

Contents

Preface.....	iii
Acknowledgements.....	iv
Overview.....	v
Contents.....	xxv
Explanatory Notes.....	xxxii
I Introduction: why a green technological transformation is needed	1
The development challenge and the emerging environmental crisis	1
Unremitting increases in population and income	2
Lopsided distribution of population and income growth	3
Environmental impact of increased population and income	3
Sustainable development and the green economy paradigms.....	8
The need for a fundamental technological and structural transformation	11
Equitable growth within environmental boundaries	17
Economic growth is a precondition for poverty alleviation	17
Growth and environmental protection.....	18
Limits to growth in developed countries?.....	19
The great green technological transformation.....	20
What kind of technological revolution?.....	20
A technological revolution like no other.....	22
Societal transformations	25
The agenda	26
II The clean energy technological transformation	27
Introduction.....	27
Global energy technology transitions.....	30
The global energy system.....	30
History of global energy transitions.....	31
History of global energy technology transitions	32
Future scenarios	33
Efforts to accelerate energy technology change.....	34
The international energy technology agenda	34
National plans for clean energy technology.....	35
National plans for universal access to modern fuels and electricity	36
National energy technology innovation strategies	37
Investments in research, development and demonstration (RD&D), market formation, and diffusion.....	38
Investment in market formation.....	39
Investment in diffusion.....	40

Government energy technology programmes.....	41
Ethanol in Brazil, the United States and Mauritius.....	41
Coal-based synthetic fuels in the United States.....	42
Hydrogen production in the United States.....	42
Nuclear power in the United States.....	42
Wind power in Germany, Denmark, the United States, the Netherlands, China and India.....	43
Photovoltaics in Germany, the United States, Japan, China and Kenya.....	44
Solar water heaters in the United States and China.....	45
Concentrated solar power in the United States, Germany, Spain and North Africa.....	45
Micro-hydroelectricity and biogas in China.....	46
Efficient cook stoves in developing countries.....	46
Top Runner Programme on end-use efficiency in Japan.....	47
Car fuel efficiency standards in the United States.....	47
Lessons from market-based measures.....	47
Carbon price signals and emissions trading.....	48
Gasoline taxes.....	48
Feed-in tariffs.....	49
Does every little bit help: a critical assessment of current approaches.....	49
Plans need to add up globally.....	50
Plans also need to add up at the system level.....	50
Feasible timescales for transitions.....	53
Staying within limits.....	54
Limits to improving energy efficiency.....	57
Policy options and recommendations.....	58
The need for comprehensive, strategic and system approaches.....	59
A global “Top Runner Programme”.....	61
“Reality checks” through independent centres for energy systems analysis.....	63
One size does not fit all.....	64
III Towards a truly green revolution for food security.....	67
The global food crisis.....	67
Persistent food insecurity.....	68
Impact of the 2007-2008 world food price spike.....	69
Causes of the food price crisis.....	71
Policy responses to the food crisis.....	74
Unsustainable natural resource management as a threat to both food security and the environment.....	74
Environmental impacts.....	74
Drivers of unsustainable natural resource management.....	80
Food security and small farm holders.....	80

Towards a true green technological revolution in agriculture.....	82
The sustainable agricultural innovation system framework.....	83
Building on existing approaches to technological innovation in agriculture and natural resource management	86
National strategies for support of education, science and technology in addressing food security.....	93
Reviving agricultural R&D	93
Agricultural research and development for food security.....	94
Regional and global partnerships for food security and environmental sustainability	100
IV Reducing human harm from natural hazards.....	101
Introduction.....	101
Multidimensional impacts of natural disasters	102
Mapping disaster risks.....	103
Is climate change to blame?.....	105
Unequal impacts on livelihoods	106
Enhanced risk of “extreme” disruptions?.....	107
Approaches to disaster risk reduction and climate change adaptation.....	109
Existing incremental approaches.....	109
The need for an integrated approach	109
Risk, uncertainty and catastrophes	110
The road to technological transformation.....	111
Harnessing local technologies	112
Institutional gaps.....	113
The scope of technological transformation.....	113
Existing technologies and knowledge systems for adaptation and disaster prevention.....	113
Technology gaps to be bridged.....	116
Enabling sector-level disaster-resilient technological change.....	119
The energy challenge	119
Water and sanitation	119
Health	120
Coastal zones	121
Institutional change and capacity building	122
Financing and external transfers.....	123
The way forward	125
Annex table IV.1	126
V National policies for green development.....	131
Introduction.....	131
Market and systemic failures.....	132
Uncertainty, externalities and public goods-related problems.....	133

Systems of innovation.....	134
National innovation systems.....	134
Sector-specific green innovation systems.....	134
“Greening” national innovation systems	135
The innovation process.....	137
Basic research, development and demonstration (RD&D).....	137
Market formation and diffusion	138
Coordination and networks.....	138
Cooperation among universities, research institutions and firms	139
Networks, clusters and science parks	139
International networks and technology transfer.....	140
Education	145
Education, consumption and environmental behaviour.....	145
Formal education	146
Recent progress in education in developing countries.....	146
Innovative approaches to education.....	147
Labour market policies	148
Institutions, industrial policies and infrastructure.....	149
Regulation.....	149
Government procurement, subsidies and other incentives	150
Carbon instruments.....	150
Investment requirements and trade protection	151
Infrastructure and business environment.....	151
Government agencies.....	152
Financing.....	153
Private sector green funds.....	153
Venture capital	153
Microfinance institutions and microfinance	153
Foreign direct investment.....	154
Long-term institutional investors.....	154
Private and public sector risk-sharing.....	154
Policy implications.....	157
A framework for government decision-making	157
Policy reforms under the G-NIS	158
VI Building a global technology development and sharing regime.....	161
Two key global challenges.....	161
Global sustainable development commitments.....	162
Do stakeholders’ actions towards sustainable development add up?.....	163
Private-public sector roles in technology development and diffusion.....	164
Technology development and diffusion of industrialized and developing countries must add up	165
Cooperative international scientific efforts need to be scaled up	165

Deficiencies of existing mechanisms.....	167
Private investment-dependent technological diffusion would be too slow.....	167
Inadequate investment rates due to volatile global markets and fiscal constraints.....	169
Inadequate financing for technological development and transfer.....	170
Restricted domestic policy space from international trade and investment regimes.....	177
Incoherence and weaknesses in international governance.....	178
Reforming multilateral trading rules and international finance to accelerate green technology development and diffusion	179
Establishing an effective global technology development and diffusion regime	179
Orienting the intellectual property rights regime towards stimulating innovation of green technologies	180
Multilateral trading rules should grant developing countries greater flexibility in conducting industrial policies.....	182
Financing of green technology transfers necessitates domestic and international financial reforms.....	184
Upgrading levels and capabilities of global governance.....	185
Bibliography	187

Boxes

III. 1	Innovation in agriculture	84
III. 2	Watershed development in India.....	87
III. 3	Payment for ecosystem services in Costa Rica.....	92
IV. 1	Smart and integrated urban planning in Curitiba, Brazil	112
IV. 2	China's climate change adaptation programme and partnership framework	118
IV. 3	Green restoration projects in the Republic of Korea	122
V. 1	Solar PV in rural Kenya.....	142
V. 2	Importing solar PV in Bangladesh.....	143
VI. 1	Expert Group on Technology Transfer.....	166
VI. 2	Compulsory patent licensing in the United States of America	181

Figures

I. 1	Exponential population growth in the modern era	2
I. 2	Accelerated growth of world per capita income in the modern era.....	3
I. 3	Diverging growth of per capita income, by region, 1820-2008.....	4
I. 4	Regional divergences in population growth, 1750-2150.....	4
I. 5	Rise in energy consumption since the first industrial revolution.....	5
I. 6	Rise in atmospheric carbon dioxide concentration, 1000-2008.....	6
I. 7	Rise in global temperature, 1880-2010.....	6
I. 8	Observed and projected rises in global temperature, alternative scenarios, 1850-2100	7
I. 9	Increased use of non-biodegradables, 1900-2000	7

I.10	Material intensity of output in OECD countries, 1975-2000	12
I.11	Global trends in primary metal extraction, 1990-2007	13
I.12	Direct material consumption in OECD countries, 1975-2000	13
I.13	History and possible future of the global energy system under the B1 stabilization scenario for relative shares of the most important energy sources	14
I.14	Carbon intensities, current, and those required to stay within the 450 ppm limit of CO ₂ e concentrations under alternative scenarios	16
I.15	Intensity of CO ₂ emissions per unit of output, world and selected countries and regions, 1980-2006	16
I.16	Trends in fossil fuel consumption and CO ₂ generation, 1980-2007	21
II. 1	Global exergy system flows, 2005	30
II. 2	Trends in per capita energy use and population in developed and developing countries, 1800-2009	31
II. 3	Two grand-scale transitions undergone by global energy systems, 1850-2008	32
II. 4	"Robust" climate change mitigation wedges, 2000-2100	34
II. 5	Annual global support for renewables in the IEA New Policies Scenario, 2007-2035	40
II. 6	Global installed wind power capacity, 1993-2010	44
II. 7	Incremental primary energy demand in the IEA New Policies Scenario, 2008-2035	53
II. 8	National greenhouse gas emissions per capita versus power use per capita, selected countries and areas	62
III. 1	Undernourished population worldwide, 1969-2010	68
III. 2	Undernourished population by region, 2010	69
III. 3	Real food price indices, annual averages, 1990-2011	70
III. 4	Annualized volatility of nominal cereal prices, 1957-2009	70
III. 5	World production and consumption of grains, 1990-2011	71
III. 6	Total volume and share of ODA allocated to agriculture, 1995-2009	73
III. 7	Global change in net primary productivity, 1981-2003	75
III. 8	Trends in forest area, 1990, 2000 and 2010	78
III. 9	Public agricultural R&D investment trends in developing countries, 1981-2008	94
IV. 1	Frequency of disasters, 1970-2009	102
IV. 2	Estimated damages caused by natural disasters and numbers of people affected, 1970-1979 and 2000-2009	103
IV. 3	Number of persons affected per disaster, by country, 1990-2009	104
V. 1	The innovation system	136
V. 2	G-NIS financing	137
VI. 1	Increase in climate change mitigation technologies, 1975-2006	169
VI. 2	Economic and market barriers to technology transfers, as reported in technology needs assessments	170
VI. 3	Aid commitments from OECD/DAC countries for core environment and water supply and sanitation, 1998-2009	176

Tables

II. 1	Global estimates of public and private investments in energy innovation, market formation, and diffusion, 2010.....	38
II. 2	Public and private spending on energy-related RD&D in selected emerging economies and the United States of America, 2004-2008	39
II. 3	Renewable energy plans for the world	55
II. 4	End-use devices ranked by their cumulative global conversion losses along their individual flow paths.....	58
II. 5	Examples of public policy measures for inducing the sustainable energy transformation.....	59
II. 6	Stylized potential impacts of sustainable energy transitions, by groups of countries.....	65
III. 1	Global environmental impacts of land degradation.....	76
III. 2	Projections of climatic changes and corresponding impacts on agriculture.....	77
III. 3	Contribution of agriculture to global greenhouse gas and other emissions	77
III. 4	Approximate average farm size by world region	81
IV. 1	Frequency of natural disasters and impact by regions, 1970-2009.....	105
IV. 2	Multiple potential impacts of changing climate conditions.....	108
IV. 3	Technology and knowledge-based systems for climate change adaptation	114
IV. 4	Adaptation technologies for water resources.....	120
IV. 5	Countries with the largest total population and with the largest share of their population in a low-elevation coastal zone (LECZ), 2000.....	121
IV. 6	Climate change adaptation technologies, by sector and stage of technological maturity	124
V. 1	Primary enrolment, 1999 and 2008.....	147
V. 2	Secondary, vocational and tertiary enrolment, 1999 and 2008	148
V. 3	A sample of green technology policy options for countries at different levels of development and administrative capacity.....	159
VI. 1	Estimated sectoral distribution of emissions reduction potential and mitigation technologies.....	164
VI. 2	Specific financing barriers related to different stages of technological maturity	171
VI. 3	Estimates of required investment levels for sustainable development	174
VI. 4	Bilateral and multilateral funds for mitigation (M) of and adaptation (A) to climate change.....	177

Explanatory Notes

The following symbols have been used in the tables throughout the report:

- .. **Two dots** indicate that data are not available or are not separately reported.
 - **A dash** indicates that the amount is nil or negligible.
 - **A hyphen** indicates that the item is not applicable.
 - **A minus sign** indicates deficit or decrease, except as indicated.
 - . **A full stop** is used to indicate decimals.
 - / **A slash** between years indicates a crop year or financial year, for example, 2010/11.
 - **Use of a hyphen** between years, for example, 2010-2011, signifies the full period involved, including the beginning and end years.
- Reference to “dollars”** (\$) indicates United States dollars, unless otherwise stated.
- Reference to “billions”** indicates one thousand million.
- Reference to “tons”** indicates metric tons, unless otherwise stated.
- Annual rates** of growth or change, unless otherwise stated, refer to annual compound rates.
- Details and percentages in tables do not necessarily add to totals, because of rounding.

The following abbreviations have been used:

CAFE	Corporate Average Fuel Economy (standards) (United States of America)	NDVI	normalized difference vegetation index
CCS	carbon capture and storage	N₂O	nitrous oxide
CDM	Clean Development Mechanism (Kyoto Protocol)	NPP	net primary productivity
CERs	certified emissions reductions	NIMBY	not in my backyard
CGIAR	Consultative Group on International Agricultural Research	NIS	National Innovation System
CH₄	Methane	ODA	official development assistance
CO₂	carbon dioxide	OECD	Organization for Economic Cooperation and Development
CSP	concentrating solar power	PES	payments for environmental services
DAC	Development Assistance Committee (OECD)	POP	persistent organic pollutant
DOE	Department of Energy (United States of America)	ppm	parts per million
EGTT	Expert Group on Technology Transfer (UNFCCC)	ppmv	parts per million by volume
EJ	exajoules	PPP	purchasing power parity
ESTs	environmentally sound technologies	PV	photovoltaic
EU	European Union	R&D	research and development
FAO	Food and Agriculture Organization of the United Nations	RD&D	research, development and demonstration
FDI	foreign direct investment	SAIS	sustainable agricultural innovation system
FFS	Farmer Field Schools	SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
FIT	feed-in tariff	SCC	social cost of carbon
F-gases	fluorinated gases	SDRs	special drawing rights
GATT	General Agreement on Tariffs and Trade	SHS	solar home systems
GDP	gross domestic product	SRI	System of Rice Intensification
GE	genetically engineered	SUV	sport utility vehicle
GEA	Global Energy Assessment	TRIPS	Agreement on Trade-related Aspects of Intellectual Property Rights
GHG	greenhouse gas	TW	terawatts
GJ	gigajoules	UNCTAD	United Nations Conference on Trade and Development
G-NIS	Green National Innovation System	UN/DESA	Department of Economic and Social Affairs of the United Nations Secretariat
Gt	gigatons	UNDP	United Nations Development Programme
GtC	gigatons of carbon	UNEP	United Nations Environment Programme
GW	gigawatts	UNESCO	United Nations Educational, Scientific and Cultural Organization
ICT	information and communications technology	UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency	UNICEF	United Nations Children's Fund
IFPRI	International Food Policy Research Institute	UNWTO	United Nations World Tourism Organization
IGCC	integrated gasification combined cycle	WEFM	World Economic Forecasting Model (of the United Nations)
IMF	International Monetary Fund	WGP	world gross product
IPCC	Intergovernmental Panel on Climate Change	WHO	World Health Organization
IPM	integrated pest management	WTO	World Trade Organization
kg	kilogram	VC	venture capital
kWh	kilowatt-hour	ZJ	zettajoules
LECZ	low-elevation coastal zone		
MCDA	multi-criteria decision analysis		
mpg	miles per gallon		
MtCO₂e	metric tons of CO ₂ equivalent		
Mtoe	millions of tons of oil equivalent		
MW	megawatt		

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations Secretariat concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The term “country” as used in the text of this report also refers, as appropriate, to territories or areas.

For analytical purposes, unless otherwise specified, the following country groupings and subgroupings have been used:

Developed economies (developed market economies):

Australia, Canada, European Union, Iceland, Japan, New Zealand, Norway, Switzerland, United States of America.

Group of Eight (G-8):

Canada, France, Germany, Italy, Japan, Russian Federation, United Kingdom of Great Britain and Northern Ireland, United States of America.

Group of Twenty (G-20):

Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Republic of Korea, Russian Federation, Saudi Arabia, South Africa, Turkey, United Kingdom of Great Britain and Northern Ireland, United States of America, European Union.

European Union (EU):

Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland.

EU-15:

Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland.

New EU member States:

Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.

Economies in transition:

South-eastern Europe:

Albania, Bosnia and Herzegovina, Croatia, Montenegro, Serbia, the former Yugoslav Republic of Macedonia.

Commonwealth of Independent States (CIS):

Armenia, Azerbaijan, Belarus, Georgia,^a Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

Developing economies:

Africa, Asia and the Pacific (excluding Australia, Japan, New Zealand and the member States of CIS in Asia), Latin America and the Caribbean.

Subgroupings of Africa:

Northern Africa:

Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia.

Sub-Saharan Africa:

All other African countries, except Nigeria and South Africa, where indicated.

Subgroupings of Asia and the Pacific:

Western Asia:

Bahrain, Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen.

South Asia:

Bangladesh, Bhutan, India, Iran (Islamic Republic of), Maldives, Nepal, Pakistan, Sri Lanka.

East Asia:

All other developing economies in Asia and the Pacific.

Subgroupings of Latin America and the Caribbean:

South America:

Argentina, Bolivia (Plurinational State of), Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela (Bolivarian Republic of).

Mexico and Central America:

Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama.

Caribbean:

Barbados, Cuba, Dominican Republic, Guyana, Haiti, Jamaica, Trinidad and Tobago.

^a As of 19 August 2009, Georgia officially left the Commonwealth of Independent States. However, its performance is discussed in the context of this group of countries for reasons of geographical proximity and similarities in economic structure.

Least developed countries:

Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Republic of Tanzania, Vanuatu, Yemen, Zambia.

Small island developing States and areas:

American Samoa, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Cape Verde, Commonwealth of the Northern Mariana Islands, Comoros, Cook Islands, Cuba, Dominica, Dominican Republic, Fiji, French Polynesia, Grenada, Guam, Guinea-Bissau, Guyana, Haiti, Jamaica, Kiribati, Maldives, Marshall Islands, Mauritius, Micronesia (Federated States of), Montserrat, Nauru, Netherlands Antilles, New Caledonia, Niue, Palau, Papua New Guinea, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Seychelles, Singapore, Solomon Islands, Suriname, Timor-Leste, Tonga, Trinidad and Tobago, Tuvalu, United States Virgin Islands, Vanuatu.

Parties to the United Nations Framework Convention on Climate Change:*Annex I Parties:*

Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America.

Annex II Parties:

Annex II parties are the parties included in Annex I that are members of the Organization for Economic Cooperation and Development but not the parties included in Annex I that are economies in transition.

