervention of the heat engine cycle, in which electrical power is produced in a controlled reaction involving a fuel, generally hydrogen, methanol or a hydrocarbon.

Fuelwood: wood and wood products, possibly including coppices, scrubs, and branches, bought or gathered, and used by direct combustion.

Global Environment Facility (GEF): a financial institution that provides grants and concessionary financing to developing countries and economies-in-transition for projects and activities that provide global benefits in four topical areas: climate change; biological diversity; international waters; and stratospheric ozone. The GEF was established for the purpose of implementing agreements stemming from the 1992 UN Conference on Environment and Development including the UN Framework Convention on Climate Change. The World Bank Group is one of the three implementing agencies for the GEF, together with the United Nations Development Program and the United Nations Environment Program.

Green pricing: labelling and pricing schemes that allow consumers to pay a premium for environmentally friendly services and products if they choose.

Greenfield investment: starting up an entirely new plant, in contrast to rebuilding an older one.

Greenhouse Gases (GHGs): heat-trapping gases in the atmosphere that warm the Earth's surface by absorbing outgoing infrared radiation and re-radiating part of it downward. Water vapour is the most important naturally occurring greenhouse gas, but the principal greenhouse gases, whose atmospheric concentrations are being augmented by emission from human activities are carbon dioxide, methane, nitrous oxide, and halocarbons.

Grid extension: extending the infrastructural network that supplies energy, such as transmission wires for electricity.

Gross National Product (GNP): total production of goods and services by the subjects of a country at home and abroad. In national income accounting, it is a measure of the performance of the nation's economy, within a specific accounting period (usually a year).

Higher heating value (HHV): quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel in the determination of which the water produced is assumed completely condensed and the heat recovered. Contrast to lower heating value.

Industrialized countries: for purposes of this report, this term refers primarily to high-income OECD countries. While many transitional economies are also characterized by a high degree of industrialization, they are often considered and discussed separately because of their specific development requirements.

Infrastructure: the physical structures and delivery systems necessary to supply energy and end-users. In the case of power plants, the infrastructure is the high-tension wires needed to carry the electricity to consumers; in the case of natural gas, it is the pipeline network; in the case of liquid fuels, it is the fueling stations.

Intergovernmental Panel on Climate Change (IPCC): a multilateral scientific organization established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization to assess the available scientific, technical, and socioeconomic information in the field of climate change and to assess technical and policy options for reducing climate change and its impacts.

Irradiance: the quantity of solar energy falling per area of plane surface and time.

Kyoto Protocol (to the UN Framework Convention on Climate Change): contains legally

binding emissions targets for industrialized (Annex I) countries for the post-2000 period. Together they must reduce their combined emissions of six key greenhouse gases by at least 5% by the period 2008-2012, calculated as an average over these five years. The Protocol will enter into force 90 days after it has been ratified by at least 55 Parties to the Climate Change Convention; these Parties must include industrialized countries representing at least 55% of this group's total 1990 carbon dioxide emissions. See also Clean Development Mechanism.

Leapfrogging: moving directly to most cleanest, most advanced technologies possible, rather than making incremental technological progress.

Liberalisation: the doctrine that advocates the greatest possible use of markets and the forces of competition to co-ordinate economic activity. It allows to the state only those activities which the market cannot perform (e.g. the provision of public goods) or those that are necessary to establish the framework within which the private enterprise economy cannot operate efficiently (e.g. the establishment of the legal framework on property and contract and the adoption of such policies and anti-monopoly legislation).

Lifecycle cost: the cost of a good or service over its entire lifetime.

Light water reactor (LWR): a nuclear reactor in which ordinary water, as opposed to heavy-water, or a steam/water mixture is used as reactor coolant and moderator. The boiling water reactor (BWR) and the pressurized water reactor (PWR) are examples of light water reactors.

Liquefied natural gas (LNG): natural gas made up mainly of methane and ethane and which, generally to facilitate its transport, has been converted to the liquid phase by having its temperature lowered.

Liquefied petroleum gas (LPG): light hydrocarbons, principally propane and butane, which

are gaseous under normal conditions, but are maintained in a liquid state by an increase of pressure or lowering of temperature.

Lower heating value (LHV): quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel in the determination of which the water produced is assumed to remain as a vapour and the heat not recovered. Contrast to higher heating value.

Macroeconomic: pertaining to a study of economics in terms of whole systems, especially with reference to general levels of output and income and to the interrelations among sectors of the economy.

Marginal cost: the cost of one additional unit of effort. In terms of reducing emissions, it represents the cost of reducing emission by one more unit.

Marginal cost pricing: a system of setting the price of energy equal to the marginal cost of providing the energy to a class of consumer.

Market barriers: conditions that prevent or impede the diffusion of cost-effective technologies or practices.

Market penetration: the percentage of all its potential purchasers to which a good or service is sold per unit time.

Market potential (or currently realizable potential): the portion of the economic potential for GHG emissions reductions or energy-efficiency improvements that could be achieved under existing market conditions, assuming no new policies and measures.

Methanol (methyl alcohol): alcohol primarily produced by chemical synthesis but also by the destructive distillation of wood. Methanol is regarded as a marketable synthetic motor

fuel.

New renewables: used in this report to refer to modern bio-fuels, wind, solar, small hydropower, marine and geothermal energy. Geothermal energy cannot be strictly considered renewable, but is included for practical reasons.

Nitrogen oxides (NO_x): oxides formed an released in all common types of combustion at high temperature. Direct harmful effects of nitrogen oxides include human respiratory tract irritation and damage to plants. Indirect effects arise from their essential role in photochemical smog reactions and their contribution to acid rain problems.

Nuclear fuel cycle: a group of processes connected with nuclear power production; using, storing, reprocessing and disposing of nuclear materials used in the operation of nuclear reactors. The closed fuel cycle concept involves the reprocessing and reuse of fissionable material from the spent fuel. The once-through fuel cycle concept involves the disposal of the spent fuel following its use in the reactor.

Opportunity cost: the cost of an economic activity foregone by the choice of another activity.

Organisation for Economic Co-operation and Development (OECD): a multilateral organization of 29 industrialized nations, producing among them two-thirds of the world's goods and services. The objective of the OECD is the development of social and economic policies and the coordination of domestic and international activities.

Pollution associated with energy use. This is usually measured as pollution per unit of energy use, or $P = (P/E)E$. Modern methods of pollution control and emerging energy technologies are capable of reducing the ratio P/E - and thus P - to very low levels, sometimes to zero. This means that if environmental policies focus on P rather than E, there is no reason why high levels of energy use (and the utility derived from it) cannot be

enjoyed and pollution virtually eliminated in the long term, a process known as delinking environmental concerns from energy use.

Primary energy is the energy that is embodied in resources as they exist in nature: chemical energy embodied in fossil fuels (coal, oil, and natural gas) or biomass, the potential energy of a water reservoir, the electromagnetic energy of solar radiation, and the energy released in nuclear reactions. For the most part, primary energy is not used directly but is first mined, harvested or converted and transformed into electricity and fuels such as gasoline, jet fuel, heating oil, or charcoal.

Public Benefits Fund (PBF): a financial mechanism created to serve the greater public interest by funding programs for environment and public health, services to the poor and disenfranchised, energy technology innovation, or other public goods not accounted for by a restructured energy sector.

Purchasing power parity (PPP): GDP estimates based on the purchasing power of currencies rather than on current exchange rates. Such estimates are a blend of extrapolated and regression-based numbers, using the result of the International Comparison Program. PPP estimates tend to lower per capita GDPs in industrialized countries and raise per capita GDPs in developing countries.

Research and development (R&D): the first two stages in the energy innovation chain. R, D & D refers to demonstration projects as well.

Reserves: those occurrences of energy sources or mineral that are identified and measured as economically and technically recoverable with current technologies and prices (see chapter 5).

Resources: those occurrences of energy sources or minerals with less certain geological and/or economic/technical recoverability characteristics, but that are considered to

become potentially recoverable with foreseeable technological and economic development (see chapter 5).

Revenue neutral taxes: governmental levies placed on certain goods or services that replace other taxes and thus do not add to total revenues collected, but rather attempt to change behaviours.

Scenario: a plausible description of how the future may develop based on analysis of a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g. rate of technology changes, prices). Note that scenarios are neither predictions nor forecasts.

Standards/performance criteria: a set of rules or codes mandating or defining product performance (e.g. grades, dimensions, characteristics, test methods, rules for use).

Structural changes: changes in the relative share of GDP produced by the industrial, agricultural or services sectors of an economy; or, more generally, systems transformations whereby some components are either replaced or partially substituted by other ones.

Subsidies: publicly supported cost reductions that may be granted to producers and consumers - directly, through price reductions, or in less visible forms, through tax breaks, market support or inadequate metering.

Sulphur oxides (SO_x): oxides produced by the combustion of fossil fuels containing sulphur. Sulphur oxides, the most widespread of which is sulphur dioxide, a colorless gas having a strong and acrid odor, are toxic at a given concentration for the respiratory system and gave harmful effects on the environment, in particular on buildings and vegetation. They contribute to the acid rain problem.

Sustainable energy: as the term is used in this document, is not meant to suggest simply a continual supply of energy. Rather it means environmentally sound, safe, reliable, affordable energy; in other words, energy that supports sustainable development in all its economic, environmental, social and security dimensions.

Syngas: a gaseous mixture composed mainly of carbon monoxide and hydrogen and synthesized from a carbonaceous feedstock such as coal or biomass. It is used as a building block for the production of synthetic liquid fuels. Syngas-based systems can make it possible to extract energy services from carbonaceous feedstocks with very low levels of pollutant or greenhouse gas emissions.

Transitional economies: see economies in transition

Unproven reserves: the estimated quantities, at a given date, which analysis of geologic and engineering data indicates might be economically recoverable from already discovered deposits, with a sufficient degree of probability to suggest their existence. Because of uncertainties as to whether, and to what extent, such unproven reserves may be expected to be recoverable in the future, the estimates should be given as a range but may be given as a single intermediate figure in which all uncertainties have been incorporated. Unproven reserves may be further categorized as probable reserves or possible reserves.

United Nations Framework Convention on Climate Change (UNFCCC): a major global convention adopted in 1992 that establishes a framework for progress in stabilizing atmospheric concentrations of greenhouse gases at safe levels. It directs that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". It also recognizes the right of developing countries to economic development, their vulnerability to the effects of climate change, and that rich countries should shoulder greater responsibility for the problem.

United Nations Conference on Environment and Development (UNCED): also known as the Rio Earth Summit. The first of a series of major United Nations conferences on global issues that were convened in the 1990s.

World Bank Group: a multilateral, United Nations affiliated lending institution which annually makes available roughly $20 billion in loans to developing countries, mainly but not exclusively for large scale infrastructure projects. The World Bank Group comprises five agencies: the International Bank for Reconstruction and Development, the International Development Association, the International Finance Corporation (IFC), the Multilateral Investment Guarantee Agency (MIGA), and the International Centre for Settlement of Investment Disputes (ICSID). The World Bank Group raises capital from both public sources and financial markets.

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An initial draft of the World Energy Assessment formed the basis for the first round of peer review at an Advisory Panel meeting that took place in July, 1999 in Geneva. Based on comments from working groups at that meeting, as well as comments received from hundreds of experts around the world, a second draft was prepared.

The second draft of the report was circulated to the Advisory Panel, energy experts, governments and NGOs by mail and via a website. With input from that second round of comments, as well as from careful scrutiny by the Editorial Board, the final versions of the chapters were produced. A list of Advisory Panel members and peer reviewers appears below.

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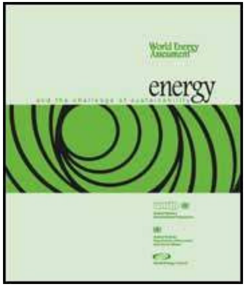

PART V. FURTHER INFORMATION AND REFERENCE MATERIAL

Foreword

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More than 175 governments have committed to Agenda 21, the programme for achieving human-centred sustainable development adopted at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. Agenda 21 noted energy's importance to sustainable development. The June 1997 Special Session of the UN General Assembly, convened to review progress on Agenda 21, went further. It emphasised that sustainable patterns of energy production, distribution, and use are crucial to continued improvements in the quality of life. It also declared that the ninth session of the United Nations Commission on Sustainable Development (CSD-9), in 2001, should focus on issues related to the atmosphere and energy and to energy and transport.

To inform the discussion and debate, the United Nations Development Programme (UNDP), United Nations Department of Economic and Social Affairs (UNDESA), and World

Energy Council (WEC) initiated the World Energy Assessment in late 1998. This report analyses the social, economic, environmental, and security issues linked to energy supply and use, and assesses options for sustainability in each area.

We offer the World Energy Assessment as an input to the CSD-9 process, the "Rio Plus Ten" meeting in 2002, and beyond. We believe that a synthesis of reviewed and validated information on energy production and consumption patterns will be a valuable tool for energy planners at the regional and national levels, and for many other audiences as well.

Our energy future will largely depend on the actions not only of governments, but also regional alliances, the private sector, and civil society. For this reason, this assessment is the centrepiece of an outreach effort by UNDP, UNDESA, and WEC. This outreach includes regional dialogues, exchanges among developing countries and between developing and industrialised countries, and consultations with a wide range of stakeholders, including the private sector, which is not always brought into debates.

The World Energy Assessment represents a collaborative effort involving the three founding organisations, 12 convening lead authors, and the teams of experts they assembled. Drafts of the report were sent out to a wide audience of experts and government representatives for review and consultation. This review included a special Advisory Panel meeting, an electronic posting, and consultations at the local, regional, and global levels, as well as with non-governmental organisations. The Editorial Board considered the content of the chapters at six meetings over the course of 16 months. Whereas the overview reflects the combined judgement and scrutiny of the Editorial Board, each chapter is the responsibility of its convening lead author.

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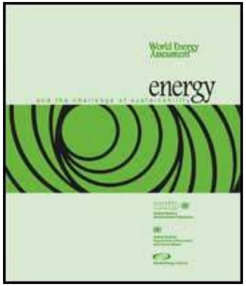


Preface

Jos Goldemberg
Chair, World Energy Assessment

Energy is central to achieving the interrelated economic, social, and environmental aims of sustainable human development. But if we are to realise this important goal, the kinds of energy we produce and the ways we use them will have to change. Otherwise, environmental damage will accelerate, inequity will increase, and global economic growth will be jeopardised.

We cannot simply ignore the energy needs of the 2 billion people who have no means of

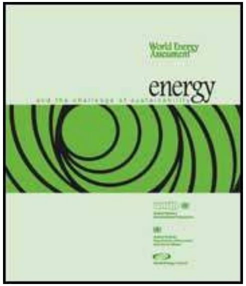
escaping continuing cycles of poverty and deprivation. Nor will the local, regional, and global environmental problems linked to conventional ways of using energy go away on their own. Other challenges confront us as well: the high prices of energy supplies in many countries, the vulnerability to interruptions in supply, and the need for more energy services to support continued development.

The World Energy Assessment affirms that solutions to these urgent problems are possible, and that the future is much more a matter of choice than destiny. By acting now to embrace enlightened policies, we can create energy systems that lead to a more equitable, environmentally sound, and economically viable world.

But changing energy systems is no simple matter. It is a complex and long-term process - one that will require major and concerted efforts by governments, businesses, and members of civil society. Consensus on energy trends and needed changes in energy systems can accelerate this process.

The World Energy Assessment was undertaken, in part, to build consensus on how we can most effectively use energy as a tool for sustainable development. Its analysis shows that we need to do more to promote energy efficiency and renewables, and to encourage advanced technologies that offer alternatives for clean and safe energy supply and use. We also need to help developing countries find ways to avoid retracing the wasteful and destructive stages that have characterised industrialisation in the past.

Considerable work by many individuals went into this publication, and my hope is that it contributes to a more equitable, prosperous, and sustainable world.



Acknowledgements

This publication would not have been possible without the strenuous efforts of many people, starting with the members of the Editorial Board and the authors of each chapter, as well as those who represented the establishing institutions. The establishing institutions greatly appreciate their efforts.

The editorial process was skilfully guided by Chair Jos Goldemberg of Brazil. His extensive experience in energy, policy issues, and international relations has been invaluable, and his unwavering commitment to the success of this project has been an inspiration to everyone involved. We are also deeply grateful to the other members of the Editorial Board for their painstaking work in preparing and reviewing this publication

under an extremely tight schedule, for their willingness to challenge one another while maintaining a spirit of cooperation, and for their shared commitment to the idea of energy as a tool for sustainable human development.

Project manager Caitlin Allen was instrumental to the success of this project. Her desk was the nexus of communications for the members of the Editorial Board, who were located all over the world. She also managed the administrative, editorial, and graphic design staff that assisted in the preparation of this book, and planned and implemented the outreach phase.

We appreciate the dedicated work of the entire World Energy Assessment team, including Janet Jensen for editorial assistance throughout the project, Nerissa Cortes for handling myriad administrative details, and Natty Davis for assisting with the outreach phase. We are grateful to Julia Ptasznik for creating the distinctive look of the publication and associated materials, and to Communications Development Incorporated for final editing and proofreading.

The establishing organisations also thank the Advisory Panel, peer reviewers, and participants in the consultative and outreach phases of the book.

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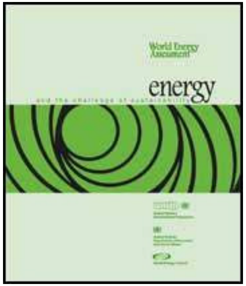

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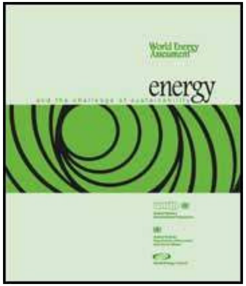


Establishing institutions

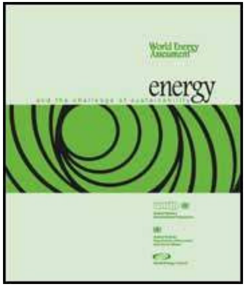
The United Nations Development Programme's (UNDP) mission is to help countries achieve sustainable human development by assisting their efforts to build their capacity to design and carry out development programmes in poverty eradication, employment creation and sustainable livelihoods, empowerment of women, and protection and regeneration of the environment, giving first priority to poverty eradication. UNDP focuses on policy support and institution building in programme countries through its network of 136 country offices.

The United Nations Department of Economic and Social Affairs (UNDESA) facilitates intergovernmental processes and, through its Division for Sustainable Development, services such bodies as the UN Commission on Sustainable Development and the UN Committee on Energy and Natural Resources for Development. UNDESA also undertakes, among other things, statistical and analytical work to monitor the environment and sustainable development, provides policy and technical advisory services, and implements technical cooperation projects at the request of developing countries in the followup to the 1992 Earth Summit.

The World Energy Council (WEC) is a multi-energy, non-governmental, global organisation founded in 1923. In recent years, WEC has built a reputation in the energy field through its studies, technical services, and regional programmes. Its work covers long-term energy scenarios, developing country and transitional economy energy issues, energy financing,

energy efficiency and liberalization policies, and environmental concerns. Through its member committees in close to 100 countries, it has encouraged the participation of private industry throughout the editorial and consultative process for this report.

For more information on the activities and publications of the three establishing organisations, please visit the following Websites:
UNDP: http://www.undp.org/seed/eap
UNDESA: http://www.un.org/esa
WEC: http://www.worldenergy.org



World Energy Assessment - Energy and the Challenge of Sustainability (UNDESA - UNDP - WEA - WEC, 2000, 517 p.)

Overview - Energy and the challenge of sustainability

Introduction

The World Energy Assessment provides analytical background and scientific information for decision-makers at all levels. It describes energy's fundamental relationship to sustainable development and analyses how energy can serve as an instrument to reach that goal. This overview synthesises the key findings of the report, which is divided into four parts.

Part 1 (chapters 1-4) begins with an introduction to energy, especially its relationship to economic development. It then considers the linkages between the present energy system and major global challenges, including poverty alleviation, health, environmental protection, energy security, and the improvement of women's lives. The chapters find that although energy is critical to economic growth and human development, affordable commercial energy is beyond the reach of one-third of humanity, and many countries and individuals are vulnerable to disruptions in energy supply. Further, energy production and use have negative impacts at the local, regional, and global levels that threaten human health and the long-term ecological balance.

Part 2 (chapters 5-8) examines the energy resources and technological options available to meet the challenges identified in part 1. It concludes that physical resources are plentiful enough to supply the world's energy needs through the 21st century and beyond, but that their use may be constrained by environmental and other concerns. Options to address these concerns - through greater energy efficiency, renewables, and next-generation technologies - are then analysed. The analysis indicates that the technical and economic potential of energy efficiency measures are under-realised, and that a larger contribution of renewables to world energy consumption is already economically viable. Over the longer term, a variety of new renewable and advanced energy technologies may be able to provide substantial amounts of energy safely, at affordable costs and with near-zero emissions.

Part 3 (chapters 9-10) synthesises and integrates the material presented in the earlier chapters by considering whether sustainable futures - which simultaneously address the issues raised in part 1 using the options identified in part 2 - are possible. As a way of answering that question, chapter 9 examines three scenarios to explore how the future might unfold using different policy approaches and technical developments. The analysis shows that a reference scenario based on current trends does not meet several criteria of sustainability. Two other scenarios, particularly one that is ecologically driven, are able to incorporate more characteristics of sustainable development. Chapter 10 examines the challenge of bringing affordable energy to rural areas of developing countries. It presents approaches to widening access to liquid and gaseous fuels for cooking and heating and to electricity for meeting basic needs and stimulating income-generating activities.

Part 4 (chapters 11-12) analyses policy issues and options that could shift current unsustainable practices in the direction of sustainable development (as called for by every major United Nations conference of the 1990s), using energy as an instrument to reach that goal. Creating energy systems that support sustainable development will require policies that take advantage of the market to promote higher energy efficiency, increased use of renewables, and the development and diffusion of cleaner, next-generation energy. Given proper signals, the market could deliver much of what is needed. But because market forces alone are unlikely to meet the energy needs of poor people, or to adequately protect the environment, sustainable development demands frameworks (including consistent policy measures and transparent regulatory regimes) to address these issues.

One way of looking at human development is in terms of the choices and opportunities available to individuals. Energy can dramatically widen these choices. Simply harnessing oxen, for example, multiplied the power available to a human being by a factor of 10. The invention of the vertical waterwheel increased productivity by another factor of 6; the steam engine increased it by yet another order of magnitude. The use of motor vehicles

greatly reduced journey times and expanded human ability to transport goods to markets.

Today the ready availability of plentiful, affordable energy allows many people to enjoy unprecedented comfort, mobility, and productivity. In industrialised countries people use more than 100 times as much energy, on a per capita basis, as humans did before they learned to exploit the energy potential of fire.[1]

Although energy fuels economic growth, and is therefore a key concern for all countries, access to and use of energy vary widely among them, as well as between the rich and poor within each country. In fact, 2 billion people - one-third of the world's population - rely almost completely on traditional energy sources and so are not able to take advantage of the opportunities made possible by modern forms of energy (World Bank, 1996; WEC-FAO, 1999; UNDP, 1997).[2] Moreover, most current energy generation and use are accompanied by environmental impacts at local, regional, and global levels that threaten human well-being now and well into the future.

In Agenda 21 the United Nations and its member states have strongly endorsed the goal of sustainable development, which implies meeting the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987, p. 8).[3] The importance of energy as a tool for meeting this goal was acknowledged at every major United Nations conference in the 1990s, starting with the Rio Earth Summit (UN Conference on Environment and Development) in 1992.[4] But current energy systems, as analysed in this report and summarised here, are not addressing the basic needs of all people, and the continuation of business-as-usual practices may compromise the prospects of future generations.

Energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions, is what is meant in this report by

the term *sustainable energy.* In other words, this term does not refer simply to a continuing supply of energy, but to the production and use of energy resources in ways that promote - or at least are compatible with - long-term human well-being and ecological balance.

Energy produced and used in ways that support human development in all its social, economic and environmental dimensions is what is meant by sustainable energy.

Many current energy practices do not fit this definition. As noted in Agenda 21, "Much of the world's energy...is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially" (UN, 1992, chapter 9.9).[5] Energy's link to global warming through greenhouse gas emissions (most of which are produced by fossil fuel consumption) was addressed by the United Nations Framework Convention on Climate Change, adopted in 1992. And in 1997 a United Nations General Assembly Special Session identified energy and transport issues as being central to achieving a sustainable future, and set key objectives in these areas.

The energy industry also recognises the need to address energy issues within a broad context. For example, the conclusions and recommendations of the 17th Congress of the World Energy Council discuss the need to provide commercial energy to those without it, and to address energy-linked environmental impacts at all levels (WEC, 1998).[6]

Although there seem to be no physical limits to the world's energy supply for at least the next 50 years, today's energy system is unsustainable because of equity issues as well as

environmental, economic, and geopolitical concerns that have implications far into the future. Aspects of the unsustainability of the current system include:

- **Modern fuels and electricity are not universally accessible, an inequity that has moral, political, and practical dimensions in a world that is becoming increasingly interconnected.**

- **The current energy system is not sufficiently reliable or affordable to support widespread economic growth. The productivity of one-third of the world's people is compromised by lack of access to commercial energy, and perhaps another third suffer economic hardship and insecurity due to unreliable energy supplies.**

- **Negative local, regional, and global environmental impacts of energy production and use threaten the health and well-being of current and future generations.**

More specific - and more quantifiable - elements of sustainability are identified below in the section on energy scenarios. Before looking into the future, however, some basic features of energy and its relationship to economic development are described, and the linkages between energy and major global challenges are analysed.

Part I: Energy and major global issues

Part 1 analyses the linkages between energy and the economy, social and health issues, environmental protection, and security, and describes aspects of energy use that are incompatible with the goal of sustainable development. It shows that:

- **Affordable, modern energy supplies - including gaseous and liquid fuels, electricity, and more efficient end-use technologies - are not accessible by 2 billion people. This constrains their opportunities for economic development and improved living standards. Women and children are disproportionately burdened**

by a dependence on traditional fuels.

- **Wide disparities in access to affordable commercial energy and energy services are inequitable, run counter to the concept of human development, and threaten social stability.**

- **Unreliable supplies are a hardship and economic burden for a large portion of the world's population. In addition, dependence on imported fuels leaves many countries vulnerable to disruptions in supply.**

- **Human health is threatened by high levels of pollution resulting from energy use at the household, community, and regional levels.**

- **The environmental impacts of a host of energy-linked emissions - including suspended fine particles and precursors of acid deposition - contribute to air pollution and ecosystem degradation.**

- **Emissions of anthropogenic greenhouse gases, mostly from the production and use of energy, are altering the atmosphere in ways that may already be having a discernible influence on the global climate.**

Finding ways to expand energy services while simultaneously addressing the environmental impacts associated with energy use represents a critical challenge to humanity. The resources and options available to meet this challenge - energy efficiency, renewables, and advanced energy technologies - are analysed in the next sections.

An introduction to energy

An energy system is made up of an energy supply sector and energy end-use technologies. The object of the energy system is to deliver to consumers the benefits that energy offers.

The term *energy services* is used to describe these benefits, which in households include illumination, cooked food, comfortable indoor temperatures, refrigeration, and transportation. Energy services are also required for virtually every commercial and industrial activity. For instance, heating and cooling are needed for many industrial processes, motive power is needed for agriculture, and electricity is needed for telecommunications and electronics.

The energy chain that delivers these services begins with the collection or extraction of primary energy that, in one or several steps, may be converted into energy carriers, such as electricity or diesel oil, that are suitable for end uses. Energy end-use equipment - stoves, light bulbs, vehicles, machinery - converts final energy into useful energy, which provides the desired benefits: the energy services. An example of an energy chain - beginning with coal extraction from a mine (primary energy) and ending with produced steel as an energy service - is shown in figure 1.

Energy services are the result of a combination of various technologies, infrastructure (capital), labour (know-how), materials, and primary energy. Each of these inputs carries a price tag, and they are partly substitutable for one another. From the consumer's perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services.

Per capita consumption of primary energy in the United States was 330 gigajoules in 1995, more than eight times as much as used by an average Sub-Saharan African (who used 40 gigajoules that year when both commercial and traditional energy are included). Many people in the least developed countries use much less. Figure 2 shows commercial and non-commercial energy consumption in various regions.

In most low-income developing countries, a small, affluent minority uses various forms of

commercial energy in much the same way as do most people in the industrialised world. But most people in low-income developing countries rely on traditional, non-commercial sources of energy using inefficient technologies such as unventilated stoves or open fires. Traditional energy sources are generally not reflected in energy statistics. Analysis based on per capita consumption of commercially distributed energy resources is common because the data are much easier to collect. The resulting analysis, however, does not accurately reflect the world's energy situation, which is why estimates of non-commercial energy use are included in table 1 and figure 2. Though less well documented, non-commercial energy is very significant globally, and is used far more widely than commercial energy in rural areas of many developing countries, particularly the least developed countries.

The rate of global commercial energy consumption is thousands of times smaller than the energy flows from the sun to the earth. Primary energy consumption is reliant on fossil fuels (oil, natural gas, and coal), which represent nearly 80 percent of the total fuel mix (table 1). Nuclear power contributes slightly more than 6 percent, and hydropower and new renewables each contribute about 2 percent.

World-wide, traditional (often non-commercial) energy accounts for about 10 percent of the total fuel mix. But the distribution is uneven: non-commercial energy accounts for perhaps 2 percent of energy consumption in industrialised countries, but an average of 30 percent in developing ones. In some low-income developing countries, traditional biomass accounts for 90 percent or more of total energy consumption.

If the global growth rate of about 2 percent a year of primary energy use continues, it will mean a doubling of energy consumption by 2035 relative to 1998, and a tripling by 2055. In the past 30 years developing countries' commercial energy use has increased at a rate three and a half times that of OECD countries, the result of life-style changes made possible by rising personal incomes, coupled with higher population growth rates and a

shift from traditional to commercial energy. On a per capita basis, however, the increase in total primary energy use has not resulted in any notable way in more equitable access to energy services between industrialised and developing countries. Clearly, more energy will be needed to fuel global economic growth and to deliver opportunities to the billions of people in developing countries who do not have access to adequate energy services.

However, the amount of additional energy required to provide the energy services needed in the future will depend on the efficiencies with which the energy is produced, delivered, and used. Energy efficiency improvements could help reduce financial investments in new energy supply systems, as they have over the past 200 years. The degree of interdependence between economic activity and energy use is neither static nor uniform across regions. Energy intensity (the ratio of energy demand to GDP) often depends on a country's stage of development. In OECD countries, which enjoy abundant energy services, growth in energy demand is less tightly linked to economic productivity than it was in the past (figure 3).

The trend towards a reduction in energy intensity as economic development proceeds can be discerned over a long historical period, as shown in figure 4, which includes the developing country examples of China and India. A detailed, long-term analysis of energy intensity for a number of countries reveals a common pattern of energy use driven by the following factors:

- **The shift from non-commercial to commercial forms of energy, industrialisation, and motorisation initially increase the commercial energy-GDP ratio. (In the 1990s this ratio increased in transition in economies, mainly because of slower economic growth.)**

- **As industrialisation proceeds and incomes rise, saturation effects, as well as an expansion of the service sector (which is less energy intensive), decrease the ratio**

of commercial energy to GDP after it reaches a peak. This maximum energy intensity has been passed by many countries, but not by low-income developing countries.

- **As a result of world-wide technology transfer and diffusion, energy efficiency improvements can be the main limiting factor in the growth of energy demand arising from increasing populations and growing production and incomes.**

- **The more efficient use of materials in better-quality, well-designed, miniaturised products, the recycling of energy-intensive materials, and the saturation of bulk markets for basic materials in industrialised countries contribute to additional decreases in energy intensity.**

- **In developing countries, technological leapfrogging to the use of highly efficient appliances, machinery, processes, vehicles, and transportation systems offers considerable potential for energy efficiency improvements.**

These drivers are leading to a common pattern of energy use per unit of GDP in industrialised and developing countries.

Energy prices influence consumer choices and behaviour and can affect economic development and growth. High energy prices can lead to increasing import bills, with adverse consequences for business, employment, and social welfare. High energy prices can also stimulate exploration and development of additional resources, create a pull for innovation, and provide incentives for efficiency improvements.

Although some impacts of energy prices are fairly steady, others are more transient. For example, different absolute price levels have had little effect on economic development in OECD European countries or Japan relative to the much lower energy prices in the United States and some developing countries. What affected economic growth in all energy-

importing countries were the price hikes of the 1970s. It appears that economies are more sensitive to price changes than to prices per se.

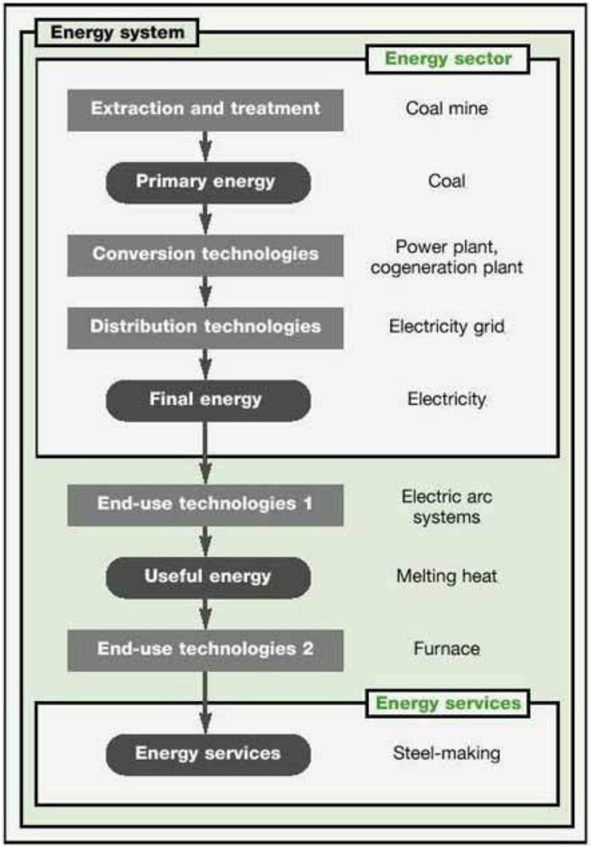


FIGURE 1. AN EXAMPLE OF THE ENERGY CHAIN FROM EXTRACTION TO SERVICES

Source: Adapted from chapter 6.

TABLE 1. WORLD PRIMARY ENERGY CONSUMPTION, 1998

Source	Primary energy (exajoules)	Primary energy (10^9 tonnes of oil equivalent)	Percentage of total	Static reserve-production ratio (years)[a]	Static resource base - production ratio (years)[b]	Dynamic resource base - production ratio (years)[c]
Fossil fuels	**320**	**7.63**	**79.6**			
Oil	142	3.39	35.3	45	~ 200	95
Natural gas	85	2.02	21.1	69	~ 400	230
Coal	93	2.22	23.1	452	~ 1,500	1,000
Renewables	**56**	**1.33**	**13.9**			
Large hydro	9	0.21	2.2	Renewable		
Traditional biomass	38	0.91	9.5	Renewable		
'New' renewables[d]	9	0.21	2.2	Renewable		
Nuclear	**26**	**0.62**	**6.5**			
Nuclear[e]	26	0.62	6.5	50[f]	>> 300[f]	
Total	**402**	**9.58**	**100.0**			

a. Based on constant production and static reserves. b. Includes both conventional and unconventional reserves and resources. c. Data refer to the energy use of a business-as-usual scenario - that is, production is dynamic and a function of demand (see chapter 9). Thus these ratios are subject to change under different scenarios. d. Includes modern biomass, small hydropower, geothermal energy, wind energy, solar energy, and marine energy (see chapter 7). Modern biomass accounts for about 7 exajoules, and 2 exajoules comes from all other renewables. e. Converted from electricity produced to fuels consumed assuming a 33 percent thermal efficiency of power plants. f. Based on once-through uranium fuel cycles excluding thorium and low-concentration uranium from seawater. The uranium resource base is effectively 60 times larger if fast breeder reactors are used.

Source: Chapter 5.

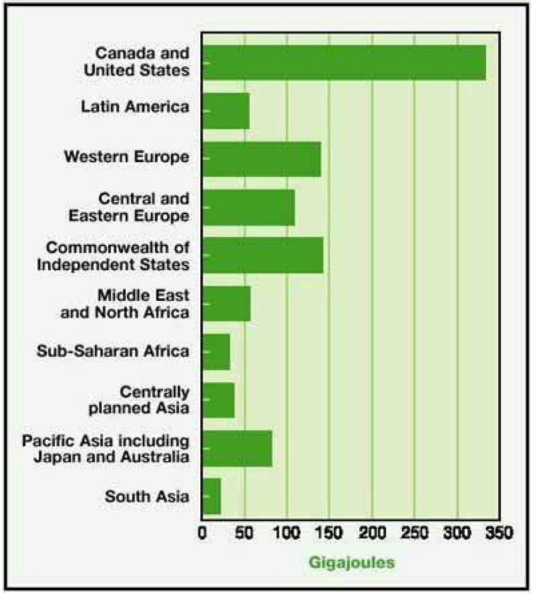


FIGURE 2. PRIMARY PER CAPITA ENERGY CONSUMPTION (COMMERCIAL AND NON-COMMERCIAL) BY REGION, 1995

Source: World Bank, 1997; WRI, 1998.

Capital investment is a prerequisite for energy development. Energy system development and structural change are the results of investment in plants, equipment, and energy system infrastructure. Difficulties in attracting capital for energy investment may impede economic development, especially in the least developed countries. Scarce public funds, especially in developing countries, are needed for many projects - ranging from rural development, education, and health care to energy supplies. Because energy supply, more

than any other alternative, is often seen as more readily capable of generating early revenues, energy investments are increasingly viewed as a private sector affair. Yet private funds are not flowing into many developing countries for a variety of reasons, especially risks to investors.

Foreign direct investment approached $400 billion in 1997 - up from $50 billion in 1984 - and represents an increasing share of international investment flows.[7] Foreign direct investment is generally commercially motivated, and investors not only expect to recover the initial capital but also count on competitive returns. These outcomes cannot be guaranteed in developing countries with potentially fragile governments or without free markets. In fact, very little foreign direct investment reaches the least developed countries.

Unlike foreign direct investment, official development assistance has remained flat relative to gross world product. In 1997 it totalled $56 billion, or 0.25 percent of the GDP of OECD countries - which have agreed in principle to a target of 0.7 percent of GDP.[8] Against this backdrop, financing is inadequate for energy projects in developing countries. Until the economic risks to foreign investors can be managed (for example, through clear and stable rules for energy and financial markets, steady revenue generation through bill collection, and profit transfers), most developing countries may have to continue to finance their energy development from domestic savings.

Although energy investment as a share of total investment varies greatly among countries and at different stages of economic development, on balance, 1.0-1.5 percent of GDP is invested in the energy sector. This ratio is expected to remain relatively stable. Based on these rules of thumb, current energy supply sector investment totals $290-430 billion a year. But this does not include investment in end-use energy efficiency.

Energy and social issues

Energy use is closely linked to a range of social issues, including poverty alleviation, population growth, urbanisation, and a lack of opportunities for women. Although these issues affect energy demand, the relationship is two-way: the quality and quantity of energy services, and how they are achieved, have an effect on social issues as well.

Poverty is the overriding social consideration for developing countries. Some 1.3 billion people in the developing world live on less than $1 a day. Income measurement alone, however, does not fully capture the misery and the absence of choice that poverty represents. The energy consumption patterns of poor people - especially their reliance on traditional fuels in rural areas - tend to keep them impoverished.

World-wide, 2 billion people are without access to electricity and an equal number continue to use traditional solid fuels for cooking. As shown in the next section, cooking with poorly vented stoves has significant health impacts. In addition, hundreds of millions of people - mainly women and children - spend several hours a day in the drudgery of gathering firewood and carrying water, often from considerable distances, for household needs. Because of these demands on their time and energy, women and children often miss out on opportunities for education and other productive activities.

Lack of electricity usually means inadequate illumination and few labour-saving appliances, as well as limited telecommunications and possibilities for commercial enterprise. Greater access to electricity and modern fuels and stoves for cooking can enable people to enjoy both short-term and self-reinforcing, long-term advances in their quality of life. Table 2 summarises some of the specific improvements that may result.

Limited income may force households to use traditional fuels and inefficient technologies. Figure 5 shows the average primary energy demand for various fuels as a function of income levels in Brazil. For low-income households, firewood is the dominant fuel. At higher incomes, wood is replaced by commercial fuels and electricity, which offer much

greater convenience, energy efficiency, and cleanliness. Because convenient, affordable energy can contribute to a household's productivity and income-generating potential, its availability can become a lever for breaking out of a cycle of poverty.

World-wide, 2 billion people are without access to electricity and an equal number continue to use traditional solid fuels for cooking.

Although population growth tends to increase energy demand, it is less widely understood that the availability of adequate energy services can lower birth rates. Adequate energy services can shift the relative benefits and costs of fertility towards a lower number of desired births in a family. An acceleration of the demographic transition to low mortality and low fertility (as has occurred in industrialised countries) depends on crucial developmental tasks, including improving the local environment, educating women, and ameliorating the extreme poverty that may make child labour a necessity. All these tasks have links to the availability of low-cost energy services.

The growing concentration of people in urban centres is another key demographic issue linked to energy. Although the general trend towards urbanisation has many components and may be inevitable, providing more options to rural residents through energy interventions could potentially slow migration and reduce pressure on rapidly growing cities. Although the negative externalities associated with energy use in urban areas can be severe, various strategies can mitigate their effects and promote energy conservation. Taking energy into consideration in land-use planning, and in designing physical infrastructure, construction standards, and transportation systems, can reduce some of the growth in energy demand that accompanies rapid urbanisation.

Transportation systems may be especially important in this regard, given the rapid growth in the number of motor vehicles world-wide. Since about 1970 the global fleet has been increasing by 16 million vehicles a year, and more than 1 billion cars will likely be on the road by 2020. Most of these cars will be driven in the cities of the developing world, where they will create more congestion, aggravate urban pollution, and undermine human health - even with optimistic projections about efficiency improvements and alternative fuels.

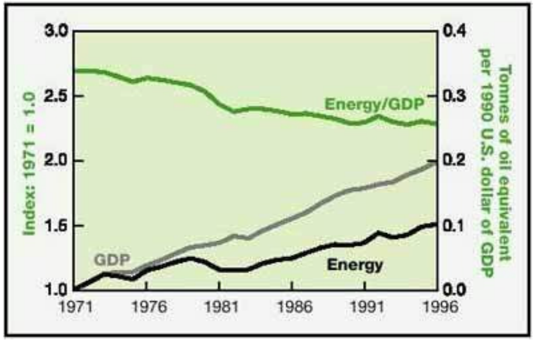


FIGURE 3. GDP AND PRIMARY ENERGY CONSUMPTION IN OECD COUNTRIES, 1971-96

Source: IEA, 1999.

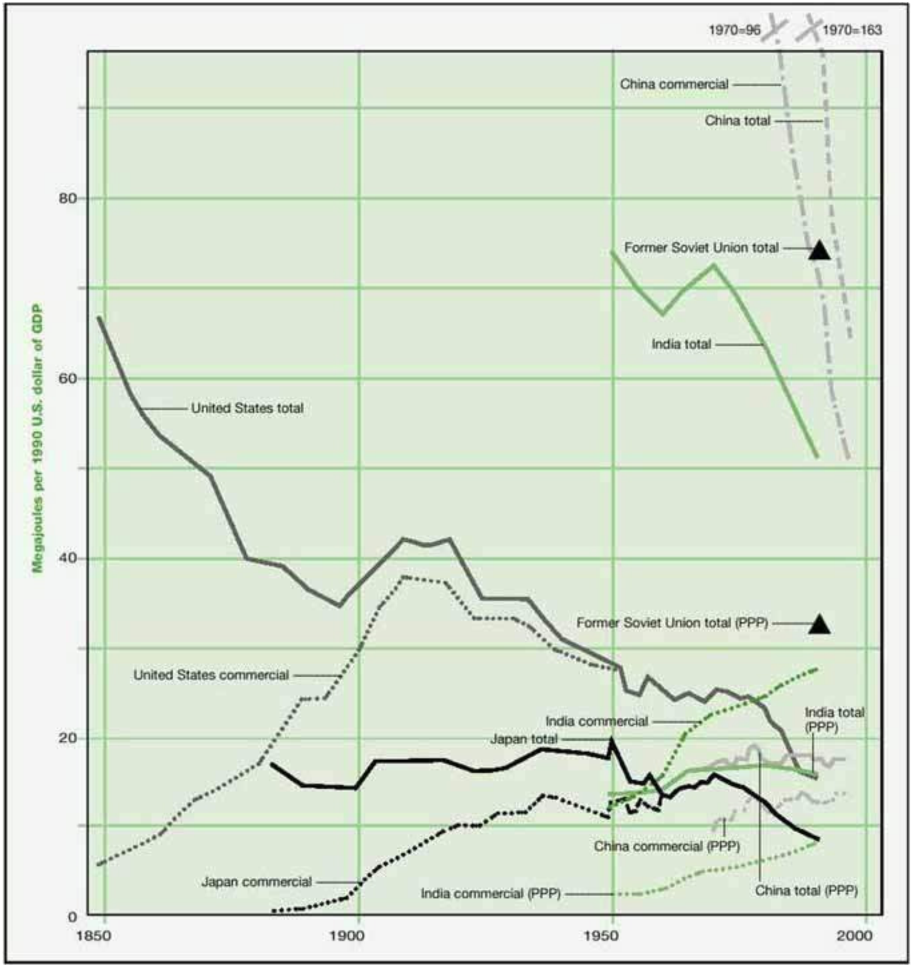

1970=96
1970=163
China commercial
China total
80
Former Soviet Union total
India total
60
United States total
Megajoules per 1990 U.S. dollar of GDP
40
Former Soviet Union total (PPP)
United States commercial
India commercial
India total (PPP)
20
Japan total
China commercial (PPP)
Japan commercial
India commercial (PPP)
China total (PPP)
0
1850
1900
1950
2000

FIGURE 4. PRIMARY ENERGY INTENSITIES IN VARIOUS COUNTRIES, 1850-2000

Two energy intensity paths are shown for Japan and the United States, one based on total energy consumption from all sources and the other only on commercial energy. The paths converge where traditional sources have been replaced by commercial energy. Because of distortions from market fluctuations, energy intensity paths for China and India are calculated in two ways: using total and commercial energy divided by GDP measured at market exchange rates (as with Japan and the United States), and divided by GDP measured at purchasing power parities (PPP). Energy intensities for the former Soviet Union, derived using both market exchange rates and PPP, are data points only.

Source: Nakicenovic, Grbler, and McDonald, 1998.

In developing countries, addressing the energy needs of the poor, who represent a large majority, will require major structural changes. On the other hand, in industrialised countries adequate access to affordable energy is problematic only for a minority, and thus more amenable to social policy solutions. Throughout the world, however, poor households pay a larger fraction of their incomes for energy than do the rich, and so are vulnerable to rapid increases in the price of energy. Increases in the price of oil in the winter of 1999/2000, for example, posed a hardship for many people, even in some industrialised countries.

Eradicating poverty is a long-term goal of development. But long before that goal is achieved, convenient and affordable energy services could dramatically improve living standards and offer more opportunities to people. Today's inequity is unsustainable. Satisfying the energy needs of the poor with modern technologies has the potential to improve standards of living and health, and to create new jobs and business opportunities. Allowing one-third of the world's population to continue to endure the constraints

associated with traditional energy is unacceptable from a humanitarian and moral standpoint. Making commercial energy more widely available makes sense from a political perspective as well. The wave of democratisation sweeping the world is putting political power in the hands of the economically disenfranchised. Societies with grave inequalities and disparities tend to be unstable, and large populations below the poverty line are fertile ground for social upheavals.

TABLE 2. ENERGY-RELATED OPTIONS TO ADDRESS SOCIAL ISSUES

Social challenge	**Energy linkages and interventions**
Alleviating poverty in developing countries	• Improve health and increase productivity by providing universal access to adequate energy services - particularly for cooking, lighting, and transport - through affordable, high-quality, safe, and environmentally acceptable energy carriers and end-use devices. • Make commercial energy available to increase income-generating opportunities.
Increasing opportunities for women	• Encourage the use of improved stoves and liquid or gaseous fuels to reduce indoor air pollution and improve women's health. • Support the use of affordable commercial energy to minimise arduous and time-consuming physical labour at home and at work. • Use women's managerial and entrepreneurial skills to develop, run, and profit from decentralised energy systems.
Speeding the demographic transition (to low mortality and low fertility)	• Reduce child mortality by introducing cleaner fuels and cooking devices and providing safe, potable water. • Use energy initiatives to shift the relative benefits and costs of fertility - for example, adequate energy services can reduce the need for children's physical labour for household chores. • Influence attitudes about family size and opportunities for women through

	communications made accessible through modern energy carriers.
Mitigating the problems associated with rapid urbanisation	• Reduce the 'push' factor in rural-urban migration by improving the energy services in rural areas. • Exploit the advantages of high-density settlements through land planning. • Provide universal access to affordable multi-modal transport services and public transportation. • Take advantage of new technologies to avoid energy-intensive, environmentally unsound development paths.

Source: Adapted from chapter 2.

Energy, the environment, and health

The environmental impacts of energy use are not new. For centuries, wood burning has contributed to the deforestation of many areas. Even in the early stages of industrialisation, local air, water, and land pollution reached high levels. What is relatively new is an acknowledgement of energy linkages to regional and global environmental problems and of their implications. Although energy's potential for enhancing human well-being is unquestionable, conventional energy[9] production and consumption are closely linked to environmental degradation. This degradation threatens human health and quality of life, and affects ecological balance and biological diversity.

The environment-energy linkage is illustrated in table 3, which shows the share of toxic emissions and other pollutants attributable to the energy supply. The human disruption index is the ratio of the human-generated flow of a given pollutant (such as sulphur dioxide) to the natural, or baseline, flow. Thus, in the case of sulphur, the index is 2.7, which means that human-generated emissions of 84 million tonnes a year are 2.7 times the natural baseline flow of 31 million tonnes a year. The table indicates that, together with other human activities, energy systems significantly affect the global cycling of

important chemicals. Although by itself the index does not demonstrate that these emissions translate into negative impacts, their magnitudes provide warning that such impacts could be considerable. Some impacts, as discussed below, are already significant.

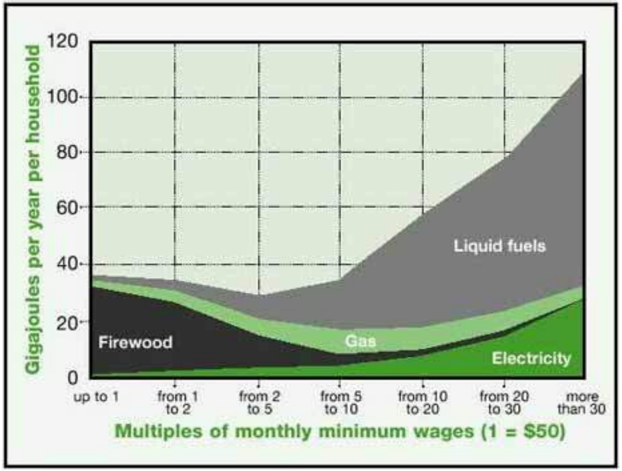


FIGURE 5. AVERAGE ENERGY DEMAND BY INCOME SEGMENT IN BRAZIL, 1988

Source: De Almeida and de Oliveira, 1995.

Just in the course of the past 100 years, during which the world's population more than tripled, human environmental insults[10] grew from local perturbations to global disruptions. The human disruptions of the 20th century - driven by more than 20-fold growth in the use of fossil fuels, and augmented by a tripling in the use of traditional energy forms such as biomass - have amounted to no less than the emergence of civilisation as a global ecological and geochemical force. In other words, the accelerating impact of human life is altering the world at the global level.

TABLE 3. ENVIRONMENTAL INSULTS DUE TO HUMAN ACTIVITIES BY SECTOR, MID-1990s

Insult	Natural base- line (tonnes per year)	Human disruption index[a]	Share of human disruption caused by			
			Commercial energy supply	Traditional energy supply	Agriculture	Manufacturing, other
Lead emissions to atmosphere[b]	12,000	18	41% (fossil fuel burning, including additives)	Negligible	Negligible	59% (metal processing, manufacturing, refuse burning)
Oil added to oceans	200,000	10	44% (petroleum harvesting, processing, and transport)	Negligible	Negligible	56% (disposal of oil wastes, including motor oil changes)
Cadmium emissions to atmosphere	1,400	5.4	13% (fossil fuel burning)	5% (traditional fuel burning)	12% (agricultural burning)	70% (metals processing, manufacturing, refuse burning)
Sulphur emissions to atmosphere	31 million (sulphur)	2.7	85% (fossil fuel burning)	0.5% (traditional fuel burning)	1% (agricultural burning)	13% (smelting, refuse burning)
Methane flow to atmosphere	160 million	2.3	18% (fossil fuel harvesting	5% (traditional	65% (rice paddies,	12% (landfills)

			and processing)	fuel burning)	domestic animals, land clearing)	
Nitrogen fixation (as nitrogen oxide and ammonium)[c]	140 million (nitrogen)	1.5	30% (fossil fuel burning)	2% (traditional fuel burning)	67% (fertiliser, agricultural burning)	1% (refuse burning)
Mercury emissions to atmosphere	2,500	1.4	20% (fossil fuel burning)	1% (traditional fuel burning)	2% (agricultural burning)	77% (metals processing, manufacturing, refuse burning)
Nitrous oxide flows to atmosphere	33 million	0.5	12% (fossil fuel burning)	8% (traditional fuel burning)	80% (fertiliser, land clearing, aquifer disruption)	Negligible
Particulate emissions to atmosphere	3,100 million[d]	0.12	35% (fossil fuel burning)	10% (traditional fuel burning)	40% (agricultural burning)	15% (smelting, non-agricultural land clearing, refuse)
Non-methane hydrocarbon emissions to atmosphere	1,000 million	0.12	35% (fossil fuel processing and burning)	5% (traditional fuel burning)	40% (agricultural burning)	20% (non-agricultural land clearing, refuse burning)
Carbon dioxide	150 billion	0.05[e]	75% (fossil	3% (net	15% (net	7% (net

flows to atmosphere	(carbon)		fuel burning)	deforestation for fuelwood)	deforestation for land clearing)	deforestation for lumber, cement manufacturing)

Note: The magnitude of the insult is only one factor determining the size of the actual environmental impact. a. The human disruption index is the ratio of human-generated flow to the natural (baseline) flow. b. The automotive portion of human-induced lead emissions in this table is assumed to be 50 percent of global automotive emissions in the early 1990s. c. Calculated from total nitrogen fixation minus that from nitrous oxide. d. Dry mass. e. Although seemingly small, because of the long atmospheric lifetime and other characteristics of carbon dioxide, this slight imbalance in natural flows is causing a 0.4 percent annual increase in the global atmospheric concentration of carbon dioxide.

Source: Chapter 3.

At every level (local, regional, global), the environmental consequences of current patterns of energy generation and use make up a significant fraction of human impacts on the environment. At the household level, solid fuel use for cooking and heat has significant health impacts. Poor air quality - at the household, local, and regional levels - is associated with increased sickness and premature death. About 2 million premature deaths a year - disproportionately of women and children - are estimated to occur from exposure to indoor air pollution caused by burning solid fuels in poorly ventilated spaces. Particulate matter (which is both emitted directly and formed in the air as the result of the emissions of gaseous precursors in the form of oxides of sulphur and nitrogen) and hydrocarbons are growing concerns world-wide. They are especially troublesome in many parts of the developing world, where dirtier fuels predominate with little emissions abatement. No safe threshold level for exposure to small particulate matter has been established.

Fossil fuel combustion is problematic on several levels (although natural gas produces significantly fewer harmful emissions than do oil or coal). 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 interactions among hydrocarbons, nitrogen oxides, and sunlight. Energy-related emissions from fossil fuel combustion, including in the transport sector, are major contributors to urban air pollution. 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. In many regions acidification has diminished the productivity of forests, fisheries, and farmlands. Large hydropower projects often raise environmental issues related to flooding, whereas in the case of nuclear power, issues such as waste disposal raise concern.

Fossil fuel combustion produces more carbon dioxide (CO_2) than any other human activity. This is the biggest source of the anthropogenic greenhouse gas emissions that are changing the composition of the atmosphere and could alter the global climate system, including the amount and pattern of rainfall. Achieving a stable atmospheric CO_2 concentration at any level would require that CO_2 emissions eventually be cut by more than half from current levels. Stabilising CO_2 at close to the present concentration would require reducing emissions to half of current levels within the next few decades. Instead, CO_2 emissions continue to increase. Current CO_2 emission trends, if not controlled, will lead to more than a doubling of atmospheric concentrations before 2070, relative to pre-industrial levels. Changes have been observed in climate patterns that correspond to scientific projections based on increasing concentrations of greenhouse gases. The balance of evidence, according to the Intergovernmental Panel on Climate Change, suggests that there is already a discernible human influence on global climate.

Numerous energy strategies could simultaneously benefit the environment, the economy and human well-being.

Because, by definition, sustainable energy systems must support both human and ecosystem health over the long term, goals on tolerable emissions should look well into the future. They should also take into account the public's tendency to demand more health and environmental protection as prosperity increases.

Although the scope of environmental problems related to energy may seem overwhelming, numerous 'win-win' strategies could simultaneously benefit the environment (at several levels), the economy, and human well-being. For example, the replacement of solid fuels for cooking with gaseous or liquid fuels could have significant environmental benefits at the local, community, regional, and global scales, with attendant benefits for health and productivity.

Energy security

Energy security means the availability of energy at all times in various forms, in sufficient quantities, and at affordable prices. These conditions must prevail over the long term if energy is to contribute to sustainable development.

Attention to energy security is critical because of the uneven distribution both of the fossil fuel resources on which most countries currently rely and of capacity to develop other resources. The energy supply could become more vulnerable over the near term due to the growing global reliance on imported oil. For example, the oil dependence (net imports as a share of total demand) of OECD countries is expected to grow from 56 percent in 1996 to

72 percent in 2010.

In addition, although energy security has been adequate for the past 20 years, and has in fact improved, the potential for conflict, sabotage, disruption of trade, and reduction in strategic reserves cannot be dismissed. These potential threats point to the necessity of strengthening global as well as regional and national energy security. Options to enhance energy security include:

- **Avoiding excessive dependence on imports by increasing end-use efficiency and encouraging greater reliance on local resources (particularly those whose development will have other positive externalities such as job creation, capacity building, and pollution reduction), provided these do not involve disproportionate costs or waste scarce resources.**

- **Diversifying supply (including both suppliers and energy forms).**

- **Fostering greater political stability through international cooperation and long-term agreements among energy-importing countries and between importing and exporting countries. Examples might include wider adoption - and more effective implementation of - the Energy Charter Treaty,[11] as well as increased sharing of infrastructure for transporting natural gas.**

- **Encouraging technology transfers (for example, through joint ventures and public-private partnerships) to developing countries so they can develop local resources and improve energy efficiencies.**

- **Increasing national and regional strategic reserves of crude oil and oil products through increased investment and advanced exploration technologies.**

Although markets play a prominent role in securing energy supply in OECD countries, their

role is modest in some developing countries and absent in others. Where markets do not flourish, the security of supply and services depends almost solely on government action and multinational companies, which may not serve the best interests of consumers. In such situations, energy security can be enhanced by encouraging the development of frameworks that allow markets to contribute to the allocation of energy resources.

Because of small fuel requirements, nuclear power contributes to the diversity of supply and to supply security. But public concerns about economic necessity, reactor safety, and radioactive waste transport and disposal - as well as weapons proliferation - have curbed nuclear energy development in many countries. A nuclear accident anywhere in the world or a proliferation incident linked to nuclear power could further reduce support for nuclear power programmes, with long-term loss in the diversity of the energy supply mix. But if generally accepted responses could be found to the above concerns, nuclear energy could contribute significantly to secure electricity generation in many parts of the world.

Individuals and commercial enterprises are also vulnerable to disruptions of energy supply. Although the trend towards the liberalisation of energy markets generally has enhanced energy security by offering more options, supplies, and competition, it has also raised concerns that those who are impoverished will be left out of the process, resulting in continued energy insecurity for some individuals.

Part II: Energy resources and technological options

Physical resources and technical opportunities are available - or could become available - to meet the challenge of sustainable development. Without policy changes, cost differentials may favour conventional fuels for years to come. Options for using energy in ways that support sustainable development, which requires addressing environmental concerns, include:

- **More efficient use of energy, especially at the point of end use in buildings, electric appliances, vehicles, and production processes.**

- **Increased reliance on renewable energy sources.**

- **Accelerated development and deployment of new energy technologies, particularly next-generation fossil fuel technologies that produce near-zero harmful emissions - but also nuclear technologies, if the problems associated with nuclear energy can be resolved.**

All three options have considerable potential, but realising this potential will require removing obstacles to wider diffusion, developing market signals that reflect environmental costs, and encouraging technological innovation.

Energy resources

Careful analysis of the long-term availability of energy resources, starting with conventional and unconventional oil and gas, indicates that these resources could last another 50-100 years - and possibly much longer - with known exploration and extraction technologies and anticipated technical progress in upstream operations. Coal resources and nuclear materials are so abundant that they could, respectively, last for centuries or millennia. Moreover, although fossil fuel prices may rise slowly over time, the large, cost-driven increases in energy prices projected in the 1970s and 1980s will not take place in the foreseeable future.

As evidenced by rising oil prices in the winter of 1999/2000, however, prices are subject to volatility. This may occur, for example, if cartels set prices independent of production costs. Some fluctuations in prices can also be expected, especially during the transition to a large-scale use of unconventional oil and gas resources, because the timing of investments in upstream production capacities may not correspond with demand. Other

cost-pushing factors could arise from the environmentally more challenging extraction of unconventional oil resources.

Renewable resources are more evenly distributed than fossil and nuclear resources, and energy flows from renewable resources are more than three orders of magnitude higher than current global energy use. But the economic potential of renewables is affected by many constraints - including competing land uses, the amount and timing of solar irradiation, environmental concerns, and wind patterns.

Although there are no real limitations on future energy availability from a resource point of view, the existence of resources is of little relevance without consideration of how these can contribute to the supply of (downstream) energy services. Rather, the key concerns are: Can technologies to extract, harvest, and convert these vast energy stocks and flows be developed in time? Will these processes have adverse implications? Will the energy services eventually generated from these resources be affordable? Historical evidence suggests that these concerns may be at least partly offset by technological progress, but that such progress needs to be encouraged - by regulations to improve market performance, temporary subsidies, tax incentives, or other mechanisms - if it is to occur in a timely fashion.

Energy end-use efficiency

The quadrupling of oil prices in the 1970s, the growing awareness of energy-related pollution, and the possibility of climate change have all contributed to a re-evaluation of energy use. The result has been an improvement in the efficiency with which energy is used in industry and power generation as well as in lighting, household appliances, transportation, and heating and cooling of buildings. This more efficient use of energy is a major factor contributing to the improvements in energy intensity that have occurred historically in almost all OECD countries, and more recently in many transition economies,

as well as in some in fast-growing developing countries such as Brazil and China.

Today the global energy efficiency of converting primary energy to useful energy is about one-third (see figure 1). In other words, two-thirds of primary energy is dissipated in the conversion processes, mostly as low-temperature heat. Further significant losses occur when the useful energy delivers the energy service. Numerous and varied economic opportunities exist for energy efficiency improvements, particularly in this final conversion step from useful energy to energy services. Taking advantage of these opportunities, which have received relatively little attention, has the largest potential for cost-effective efficiency improvements. It would mean less costly energy services and lower energy-related pollution and emissions.

Over the next 20 years the amount of primary energy required for a given level of energy services could be cost-effectively reduced by 25-35 percent in industrialised countries (the higher figure being achievable by more effective policies). These reductions are mostly in the conversion step of useful energy to energy services in the residential, industrial, transportation, public, and commercial sectors. Reductions of more than 40 percent are cost-effectively achievable in transition economies. And in most developing countries - which tend to have high economic growth and old capital and vehicle stocks - the cost-effective improvement potentials range from 30 to more than 45 percent, relative to energy efficiencies achieved with existing capital stock.[12]

The improvements of about 2 percent a year implied by the above figures could be enhanced by structural changes in industrialised and transition economies, by shifts to less energy-intensive industrial production, and by saturation effects in the residential and transportation sectors. These combined effects, made up by efficiency improvements and structural changes, could lead to decreases in energy intensity of 2.5 percent a year. How much of this potential will be realised depends on the effectiveness of policy frameworks and measures, changes in attitudes and behaviour, and the level of entrepreneurial activity

in energy conservation.

The next few decades will likely see new processes, motor systems, materials, vehicles, and buildings designed to reduce useful energy demand. Because the demand for cars is expected to grow rapidly in the developing world, gaining greater efficiencies in this area will be very important. In addition, rapidly industrialising countries could greatly profit from the introduction of radically new and more efficient technologies in their energy-intensive basic materials processing. Because these countries are still building their physical infrastructure, they have a growing demand for basic materials. This opens a window of opportunity to innovate and improve efficiencies of production, particularly in countries undergoing market reform. The opportunities are larger at the point of new investment, relative to retrofitting.

Over the next 20 years the amount of primary energy required for a given level of energy services could be cost-effectively reduced by 25-35 percent in industrialised countries.

Over the long term, additional and dramatic gains in efficiency are possible at all stages of energy conversion, particularly from useful energy to energy services. Analysis shows that current technologies are not close to reaching theoretical limits, and that improvements of an order of magnitude for the whole energy system may eventually be achieved.[13]

For a number of reasons the technical and economic potentials of energy efficiency, as well as its positive impact on sustainable development, have traditionally been under-realised. Achieving higher end-use efficiency involves a great variety of technical options and players. Because it is a decentralised, dispersed activity, it is a difficult issue for which

to organise support. And because it has little visibility, energy efficiency is not generally a popular cause for politicians, the media, or individuals looking for recognition and acknowledgement. In addition, significant barriers - primarily market imperfections that could be overcome by targeted policy instruments - prevent the realisation of greater end-use efficiencies. These barriers include:

- **Lack of adequate information, technical knowledge, and training.**
- **Uncertainties about the performance of investments in new and energy-efficient technologies.**
- **Lack of adequate capital or financing possibilities.**
- **High initial and perceived costs of more efficient technologies.**
- **High transaction costs (for searching and assessing information and for training).**
- **Lack of incentives for careful maintenance.**
- **The differential benefits to the user relative to the investor (for example, when energy bills are paid by the renter rather than the property owner).**
- **External costs of energy use, not included in energy prices.**
- **Patterns and habits of consumers, operators, and decision-makers, which may be influenced by many factors, including ideas of social prestige and professional norms.**

Realising cost-effective energy efficiency potentials will be beneficial not only for individual energy consumers, but also for the economy as a whole. For example, saved energy costs can be used to produce energy-saving domestic goods and services. And as

cost-effective energy improvements are realised, additional profitable opportunities for improvement will continue to open up as a result of research and development, learning curves, and economies of scale. That means that continual cost-effective energy efficiency improvements can be expected.

Energy efficiency policies that use direct or indirect price mechanisms (such as the removal of subsidies and the incorporation of externalities) are effective in lowering consumption trends in price-sensitive sectors and applications. But even without changing the overall price environment, energy efficiency policies should be pursued to address market failures. For example, efficiency standards, appliance and product labelling, voluntary agreements, and professional training or contracting can increase GDP growth by improving environmental and economic performance, using a given quantity of energy. Legal standards; well-informed consumers, planners, and decision-makers; motivated operators; and an adequate payments system for energy are central to the successful implementation of energy efficiency improvements.[14]

Renewable energy technologies

Renewable energy sources (including biomass, solar, wind, geothermal, and hydropower) that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Currently, renewable energy sources supply 14 percent of the total world energy demand. The supply is dominated by traditional biomass used for cooking and heating, especially in rural areas of developing countries. Large-scale hydropower supplies 20 percent of global electricity. Its scope for expansion is limited in the industrialised world, where it has nearly reached its economic capacity. In the developing world, considerable potential still exists, but large hydropower projects may face financial, environmental, and social constraints.

Altogether, new renewable energy sources contributed 2 percent of the world's energy

consumption in 1998, including 7 exajoules from modern biomass and 2 exajoules for all other renewables (geothermal, wind, solar, and marine energy, and small-scale hydropower). Solar photovoltaics and grid-connected wind installed capacities are growing at a rate of 30 percent a year. Even so, it will likely be decades before these new renewables add up to a major fraction of total energy consumption, because they currently represent such a small percentage.

Substantial price reductions in the past few decades have made some renewables competitive with fossil fuels in certain applications in growing markets. Modern, distributed forms of biomass seem particularly promising for their potential to provide rural areas with clean forms of energy based on the use of biomass resources that have traditionally been used in inefficient, polluting ways. Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops. Wind power in coastal and other windy regions is promising as well.

Unlike hydropower and conventional thermal power sources, wind and solar thermal or electric sources are intermittent. Nevertheless, they can be important energy sources in rural areas where grid extension is expensive. They can also contribute to grid-connected electricity supplies in appropriate hybrid configurations. Intermittent renewables can reliably provide 10-30 percent of total electricity supplies if operated in conjunction with hydropower - or fuel-based power generation. Emerging storage possibilities and new strategies for operating grids offer promise that the role of intermittent technologies could be considerably larger.

Renewable energy sources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and green-

house gases.

Significant barriers, which could be overcome by appropriate frameworks and policies, stand in the way of the accelerated development of renewable technologies. These barriers include economic risks, regulatory obstacles, limited availability of products, information and technology gaps, and lack of investment. The greatest challenge is financial, even though costs have come down significantly over the past several decades. Table 4 summarises the status of various renewable technologies, and also provides information on trends in cost and capacity.

Many renewable technologies, because they are small in scale and modular, are good candidates for continued cost-cutting as a result of field experience. The cost reductions of manufactured goods, which are typically rapid at first and then taper off as the industry matures, are called experience curves. These curves resulted in industry-wide cost declines of about 20 percent for each cumulative doubling of production for solar photovoltaics, wind generators, and gas turbines - due to learning effects, marginal technological improvements, and economies of scale (figure 6). Similar declines are expected for other small-scale renewables.

A rapid expansion of renewable-based energy systems 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 renewables in their early stages of development and commercialisation, while still taking advantage of the economic efficiencies of the marketplace. Pricing based on the full costs of conventional energy sources (including phasing out subsidies and internalising externalities) will make renewables more competitive. Because internalising external costs may be controversial for some time, 'green' pricing of electricity and heat (which lets consumers pay more for environmentally benign energy supplies if they choose) may be an immediate option in industrialised countries.

Advanced energy technologies

Fossil energy

Sustainability goals indicate the importance of evolving fossil energy technologies towards the long-term goal of near-zero air pollutant and greenhouse gas emissions without complicated end-of-pipe control technologies. Near-term technologies and strategies should support this long-term goal.

The technological revolution under way in power generation, where advanced systems are replacing steam turbine technologies, does support this long-term goal. Natural-gas-fired combined cycles offering low costs, high efficiency, and low environmental impacts are being chosen wherever natural gas is readily available - in some countries even displacing large new hydropower projects. Cogeneration is more cost-effective and can play a much larger role in the energy economy - if based on gas turbines and combined cycles rather than on steam turbines.

Reciprocating engines and emerging microturbine and fuel cell technologies are also strong candidates for cogeneration at smaller scales, including commercial and apartment buildings. Coal gasification by partial oxidation with oxygen to produce syngas (mainly carbon monoxide and hydrogen) makes it possible to provide electricity through integrated gasifier combined cycle (IGCC) plants with air pollutant emissions nearly as low as for natural gas combined cycles. Today power from IGCC cogeneration plants is often competitive with power from coal steam-electric plants in either cogeneration or power-only configurations.

Although synthetic liquid fuels made in single-product facilities are not competitive, superclean syngas-derived synthetic fuels (such as synthetic middle distillates and dimethyl ether) produced in polygeneration facilities that make several products simultaneously may soon be. Syngas can be produced from natural gas by steam

reforming or other means or from coal by gasification using oxygen, as noted. Expanding markets for clean synthetic fuels are likely to result from toughening air pollution regulations. Synthetic fuels produced through polygeneration will be based on natural gas if it is readily available. Synthetic middle distillates so produced are likely to be competitive where low-cost natural gas is available (as at remote developing country sites); the technology might facilitate exploitation of relatively small remote natural gas fields.

In natural-gas-poor, coal-rich regions, polygeneration based on coal gasification is promising. Such systems might include production of extra syngas for distribution by pipelines to small-scale cogeneration systems in factories and buildings - making possible clean and efficient use of coal at small as well as large scales. Rapidly growing polygeneration activity is already under way in several countries based on the gasification of low-quality petroleum feedstocks - activity that is helping to pave the way for coal-based systems.

TABLE 4. CURRENT STATUS AND POTENTIAL FUTURE COSTS OF RENEWABLE ENERGY TECHNOLOGIES

Technology	Increase in installed capacity in past five years (percent a year)	Operating capacity, end 1998	Capacity factor (percent)	Energy production, 1998	Turnkey investment costs (U.S. dollars per kilowatt)	Current energy cost	Potential future energy cost
Biomass energy							
Electricity	≈ 3	40 Gwe	25-80	160 TWh (e)	900-3000	5-15	4-10

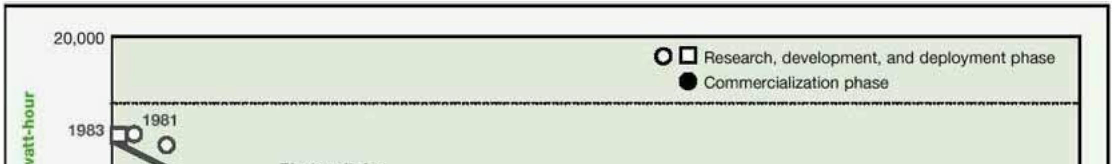
							¢/kWh	¢/kWh
	Heat[a]	≈ 3	> 200 GWth	25-80	>700 TWh (th)	250-750	1-5 ¢/kWh	1-5 ¢/kWh
	Ethanol	≈ 3	18 billion litres		420 PJ		8-25 $/GJ	6-10 $/GJ
Wind electricity		≈ 30	10 Gwe	20-30	18 TWh (e)	1100-1700	5-13 ¢/kWh	3-10 ¢/kWh
Solar photovoltaic electricity		≈ 30	500 MWe	8-20	0.5 TWh (e)	5000-10000	25-125 ¢/kWh	5 or 6-25
Solar thermal electricity		≈ 5	400 MWe	20-35	1 TWh (e)	3000-4000	12-18 ¢/kWh	4-10 ¢/kWh
Low-temperature solar heat		≈ 8	18 GWth (30 million m^2)	8-20	14 TWh (th)	500-1700	3-20 ¢/kWh	2 or 3-10
Hydroelectricity								
	Large	≈ 2	640 GWe	35-60	2510 TWh (e)	1000-3500	2-8 ¢/kWh	2-8 ¢/kWh
	Small	≈ 3	23 Gwe	20-70	90 TWh (e)	1200-3000	4-10 ¢/kWh	3-10 ¢/kWh
Geothermal energy								
	Electricity	≈ 4	8 GWe	45-90	46 TWh (e)	800-3000	2-10 ¢/kWh	1 or 2-8 ¢/kWh
	Heat	≈ 6	11 GWth	20-70	40 TWh (th)	200-2000	0.5-5¢/kWh	0.5-5 ¢/kWh

Marine energy							
Tidal	0	300 MWe	20-30	0.6 TWh (e)	1700-2500	8-15 ¢/kWh	8-15 ¢/kWh
Wave	-	exp. phase	20-35	Unclear	1500-3000	8-20 ¢/kWh	Unclear
Current	-	exp. phase	25-35	Unclear	2000-3000	8-15 ¢/kWh	5-7 ¢/kWh
OTEC	-	exp. phase	70-80	Unclear	Unclear	Unclear	Unclear

Note: The cost of grid-supplied electricity in urban areas ranges from 2-3 (c/kWh (off-peak) to 15-25c/kWh) (peak). See chapter 11. a. Heat embodied in steam (or hot water in district heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

Source: Chapter 7.

Barriers to widespread deployment of advanced cogeneration and polygeneration systems are mainly institutional. Most systems will produce far more electricity than can be consumed on-site, so achieving favourable economics depends on being able to sell co-product electricity at competitive prices into electric grids. Utility policies have often made doing so difficult, but under the competitive market conditions towards which electric systems are evolving in many regions, cogeneration and polygeneration systems will often fare well.



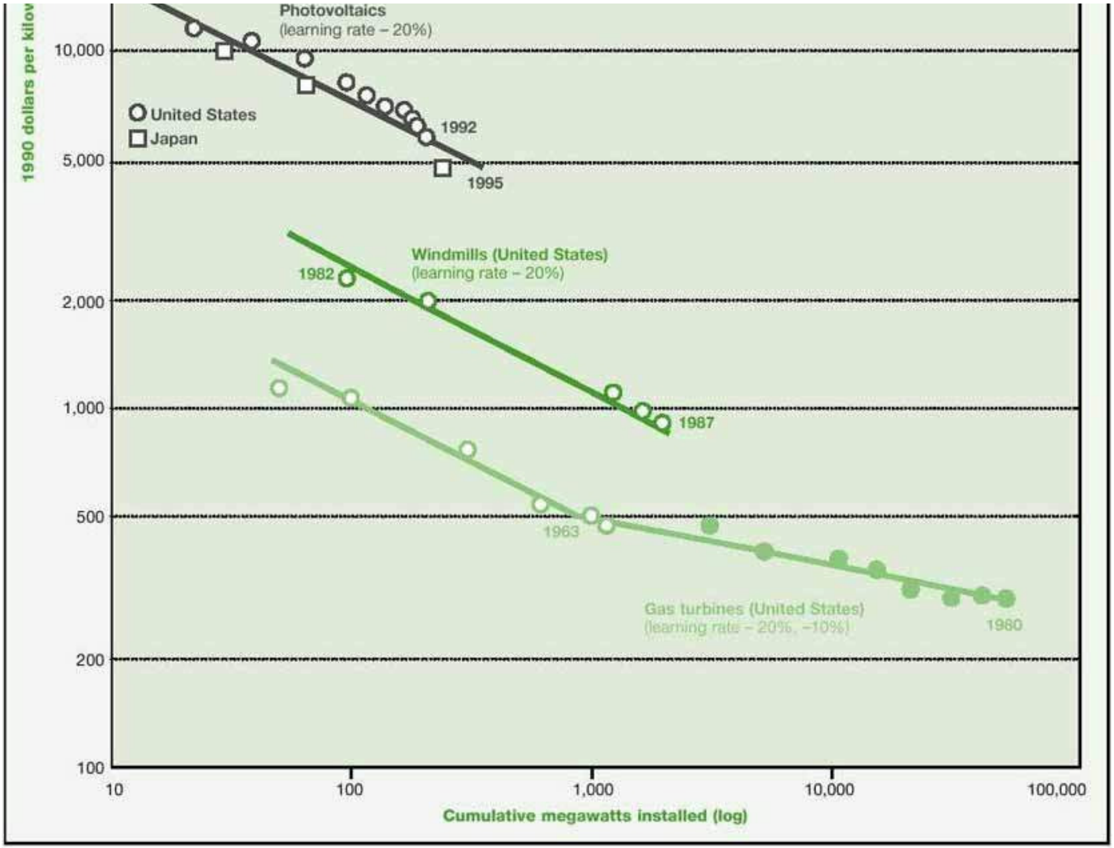


FIGURE 6. EXPERIENCE CURVES FOR PHOTOVOLTAICS, WINDMILLS, AND GAS TURBINES IN JAPAN AND THE UNITED STATES

Technology performance and costs improve with experience, and there is a pattern to such improvements common to many technologies. The specific shape depends on the technology, but the persistent characteristic of diminishing costs is termed the 'learning' or 'experience' curve. The curve is likely to fall more sharply as technologies first seek a market niche, then full commercialisation, because lower costs become increasingly important for wider success.

Source: Nakicenovic, Grbler, and McDonald, 1998.

The near-term pursuit of a syngas-based strategy could pave the way for widespread use of hydrogen (H_2) as an energy carrier, because for decades the cheapest way to make H_2 will be from fossil-fuel-derived syngas. The successful development of fuel cells would facilitate the introduction of H_2 for energy. Fuel cells are getting intense attention, especially for transportation, because they offer high efficiency and near-zero air pollutant emissions. Automakers are racing to develop fuel cell cars, with market entry targeted for 2004-10. The fuel cell car will compete for the role of 'car of the future' with the hybrid internal combustion engine/battery powered car already being introduced into the market.

Syngas-based power and H_2 production strategies also facilitate separation and storage of CO_2 from fossil energy systems, making it possible to obtain useful energy with near-zero emissions of green-house gases without large increases in energy costs. Recent research suggests that the global capacity for secure disposal of CO_2 in geological reservoirs might be adequate to dispose of CO_2 from fossil fuel use for hundreds of years, although more research is needed to be sure about this.

Other advanced technologies (ultrasupercritical steam plants, pressurised fluidised-bed combustion, coal IGCC based on partial oxidation in air for power generation, direct coal liquefaction for synthetic fuels production) offer benefits relative to conventional

technologies. But unlike syngas-based technologies, such options in the near term would not offer clear paths to the long-term goal of near-zero emissions without significant increases in costs for energy services.

Nuclear energy

World-wide, nuclear energy accounts for 6 percent of energy and 16 percent of electricity. Although nuclear energy dominates electricity generation in some countries, its initial promise has not been widely realised. Most analysts project that nuclear energy's contribution to global energy will not grow - and might decline during the initial decades of the 21st century. Nuclear power is more costly than originally projected, competition from alternative technologies is increasing, and there has been a loss of public confidence because of concerns related to safety, radioactive waste management, and potential nuclear weapons proliferation.

But because nuclear power can provide energy without emitting conventional air pollutants and greenhouse gases, it is worth exploring if advanced technologies could offer simultaneously lower costs, boost public confidence in the safety of nuclear reactors, assure that peaceful nuclear programs are not used for military purposes, and demonstrate effective nuclear waste management practices. Unlike Chernobyl-type reactors, the light water reactors (LWRs) that dominate nuclear power globally have a good safety record - although this record has been achieved at considerable cost to minimise the risk of accidents.

If wise decisions are not made during the next few decades, certain development opportunities might not be achievable.

The potential linkage between peaceful and military uses of nuclear energy was recognised at the dawn of the nuclear age. Efforts to create a non-proliferation regime through the Nuclear Non-Proliferation Treaty and a series of regional treaties, controls on commerce in nuclear materials and goods and services that might be used to further military ambitions, and safeguards applied to nuclear materials in peaceful nuclear applications have been largely successful in separating peaceful and military uses. If there is to be an energy future in which nuclear power eventually contributes much more than at present, stronger institutional measures will be needed to maintain this separation. These measures should be complemented by technological advances aimed at limiting opportunities to acquire nuclear weapons under the guise of peaceful nuclear energy applications and to steal weapons-usable nuclear materials.

Reactor development activity for the near term has involved both evolutionary LWRs and new concepts. Reactor vendors now offer several evolutionary LWRs with improved safety features and standardised designs, for which there can be a high degree of confidence that performance and cost targets will be met. Another evolutionary activity involves modifying LWRs to make them more proliferation resistant through a denatured uranium or thorium fuel cycle. One concept being revisited, the pebble bed modular reactor, offers the potential for a high degree of inherent safety without the need for complicated, capital-intensive safety controls. A pebble bed modular reactor could also be operated on a proliferation resistant denatured uranium - or thorium fuel cycle.

Access to low-cost uranium supplies could constrain nuclear power development based on LWRs. The plutonium breeder reactor, which requires reprocessing spent fuel to recover plutonium for recycling in fresh fuel, was once thought to be a viable option for addressing this challenge. But electricity costs for breeders would probably be higher than for LWRs, at least until late in the 21st century, and preventing proliferation is much more challenging with reprocessing and plutonium recycling than with LWRs operated on once-through fuel cycles.

Other long-term options for addressing the nuclear resource constraint are alternative breeder concepts - including particle-accelerator-driven reactors, uranium from seawater, and thermonuclear fusion. The prospective costs, safety, and proliferation resistance features of such alternative breeder concepts are uncertain, and the concepts would take decades to develop. Recent research suggests it might be feasible, at relatively low cost, to extract uranium from seawater, where its concentration is low but total quantities are vast. If the technology could be deployed at globally significant scales, it might be feasible to avoid making major commitments to nuclear fuel reprocessing and plutonium recycling. Fusion could provide an almost inexhaustible energy supply, but it will probably not be commercially available before 2050.

Radioactive waste by-products of nuclear energy must be isolated so that they can never return to the human environment in concentrations that could cause significant harm. Although the safety of long-term waste disposal has not been proven, the technical community is confident that this objective can be realised - largely because of the small volumes of wastes involved. But in most countries there is no social consensus on the goals and standards for radioactive waste disposal and on strategies (both interim and long-term) for implementing them. The issues involved are only partly technical. The current social stalemate on waste disposal not only clouds prospects for nuclear expansion, it also has made spent fuel reprocessing a de facto interim nuclear waste management strategy in some countries. This has happened even though fuel reprocessing does not offer economic gains and does not solve the waste disposal problem - it merely buys time and is creating large inventories of plutonium that must be disposed of with low proliferation risk.

Part III: Are sustainable futures possible?

Analysis using energy scenarios indicates that it is possible to simultaneously address the sustainable development objectives set forth in part 1 using the resources and

technical options presented in part 2. The scenarios exercise and subsequent sections suggest that:

- **Continuing along the current path of energy system development is not compatible with sustainable development objectives.**
- **Realising sustainable futures will require much greater reliance on some combination of higher energy efficiencies, renewable resources, and advanced energy technologies.**
- **A prerequisite for achieving an energy future compatible with sustainable development objectives is finding ways to accelerate progress for new technologies along the energy innovation chain, from research and development to demonstration, deployment, and diffusion.**

- **Providing energy services to rural areas poses particular challenges. But it also offers considerable opportunity for improving the lives of billions of people within a relatively short period. Promising approaches include decentralised solutions, appropriate technologies, innovative credit arrangements, and local involvement in decision-making.**

Energy scenarios

Energy scenarios provide a framework for exploring future energy perspectives, including various combinations of technology options and their implications. Many scenarios in the literature illustrate the degree to which energy system developments will affect the global issues analysed in part 1. Some describe energy futures that are compatible with sustainable development goals. Key developments in sustainable scenarios include increases in energy efficiencies and the adoption of advanced energy supply technologies. Sustainable development scenarios are characterised by low environmental impacts (local,

regional, and global) and equitable allocation of resources and wealth.

The three cases of alternative global developments presented in chapter 9 suggest how the future could unfold in terms of economic growth, population trends, and energy use. The challenge is formidable. For example, by 2100, 6-8 billion additional people - significantly more than today's world population - will need access to affordable, reliable, flexible, and convenient energy services.[15] All three cases achieve this through different energy system developments, but with varying degrees of success in terms of sustainability (table 5).

A middle-course, or reference, case (B) includes one scenario and is based on the general direction in which the world is now headed. This scenario assumes the continuation of an intermediate level of economic growth and modest technological improvement, and it leads to adverse environmental impacts, including regional acidification and climate change. Although this middle-course scenario represents a substantial improvement relative to the current situation, it falls short of achieving a transition towards sustainable development. The other two scenarios and their variants lead to higher economic development with vigorous improvement of energy technologies. They both - and especially the ecologically driven case (C) - achieve, to a much higher degree, a transition towards sustainable development (table 6).

For instance, one of the three high-growth case A scenarios (A3) achieves some goals of sustainable development, primarily through rapid economic growth and a shift towards environmentally more benign energy technologies and options. In this scenario, higher levels of affluence result from impressive technological development, including a significant role for clean fossil, renewable, and nuclear energy. Dedicated decarbonisation of the energy system contributes to environmental sustainability. Two other variants of this high-growth case are also considered. Both lead to higher dependence on carbon-intensive fossil fuels, resulting in high energy-related emissions. Consequently, they are

unsustainable from an environmental point of view.

A third case (C) includes two scenarios and is ecologically driven, with high growth in developing countries (towards being rich and 'green'). The difference between the two scenarios is that one, C1, assumes a global phase-out of nuclear energy by 2100, whereas the other, C2, does not. Both assume the introduction of carbon and energy taxes directed at promoting renewables and end-use efficiency improvements. The revenues from carbon and energy taxes are assumed to be used to enhance economic growth and promote renewables and end-use efficiency, rather than to reduce other taxes in industrialised regions.

TABLE 5. SUMMARY OF THREE ENERGY DEVELOPMENT CASES IN 2050 AND 2100 COMPARED WITH 1990

		Case A High growth	Case B Middle growth	Case C Ecologically driven
Population (billions)	1990	5.3	5.3	5.3
	2050	10.1	10.1	10.1
	2100	11.7	11.7	11.7
Gross world product (trillions of 1990 dollars)	1990	20	20	20
	2050	100	75	75
	2100	300	200	220
Gross world product (annual percentage change)	1990 - 2050	**High**	**Medium**	**Medium**
	1990 - 2100	2.7	2.2	2.2

		2.5	2.1	2.2
Primary energy intensity (megajoules per 1990 dollar of gross world product)	1990	19.0	19.0	19.0
	2050	10.4	11.2	8.0
	2100	6.1	7.3	4.0
Primary energy intensity improvement rate (annual percentage change)	1990 - 2050	**Medium**	**Low**	**High**
	1990 - 2100	- 0.9	-0.8	- 1.4
		- 1.0	-0.8	- 1.4
Primary energy consumption (exajoules)	1990	379	379	379
	2050	1,041	837	601
	2100	1,859	1,464	880
Cumulative primary energy consumption, 1990-2100 (thousands of exajoules)	Coal	8.9 - 30.7	17.5	7.1 - 7.2
	Oil	27.6 - 15.7	15.3	10.9
	Natural gas	18.4 - 28.7	15.8	12.2 - 12.9
	Nuclear energy	6.2 - 11.2	10.5	2.1 - 6.2
	Hydropower	3.7 - 4.2	3.6	3.6 - 4.0
	Biomass	7.4 - 14.3	8.3	9.1 - 10.1

	Solar energy	1.8 - 7.7	1.9	6.3 - 7.4
	Other	3.0 - 4.7	4.3	1.4 - 2.2
	Global total	94.0 - 94.9	77.2	56.9
Energy technology cost reductions (through learning)	Fossil	**High**	**Medium**	**Low**
	Non-fossil	**High**	**Medium**	**High**
Energy technology diffusion rates	Fossil	**High**	**Medium**	**Medium**
	Non-fossil	**High**	**Medium**	**High**
Environmental taxes (excluding carbon dioxide taxes)		**No**	**No**	**Yes**
Sulphur dioxide emissions (millions of tonnes of sulphur)	1990	58.6	58.6	58.6
	2050	44.8 - 64.2	54.9	22.1
	2100	9.3 - 55.4	58.3	7.1
Carbon dioxide emission constraints and taxes		**No**	**No**	**Yes**
Net carbon dioxide emissions (gigatonnes of carbon)	1990	6	6	6
	2050	9 - 15	10	5
	2100	6 - 20	11	2
Cumulative carbon dioxide emissions	1990 -	910 -	1,000	540

(gigatonnes of carbon)	2100	1,450		
Carbon dioxide concentrations (parts per million by volume)	1990	358	358	358
	2050	460 - 510	470	430
	2100	530 - 730	590	430
Carbon intensity (grams of carbon per 1990 dollar of gross world product)	1990	280	280	280
	2050	90 - 140	130	70
	2100	20 - 60	60	10
Investments in energy supply sector (trillions of 1990 dollars)	1990 - 2020	15.7	12.4	9.4
	2020 - 50	24.7	22.3	14.1
	2050 - 2100	93.7	82.3	43.3
Number of scenarios		**3**	**1**	**2**

The three cases unfold into six scenarios of energy system alternatives: three case A scenarios (A1, ample oil and gas; A2, return to coal; and A3, non-fossil future), a single case B scenario (middle course), and two case C scenarios (C1, new renewables; and C2, new renewables and new nuclear). Some of the scenario characteristics, such as cumulative energy consumption, cumulative carbon dioxide emissions, and decarbonisation, are shown as ranges for the three case A and two C scenarios.

Source: Nakicenovic, Grbler, and McDonald, 1998.

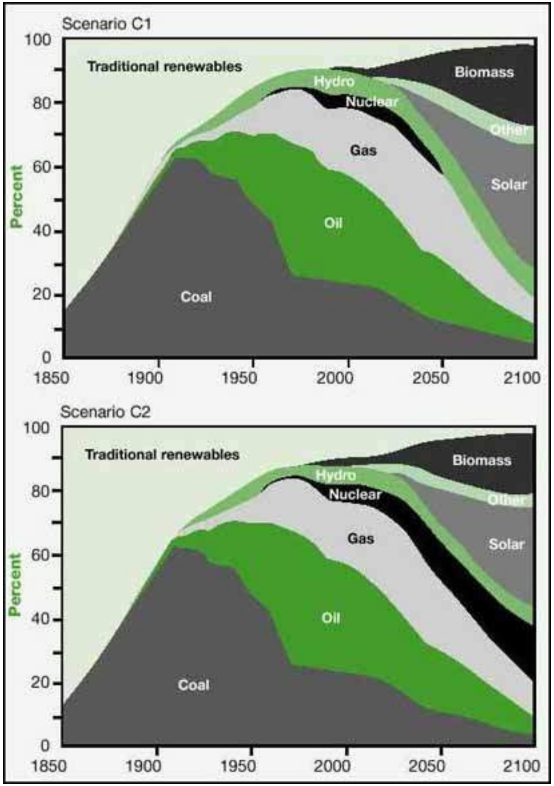


FIGURE 7. PRIMARY ENERGY SHARES, 1850-1990, AND IN SCENARIOS C1 AND C2 TO 2100

Source: Nakicenovic, Grbler, and McDonald, 1998.

Both case C scenarios assume decentralisation of energy systems and reliance on local

solutions. They also require considerably lower supply-side investments than the others. They would, however, require substantial investments in the end-use sector, which is not captured in the scenarios. Ambitious policy measures control local and regional pollutants, and a global regime results in reduced greenhouse gas emissions. Of the three cases considered, case C is the most compatible with the aims of sustainable development, as analysed in part 1 (table 6). In scenario C1 this occurs through a diminishing contribution of coal and oil to the primary energy mix, with a large increase in the share of solar and biomass energy by 2100 (figure 7).

Also shown for illustrative purposes is the primary energy mix for scenario C2, in which nuclear energy could play a large role if the problems associated with it (cost, safety, waste disposal and weapons proliferation) can be adequately resolved.

The considerable differences in expected total energy consumption among the scenarios reflect different approaches to addressing the needs for energy services in the future, and they demonstrate clearly that policy matters (figure 8). Achieving the two scenarios with characteristics of sustainable development will require a substantial increase in private and public research, development, and deployment efforts to support new energy technologies. Otherwise, most clean fossil and renewable technologies, as well as many energy-efficient end-use technologies, may not reach competitiveness. (The mix of needed efforts may vary depending on the maturity of the specific technology.) Significant technological advances will be required, as will incremental improvements in conventional energy technologies.

In terms of their expected high growth in energy demand, developing countries are well-positioned to take advantage of innovations in energy technologies and policies that support them. In general, scenarios A3, C1, and C2 require significant policy and behavioural changes within the next several decades to achieve more sustainable development paths. Taken together, the outcomes of these changes, which are described

in more detail in part 4, represent a clear departure from a business-as-usual approach.

Another crucial prerequisite for achieving sustainability in the scenarios is near-universal access to adequate, affordable energy services and more equitable allocation of resources. Finally, environmental protection - from indoor pollution to climate change - is an essential characteristic of sustainable development in these scenarios. The resolution of these future challenges offers a window of opportunity between now and 2020. The nature of the decisions made during this time will largely determine whether the evolution of the energy system is consistent with current practices (along the lines of the B scenario), or whether it achieves the transition towards more sustainable development paths (along the lines of the A3, C1, and C2 scenarios).

Because of the long lifetimes of power plants, refineries, steel plants, buildings, and other energy-related investments such as transportation infrastructure, there is not sufficient turnover of such facilities to reveal large differences among the alternative scenarios presented here before 2020. But the seeds of the post-2020 world will have been sown by then. Thus choices about the world's future energy systems are relatively wide open now. This window of opportunity is particularly significant where much infrastructure has yet to be installed, offering the possibility of a rapid introduction of new, environmentally sound technologies.

Once the infrastructure is in place, a phase of largely replacement investments begins. Changes can be made in this phase, but they take much longer to affect average system performance. If wise decisions are not made during the next few decades, we will be locked into those choices, and certain development opportunities might not be achievable. Thus the achievement of sustainable development demands a global perspective, a very long time horizon, and the timely introduction of policy measures.

Rural energy in developing countries

Between 1970 and 1990 about 800 million additional people were reached by rural electrification programmes. Some 500 million saw their lives improve substantially through the use of better methods for cooking and other rural energy tasks, particularly in China. Despite these enormous efforts to improve energy services to rural populations in the past 20-30 years, the unserved population has remained about the same in absolute numbers - 2 billion people.

An effective strategy to address the energy needs of the rural populations is to promote the climbing of the 'energy ladder'.

Although the unavailability of adequate energy services in rural areas is probably the most serious energy problem confronting humanity in the near future, rural energy remains low on the list of priorities of most government and corporate planners. And the increased demands of the more influential (and rapidly growing) urban population will make it more difficult to keep rural development on the agenda.

An effective strategy to address the energy needs of rural populations is to promote the climbing of the 'energy ladder'. This implies moving from simple biomass fuels (dung, crop residues, firewood) to the most convenient, efficient form of energy appropriate to the task at hand - usually liquid or gaseous fuels for cooking and heating and electricity for most other uses. Such climbing involves not only a shift to modern fuels but is often also complemented by the synergistic use of modern, more efficient end-use devices such as cooking stoves.

Climbing the energy ladder does not necessarily mean that all the rungs used in the past should be reclimbed. In the case of cooking, for example, users do not have to go from

fuelwood to kerosene to liquefied petroleum gas (LPG) or electricity. What users should do - whenever possible - is leapfrog directly from fuelwood to the most efficient end-use technologies and the least polluting energy forms (including new renewables) available. Because of the emergence of new technologies, it is also possible to introduce new rungs on the energy ladder, and gain even greater efficiencies and environmental acceptability.

TABLE 6. CHARACTERISTICS OF SUSTAINABILITY IN THREE ENERGY DEVELOPMENT SCENARIOS IN 2050 AND 2100 COMPARED WITH 1990

Indicator of sustainability	1990	Scenario A3	Scenario B	Scenario C1
Eradicating poverty	Low	Very high	Medium	Very high
Reducing relative income gaps	Low	High	Medium	Very high
Providing universal access to energy	Low	Very high	High	Very high
Increasing affordability of energy	Low	High	Medium	Very high
Reducing adverse health impacts	Medium	Very high	High	Very high
Reducing air pollution	Medium	Very high	High	Very high
Limiting long-lived radionuclides	Medium	Very low	Very low	High
Limiting toxic materials[a]	Medium	High	Low	High
Limiting GHG emissions	Low	High	Low	Very high
Raising indigenous energy use	Medium	High	Low	Very high
Improving supply efficiency	Medium	Very high	High	Very high
Increasing end-use efficiency	Low	High	Medium	Very high
Accelerating technology diffusion	Low	Very high	Medium	Medium

a. For this row only, the qualitative indicators are not based on quantitative features of the scenarios, but were specified by the authors on the basis of additional assumptions.

Source: Chapter 9.

The energy-related sustainable development goals for rural areas are to:

- **Satisfy basic human needs by providing all households with minimally adequate amounts of electricity for uses such as lighting and fans, in addition to cleaner cooking fuels. Specifically, all households should move away from unprocessed solid fuels (biomass and coal) for cooking and heating to modern energy forms, which may potentially be derived from renewable sources (biomass and solar) or fossil fuels.**

- **Provide electricity that is sufficiently affordable to support industrial activity in rural areas, which can provide employment and help curb urban migration.**

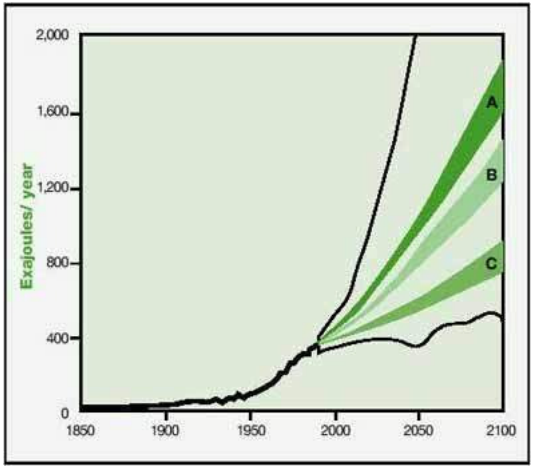


FIGURE 8. GLOBAL PRIMARY ENERGY REQUIREMENTS, 1850-1990, AND IN THREE CASES, 1990-2100

The figure also shows the wide range of future energy requirements for other scenarios in the literature. The vertical line that spans the scenario range in 1990 indicates the uncertainty across the literature of base-year energy requirements.

Source: Nakicenovic, Grbler, and McDonald, 1998; Morita and Lee, 1998; Nakicenovic, Victor, and Morita, 1998.

The current path of energy development, and the rate of change, are not compatible with key elements of sustainable development.

In many cases the rural poor are willing and able to pay for energy services if appropriate financing options are offered to help them meet high first costs. The economics of providing basic electricity to rural households should be evaluated according to the costs of supplying comparable energy services through less efficient carriers. In most cases home solar photovoltaic systems can provide energy services at a lower cost than the kerosene and batteries they replace and can be an economically viable source of rural household power, even at relatively low levels of service provision.

The availability of affordable and adequate energy services in rural areas could lead to significant improvements in living conditions and to the fulfilment of basic human needs over a relatively short time frame. The amount of energy needed to provide such services in rural areas is relatively small. Modern ways of using biomass more efficiently could go a long way towards achieving this objective. Experience has shown that to find the most viable and appropriate solutions to rural energy, the active participation of the people who will use it is a must.

The challenge is to find ways to make modern energy carriers affordable to satisfy the basic needs of all rural residents - which may, at least initially, require subsidies. The key is to introduce market efficiencies if possible to use the smallest subsidy needed to achieve social objectives. If a subsidy is required, it might be provided as an integral part of a new social contract, whereby energy providers serve rural energy needs while simultaneously, highly competitive conditions are created in the energy sector (a key element of energy reforms). One way to finance the subsidies that might be needed would be to complement the creation of competitive markets with the establishment of a public benefits fund generated by non-bypassable wire and pipe charges on electricity and on gas providers. Such funds have been adopted or are under consideration in several countries as a means of protecting public benefits under competitive market conditions. Other options include carefully designed economic incentives, perhaps using tax regimes.

Specifically, some of these revenues could be used to subsidise the very poorest households until they are able to work themselves out of poverty. This strategy could be made entirely consistent with a shift to greater reliance on market forces to efficiently allocate resources. If, for example, a rural energy concession was the preferred approach for bringing adequate energy services at a set price to a particular rural area, and if the concession was awarded competitively, market forces would be brought into play to find the least costly mix of energy technologies with the least amount of subsidy to satisfy the concessionaire's obligation to provide affordable energy services to all.

Part IV: Where do we go from here?

Part 4 identifies key strategies and policies for achieving both economic growth and sustainable human development. They include:

- **Setting the right framework conditions - including continued market reforms, consistent regulations, and targeted policies - to encourage competition in energy markets, reduce the cost of energy services to end users, and protect important public benefits.**

- **Sending accurate price signals, including phasing out subsidies to conventional energy and internalising externalities.**

- **Removing obstacles or providing incentives, as needed, to encourage greater energy efficiency and the development and diffusion to wider markets of new sustainable energy technologies.**

The challenge of sustainable energy will require a concerted effort from national governments, the energy community, civil society, the private sector, international organisations, and individuals. Whatever the difficulties of taking appropriate action, they are small relative to what is at stake. Because today's world is in a dynamic and critical

period of economic, technological, demographic, and structural transition, and because energy systems take decades to change, the time to act is now.

Energy and economic prosperity

The demand of industrialised and transition economies for energy services is likely to grow, although increasing efficiency in conversion and end uses may result in a levelling off or even a reduction in the demand for primary energy. In developing countries, however, primary energy demand is expected to grow at about 2.5 percent a year as industrialisation and motorisation proceed and living standards improve.

Meeting these projected demands will be essential if developing countries are to achieve economic prosperity. It will require considerable investment - on the order of 2.0-2.5 percent of the GDP of developing countries over the next 20 years. This is close to historical norms and, with good financial and economic policies, should be affordable. In the past, energy investments in developing countries rested heavily - and unnecessarily - on government subsidies, and too little on the financial resources that would be generated by real cost-based pricing, regulatory policies, and efficient management.

In general, there is no reason the energy sector should not be financially self-sufficient in the following sense: appropriate pricing and regulatory policies would raise revenues to cover operating costs and generate returns on investment sufficient to attract large-scale private finance and investment. Indeed, one of the primary aims of market liberalisation and the new forms of regulation introduced in many countries in the 1990s was precisely this: to reduce the need for government subvention and to attract private capital and investment to the energy sector. The other aims were to encourage innovation, cost-effectiveness, and managerial efficiency.

But temporary government subsidies may be needed to help people who are excluded

from the market by extreme poverty. Just as poor areas in today's industrialised countries benefited in the past from non-market energy policies, such options should be still available, when justified, in developing countries. Moreover, the poor may need to be shielded from economic hardships caused by trends over which they have no control. In some developing countries, for instance, the oil price increases of the 1970s and early 1980s contributed to large increases in external debt - up to 50 percent in some cases.[16] The effects of that debt - impoverishment of the country and widespread unemployment - were particularly hard on the poor, even though their main source of fuel was and continues to be firewood rather than oil. The debt burden from the 1970s persists in many developing countries.

Although there seem to be no physical limitations on total energy resources, potentially severe problems are likely if appropriate economic, technological, and environmental policies are not developed in a timely manner. Rational energy pricing is part of what is needed, but so is a willingness to prompt markets to find technological solutions to problems before they begin exacting high societal and environmental costs. Finding ways to curb energy-related greenhouse gas emissions and to address other environmental problems, while still expanding energy services, will require enlightened research, development, and demonstration policies. Much therefore will depend on the energy and environmental policies that are introduced, and on their relationship to the forces of globalisation and liberalisation (discussed below).

Thanks to technological advances and better information on impacts, developing countries are in a position to address local and regional environmental problems early in the 21st century, and at an earlier stage of development than industrialised countries did. By addressing these negative externalities of energy generation and use early on, developing countries would find their overall economic well-being and the prospects of their people improved, not diminished. The issue of global climate change, however, may prove more difficult to reconcile with high levels of economic growth.

Overall, however, the analysis in this report suggests that there are no fundamental technological, economic, or resource limits constraining the world from enjoying the benefits of both high levels of energy services and a better environment. This is not to suggest that these benefits are to be expected - only that they are achievable. As the scenarios discussed above demonstrate, sustainable futures depend on ambitious policy measures and support for technological innovation.

In analysing appropriate policies, it is important to keep in mind key features of the political and economic environment in which new energy systems will evolve:

- **The broad structure of macroeconomic and development policies - particularly those for education and broad-based growth. Below a certain level of per capita income, subsistence needs other than energy dominate household budgets and priorities. Income growth among groups without access is the most important determinant of whether they will be willing to pay for energy services (and thus provide the demand required for markets to work effectively). This, in turn, depends on policies beyond the control of energy industries.**

- **The widespread liberalisation of energy markets and the restructuring of the energy sector. These changes are driven by inefficient monopolies, government budget constraints, and expanding technological opportunities - especially in electric power generation. Liberalisation and restructuring can lower costs and generate the finance required for the expansion and extension of supplies (as long as it is profitable to do so). But in restructured energy markets, cross-subsidies will not be available to increase access in areas that are not attractive to investors, unless restructuring is accompanied by policy measures that specifically address such concerns.**

- **Globalisation and the transformations of the information age. Related to the**

liberalisation of markets is globalisation - the world-wide expansion of major companies and their acquisition of, or partnership with, local companies. Procurement of materials and services from distant and foreign sources has become common. New technologies are also diffusing at rates faster than ever before, spurred by world-wide access to the Internet and other information technologies. This expansion can expedite the awareness of sustainable energy options and the deployment of new technologies.

Energy policies for sustainable development

The scenarios exercise showed that, although energy can contribute to sustainable development, its performance in this respect will depend on a range of factors. These include attitudes and behaviour, information and technologies, the availability of finance and supporting institutions, and - in particular - policies and policy frameworks that encourage change in the desired direction. The current path of energy development, and the rate of change, are not compatible with key elements of sustainable development. The divergence of alternative futures that becomes apparent in the scenarios after about 20 years reflects the long-term nature of energy systems. It also indicates that if governments, corporations, and international institutions do not introduce appropriate policies and measures now, critical windows of opportunity are likely to close. It will then become even more difficult to change course.

The most critical issues that sustainable energy strategies and the policies derived from them need to address are how to widen access to reliable and affordable modern energy supplies, and how to ease the negative health and environmental impacts of energy use.

Given proper frameworks, pricing signals, and regulatory regimes, markets can efficiently deliver on the economic objectives of sustainable development. But markets alone cannot be expected to meet the needs of the most vulnerable groups and to protect the

environment. Where markets fail to protect these and other important public benefits, targeted government policies and consistent regulatory approaches will be needed. The problem is that government interventions are usually less efficient than market approaches. Government intervention may have unintended consequences at odds with its original aims. For that reason, there is a need to try different approaches and learn from the experiences of other countries.

Policies and policy frameworks in support of sustainable development should focus on widening access, encouraging energy efficiency, accelerating new renewable energy diffusion, and expanding the use of advanced clean fossil fuel technologies, while keeping open the nuclear option. These policy areas, as well as related decisions on private-public transportation and city planning, have the greatest relevance to the environmental and safety problems associated with conventional fuels.

The broad strategies for encouraging sustainable energy systems are straightforward. But achieving them will require wide acknowledgement of the challenges we face and stronger commitment to specific policies. The strategies are largely aimed at harnessing market efficiencies to the goal of sustainable development and using additional measures to speed up innovation, overcome obstacles and market imperfections, and protect important public benefits. Among the basic strategies, six stand out.

Making markets work better

Driven by the forces of competition, markets do a better job than administered systems in allocating resources. But the marketplace fails to adequately account for the social and environmental costs of energy provision and use. Policies that reduce market distortions - that level the playing field - would give sustainable energy (renewable sources, energy efficiency measures, new technologies with near-zero emissions) a considerably better market position relative to current uses and practices.

Market distortions can be reduced by phasing out permanent subsidies to conventional energy (estimated at $250-300 billion a year in the mid-1990s) and by including social and environmental costs in prices. Several countries have experimented with energy and environment taxes as a way to address the latter. In many cases incentives will be needed to induce or accelerate changes. One such option is a targeted, time-limited (through a 'sunset clause') subsidy. Where energy markets cannot function effectively because of absolute poverty, additional resources, including official development assistance, are required.

Another aspect of making markets work better is finding ways to overcome obstacles to energy end-use efficiency measures. Even in the absence of subsidies, market barriers - such as lack of technological knowledge, different interests of investors and users, and high transaction costs of individual investors - keep energy efficiency measures from reaching their cost-effective potential. Options to overcome these barriers include voluntary or mandatory standards (effectively applied) for appliances, vehicles, and buildings, labelling schemes to better inform consumers, procurement policies to achieve higher standards and economies of scale, technical training in new energy efficiency technologies and their maintenance, and credit mechanisms to help consumers meet higher first costs.

Complementing energy sector restructuring with regulations that encourage sustainable energy

The ongoing, world-wide restructuring of the energy industry - largely driven by the increasing globalisation of the economy - will lead to more economically efficient energy markets. This restructuring presents a window of opportunity for ensuring that the energy-related public benefits needed for sustainable development are adequately addressed in emerging policies for energy market reform. The process could be enhanced if governments set goals that define the performance characteristics of qualifying

sustainable energy technologies (for example, by specifying air pollution emission limits or minimum standards on plants, machinery, and vehicles).

These goals for suppliers can be complemented by mechanisms that favour sustainable energy technologies in energy market choices. Other regulatory approaches supportive of sustainable energy include mandating that a certain percentage of energy comes from renewable sources, requiring that energy grids be open to independent power producers, and ensuring that rural populations are served. Such regulations are based on the recognition that energy market restructuring in itself may not help achieve sustainable development.

Mobilising additional investments in sustainable energy

Energy markets in many countries are rapidly becoming more competitive. For that reason, successful sustainable energy policies, whether involving financing, incentives, taxes, or regulations, must engage the private sector and catalyse private investment on a large scale. But for political or institutional reasons, many of the transition and developing economies that most need investment have problems attracting private enterprise and gaining access to financial markets. Reliable commercial legislation and jurisdiction, as well as incentives, may be needed to encourage private companies to invest in sustainable energy - or to defray the risks associated with such investments.

Official developement assistance may also need to play a greater role in the least developed countries, especially in those where the conditions that attract private sector investment are lacking. Political stability, application of the rule of law, avoidance of arbitrary intervention, and the existence of institutions that facilitate savings and investment are generally important for promoting investment. Supportive financial and credit arrangements (including microcredit arrangements like those now in existence) will be needed to introduce commercial energy to people excluded from markets, especially in

rural areas.

Encouraging technological innovation

Currently applied technologies are not adequate and profitable enough to deliver the energy services that will be needed in the 21st century and simultaneously protect human health and environmental stability. Adequate support for a portfolio of promising advanced and new technologies is one way to help ensure that options will be available as the need for them becomes more acute. Energy innovations face barriers all along the energy innovation chain (from research and development, to demonstration projects, to cost buy-down, to widespread diffusion). Some of these barriers reflect market imperfections, some inadequacies in the public sector, and some different views about needs, corporate priorities, relevant time horizons, and reasonable costs.

Innovation and leadership in energy technologies could be highly profitable for developing countries in economic, environmental, and human terms.

The public support needed to overcome such barriers will vary from one technology to the next, depending on its maturity and market potential. Obstacles to technology diffusion, for example, may need to be given higher priority than barriers to innovation. Direct government support is more likely to be needed for radically new technologies than for incremental advances, where the private sector usually functions relatively effectively. Options to support technological innovation, while still using competition to keep down costs, include tax incentives, collaborative research and development ventures, government or cooperative procurement policies, 'green' labelling schemes, and market

transformation initiatives.

Supporting technological leadership and capacity building in developing countries

Because most of the projected growth in energy demand will occur in the developing world, innovation and leadership in energy technologies could be highly profitable for developing countries in economic, environmental, and human terms. Developing economies need to further develop their resources - human, natural, and technological - so they can create energy systems appropriate to their own circumstances. But they also need assistance with technology transfer, financing, and capacity building.

The declining share of official development assistance relative to required investment capital suggests that much of this investment will need to be led by the private sector or private-public partnerships. International industrial collaboration offers one means by which the private sector could gain markets while fostering the private research institutes, and regional institutes that provide training in technological management offer additional possibilities for furthering technology sharing and capacity building.

Encouraging greater cooperation at the international level

The ongoing process of globalisation means that ideas, finances, and energy flow from one country to another. Productive ways of moving forward might include combining national efforts, for example, in the procurement of renewable energy technologies. Other options include international harmonisation of environmental taxes and emissions trading (particularly among industrialised countries), as well as energy efficiency standards for mass-produced products and imports of used machinery and vehicles. The need for concerted action on energy is clear from Agenda 21, which emerged from the 1992 Earth Summit.

The challenge of sustainable energy includes crucial enabling roles for governments,

international organisations, multilateral financial institutions, and civil society, including non-governmental organisations and individual consumers. Partnerships will be required, based on more integrated, cooperative approaches and drawing on a range of practical experience. A common denominator across all sectors and regions is setting the right framework conditions and making public institutions work effectively and efficiently with the rest of society and other economic actors to reach beneficial, shared objectives.

Clearly, energy can serve as a powerful tool for sustainable development.

Clearly, energy can serve as a powerful tool for sustainable development. Redirecting its power to work towards that overarching goal, however, will require major changes of policy within an enabling overall framework. Poverty, inequity, inefficiency, unreliable service, immediate environmental priorities, a lack of information and basic skills, and an absence of needed institutions and resources - require changes to be made. Unless these changes occur within the next few decades, many of the opportunities now available will be lost, the possibilities for future generations diminished, and the goal of sustainable development unrealised.

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Notes

1. In this report the term *industrialised countries* refers primarily to high-income countries that belong to the Organisation for Economic Co-operation and Development (OECD). *Developing countries* generally refers to lower income countries that are members of the G-77 and China. Although many *transition economies* also have a high degree of industrialisation, they are often considered and discussed separately because of their specific development requirements.

2. In this report the terms *traditional energy* and *non-commercial energy* are used to denote locally collected and unprocessed biomass-based fuels, such as crop residues, wood, and animal dung. Although traditional energy sources can be used renewably, in this report the term *new renewables* refers to modern biofuels, wind, solar, small-scale hydropower, marine, and geothermal energy.

3. The Brundtland Report, as the World Commission on Environment and Development report is commonly known, set forth a global agenda for change.

4. Energy's links to sustainable development were most recently acknowledged by the UN General Assembly Special Session on Small Island Developing States in 1999. The major conferences that noted the importance of energy issues were the UN Conference on Population and the UN Conference on Small Island Developing States in 1994, the Copenhagen Social Summit and the Beijing Fourth World Conference on Women in 1995, and the World Food Summit and HABITAT II in 1996. The energy issues emerging from these conferences are summarised in chapters 1 and 2 of UNDP (1997).

5. Agenda 21 is the plan of action for sustainable development adopted at the Rio Earth

Summit.

6. Means for achieving these objectives are discussed in more detail in WEC (2000).

7. Unless otherwise noted, all prices are in U.S. dollars.

8. This target was reaffirmed in 1992 (in chapter 33 of Agenda 21).

9. In this report the term *conventional energy* is used to refer to fossil fuel, nuclear energy, and large-scale hydropower.

10. In this report the word *insult* is used to describe a physical stressor produced by the energy system, such as air pollution. The word *impact* is used to describe the resulting outcome, such as respiratory disease or forest degradation.

11. The Energy Charter Treaty, together with a protocol on energy efficiency and related environmental aspects, entered into force in 1998. It has been signed by about 50 countries, including the members of the European Union and the Commonwealth of Independent States, Australia, and Japan.

12. Analysis of efficiency potentials in end-use sectors in the next 20 years appears in chapter 6 of this report and is based on detailed techno-economic studies and examples of best practices.

13. Conventionally, energy efficiency has been defined on the basis of the first law of thermodynamics. The second law of thermodynamics recognises that different forms of energy have different potentials to carry out specific tasks. For example, a gas boiler for space heating may operate at close to 100 percent efficiency (in terms based on the first law of thermodynamics). This seems to suggest that limited additional efficiency improvements are possible. But by extracting heat from the ground or other sources, a

gas-driven heat pump could generate considerably more low-temperature heat with the same energy input. The second example illustrates the potential for energy efficiency improvements according to the second law of thermodynamics.

14. An adequate payments system means using meters and payment collection to ensure that all energy services have a price that is paid by all users on a regular basis.

15. Both figures include the 2 billion currently without access to commercial energy. UN population projections were revised downwards in 1998, after the scenarios described here were developed. Although the population assumption used for the scenarios described here (11.7 billion by 2100) is slightly higher than the UN medium scenario (10.4 billion), the two are not inconsistent.

16. The policies of industrialised countries and inflationary pressures from petro-dollars could also have contributed to debt levels.