

Climate Change:

A Scientific Assessment for the GEF



A STAP
INFORMATION DOCUMENT
NOVEMBER 2012

Scientific and Technical Advisory Panel

An independent group of scientists which advises the Global Environment Facility



Climate Change:

A Scientific Assessment for the GEF

A STAP INFORMATION DOCUMENT
NOVEMBER 2012

Scientific and Technical Advisory Panel

An independent group of scientists which advises the Global Environment Facility



Climate Change: A Scientific Assessment for the GEF

Prepared on behalf of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) by:

- **N.H. Ravindranath** (Scientific and Technical Advisory Panel of the GEF, Center for Sustainable Technologies Indian Institute of Science, India,
- **Ralph E. H. Sims** (Massey University, Center for Energy Research, New Zealand,
- **Diana Ürge-Vorsatz** (Central European University, Center for Climate Change and Sustainable Energy Policies (3CSEP), Hungary),
- **Milou Beerepoot** (GIZ / CIM and Joint Graduate School of Energy and Environment at the King Mongkut's University of Technology, Thailand),
- **Rajiv K. Chaturvedi** (Indian Institute of Science, Center for Sustainable Technologies, India), and
- **Lev Neretin** (Secretariat of the Scientific and Technical Advisory Panel of the Global Environment Facility, USA)

Acknowledgements

The Document benefited greatly from the peer review comments and suggestions received from Linda Heath (Forest Service, USA) and Jayant Sathaye (Lawrence Berkeley National Laboratory, USA). The authors are grateful to the contributors who have collaborated with the lead authors to produce the Document including Indu K Murthy (Indian Institute of Science, India) and Miklos Antal (Central European University, Hungary). The authors wish to thank Richard Hosier (World Bank), UNFCCC Secretariat, UNEP (Division of Technology, Industry and Economics), UNIDO (Energy and Climate Change Branch), and the GEF Secretariat Climate Change Team for their useful comments and suggestions. Special thanks are also due to Thomas Hammond, Margarita Dyubanova (STAP Secretariat) and Marie-Therese Maurice for their comments and editorial support and Matthew Espie (American University, USA) for assisting the authors in preparing report for publication.

Design and Layout: Green Communication Design Inc., Montreal, Canada

Disclaimer

The contents of this publication are believed, at the time of publication, to accurately reflect the state of the science on climate change, nevertheless STAP accepts responsibility for any errors remaining. This publication was prepared for STAP by the authors serving as independent experts. The views and positions contained herein do not necessarily reflect the views of their affiliated institutions.

This work is shared under a Creative Commons Attribution-Noncommercial-No Derivative Works License.



Citation

STAP (2012). Climate Change: A Scientific Assessment for the GEF. A STAP Information Document by N.H. Ravindranath, R.E. H. Sims, D. Ürge-Vorsatz, M. Beerepoot, R. K. Chaturvedi, and L. Neretin. Global Environment Facility, Washington, DC.

About STAP

The Scientific and Technical Advisory Panel comprises eight expert advisers supported by a Secretariat, which are together responsible for connecting the Global Environment Facility to the most up to date, authoritative and globally representative science.

<http://www.stapgef.org>

FOREWORD

One of the single greatest challenges (perhaps *the* greatest challenge) facing humanity today is climate change. As we ramp up efforts to keep global mean temperature increases to below 1.5 or 2°C, we are recording ever growing stresses on natural and production systems. What is increasingly clear is that for some ecosystems, such as coral reefs and low lying coastal regions, grasslands and semi-arid areas, and high altitude/high latitude areas, even 2°C is too much. This represents a clear and present danger to the planet's life support systems, with concomitant impacts to human well being. Many of the gains we have made in recent decades in improving human health, livelihoods, and lifting hundreds of millions out of poverty are threatened. The vulnerability of basic water supply and food production systems in many parts of the world is increasing, at a time when we need to ensure a decent quality of life for 2 billion more people over the coming decades in addition to the 7 billion already here.

This report reviews recently published climate science literature and analysis post-4th IPCC Assessment Report – noting that the preparation of the programs and strategies for the next GEF replenishment cycle will begin soon. It underscores what is obvious to both experts and policy makers in this field – that to stabilize GHG concentrations in the atmosphere “at a level that would prevent dangerous anthropogenic interference with the climate system” – **incremental reductions in GHG emissions or mitigation interventions are inadequate**. It is increasingly clear that a **transformational shift leading to significant “decarbonization” of energy supply and economic systems is required to achieve this goal**. The challenge of shifting energy supply and consumption patterns to a low-carbon pathway, based largely on substantial improvements in energy efficiency and promotion of renewables, is central to achieving the vision of *The Future We Want* adopted in 2012 by the UN General Assembly as the global roadmap for a sustainable future.

The Scientific and Technical Advisory Panel of the Global Environment Facility prepared this Information Document as a contribution to framing the GEF 6 (2014 to 2018) strategies, but we hope that conclusions and recommendations presented in the Document will be useful to policy and decision makers worldwide. The report highlights recent climate change projections, including likely climate impacts, and reviews key mitigation sectors and technologies. In addition, it addresses policies and opportunities focusing specifically on energy efficiency, renewable energy, transport and urban systems, REDD+, and a number of other key strategies. The report concludes that in order to make a significant contribution to global efforts to reduce GHG emissions and enhance the adaptive capacity of countries it serves, GEF 6 should strive to re-focus its investments from single technology or component-based initiatives to systemic approaches – encompassing a combination of energy demand reduction, low-carbon option deployment, innovative IT systems, energy security, and policy and capacity development. **In conclusion, the authors believe the GEF should emphasize assistance to recipient countries to assess, select and evaluate technologies, policies, measures, regulations, financial incentives and disincentives, financial needs, technology transfer mechanisms, and institutional capacity that will enable them to shift more rapidly and comprehensively to a low-carbon pathway, consistent with national sustainable development goals.**



Thomas E. Lovejoy
Chair, Scientific and Technical Advisory Panel



N.H. Ravindranath
Panel Member for Climate Change Mitigation

TABLE OF CONTENTS

FOREWORD	iii
Acronyms	vi
Executive Summary	vii

CHAPTER 1	The Global Environment Facility - a financial mechanism for the UNFCCC	1
	1.1. The Global Environment Facility	2
	1.2. Strategies for climate change mitigation and adaptation	2
CHAPTER 2	Need for urgent mitigation and adaptation actions	7
	2.1. New evidence on observed and projected climate change	8
	2.2. How serious are the impacts of climate change in the context of GEF focal areas?	10
	2.2.1. Biodiversity	10
	2.2.2. Land degradation, water and food security	11
	2.2.3. Sustainable management of forests and other terrestrial ecosystems	12
	2.2.4. International waters	13
	2.2.5. Impact of climate change on energy resources, infrastructure and services	14
	2.3. Urgency of mitigation and adaptation	14
	2.4. Resilience in GEF focal areas	16
	2.5. Conclusions	17
CHAPTER 3	UNFCCC agreement on <2°C and CO ₂ -eq stabilization targets to avoid dangerous climate change	19
CHAPTER 4	Energy efficiency technologies for mitigation in developing countries and economies in transition	23
	4.1. Cross-cutting technologies and issues	24
	4.2. Industry	24
	4.3. Buildings and appliances	27
	4.4. Transport	31
	4.5. Policy, institutional and regulatory options	32
	4.6. Key mitigation options, leapfrogging opportunities and promising policies	32
CHAPTER 5	Renewable energy technologies, policies and measures	35
	5.1. Modern renewable energy technologies	36
	5.1.1. Centralized renewable electricity systems	36
	5.1.2. Decentralized renewable energy systems	37
	5.1.3. Heating and cooling	37
	5.1.4. Biofuels for transport	38
	5.2. Opportunities for developing countries and economies in transition	39
	5.2.1. Energy-smart food	40
	5.3. Cost effectiveness of renewable energy technologies in the short term (2020/2030)	41
	5.4. Policy, institutional and regulatory options for promoting renewable energy	45
	5.5. Conclusions	45
CHAPTER 6	Urban systems and infrastructure: technologies, policies and tools for mitigation	47
	6.1. Mitigation technologies, policies and tools in urban and transport systems	49
	6.2. Mitigation potential and cost effectiveness of urban and transport systems	50
	6.3. Policy, institutional and regulatory options for urban systems	51
CHAPTER 7	New technologies with large mitigation potential and risks	53
	7.1. Short-lived climate forcing	54
	7.2. AFOLU/REDD+	55
	7.3. Geoengineering	56
	7.4. Carbon dioxide capture and storage	57
	7.5. Nuclear energy	59
CHAPTER 8	Climate change mitigation, transformational shifts and the role of the GEF	61
	8.1. Dangerous climate change	62
	8.2. Assessment of existing efforts	64
	8.3. Bridging the emission gap	65
	8.4. Investment costs to achieve <2°C stabilization	69
	8.5. Potential role for the GEF in limiting global warming to <2°C	69
	References	72

Acronyms

AR4	IPCC Fourth Assessment Report (2007)	LED	Light-Emitting Diode
BC	Black Carbon	LGE	Liters per Gasoline Equivalent
CCM	Climate Change Mitigation	LULUCF	Land Use, Land-Use Change and Forestry
CCS	Carbon Capture and Storage	MIT	Massachusetts Institute of Technology, USA
CDM	Clean Development Mechanism	MRV	Measurement, Reporting and Verification (for emission reduction)
CE	Consumer Electronics	NAPA	National Adaptation Programme of Action
CFL	Compact Fluorescent Lamp	NAS	National Academy of Sciences, USA
COP	Conference of the Parties to the UNFCCC	NASA	National Aeronautics and Space Administration, USA
CSP	Concentrated Solar Power	OC	Organic Carbon
DC	Developing Country	OECD	Organization for Economic Co-operation and Development
DFID	UK Department for International Development	OTEC	Ocean Thermal Energy Conversion
DME	Dimethyl Ether	PV	Photovoltaics
EE	Energy Efficiency	PWh	Petawatt-hours (10^{15} W•h)
EGS	Enhanced Geothermal Systems	R&D	Research and Development
EIT	Economy in Transition	RCP	Representative Concentration Pathway
ESCO	Energy Service Company	RD&D	Research, Development and Deployment
FAO	Food and Agriculture Organization of the United Nations	RE	Renewable Energy
FIT	Feed-in-tariff	REDD	Reducing Emissions from Deforestation and Forest Degradation
FRL	Forest Reference Level	RET	Renewable Energy Technology
GCF	Green Climate Fund	SCCF	Special Climate Change Fund
GDP	Gross Domestic Product	SFM	Sustainable Forest Management
GEA	Global Energy Assessment	SGP	Small Grants Program
GEB	Global Environmental Benefit	SPA	Strategic Priority for Adaptation
GEF	Global Environment Facility	SREX	IPCC Report (2012) "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation"
GEO	Global Environment Outlook	SRM	Solar Radiation Management
GHG	Greenhouse Gas	STAP	Scientific and Technical Advisory Panel of the GEF
GISS	NASA Goddard Institute for Space Studies	UNDP	United Nations Development Programme
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit	UNEP	United Nations Environment Programme
GJ	Giga-joule (or 10^9 J)	UNFCCC	United Nations Framework Convention on Climate Change
HVO	Hydro-treatment of Vegetable Oils	UNIDO	United Nations Industrial Development Organization
ICT	Information and Communication Technology	USDA	United States Department of Agriculture
IEA	International Energy Agency	WEO	World Energy Outlook
IFES	Integrated Food-Energy Systems	WMO	World Meteorological Organization
IPCC	Intergovernmental Panel on Climate Change		
IT	Information Technology		
KWh	Kilowatt-hour (or 10^3 W•h)		
LDV	Light Duty Vehicle		

EXECUTIVE SUMMARY



Climate change is one of the critical global environmental challenges facing humanity. The consensus within the scientific community, amongst national and international policy makers, and in civil society is increasingly pointing towards the urgent need for coordinated and transformative international action to address climate change.



The Intergovernmental Panel on Climate Change (IPCC) periodically prepares assessment reports on the status of climate change science, including impacts, adaptation and mitigation. It reports on the state of science and knowledge, providing an important basis upon which the UNFCCC takes decisions on addressing climate change. Most international agencies, including the Global Environment Facility (GEF), use IPCC Assessments for policy formulation and designing programs to both mitigate and address the impacts of climate change. IPCC Working Group III submitted its Fourth Assessment Report (AR4) on *Mitigation of Climate Change* in 2007, covering the literature up to 2006. Preparation of the IPCC Fifth Assessment Report has begun, but is not due to be published until 2014.



The science of climate change, of course, is continuously evolving and improving. Knowledge is expanding at an unprecedented rate compared to any other branch of science. The GEF, as the financial mechanism for the UNFCCC, will soon start planning for GEF-6 replenishment cycle (2014 to 2018); however, the findings from the IPCC 5th Assessment Report will be too late for informing the GEF policy formulation process on climate change. The aim of this report, therefore, is to **provide an analysis of recent scientific findings in order to assist the GEF to formulate its strategies and priorities in the context of GEF-6, and hence support its efforts in helping the world move towards a low-carbon green economy.**



This executive summary highlights recent developments in climate change projections, including projected impacts and needs for adaptation, and presents key mitigation technologies, policies and opportunities, particularly those relating to energy efficiency, renewable energy, transport and urban systems. Strategies for stabilizing atmospheric greenhouse gas (GHG) concentrations are described, as are other technology options. Some can be controversial at times, such as reducing short-lived climate forcing agents (including black carbon), geo-engineering proposals, carbon dioxide capture and storage (CCS), and nuclear power. Reducing emissions from deforestation and forest degradation (REDD+) is also presented, although few technical or scientific advances have occurred since the IPCC AR4.



The mitigation opportunities are considered in the context of the 2010 Cancun and 2011 Durban Agreements of the UNFCCC (UNFCCC, 2011a) where there was an agreement towards a goal to stabilize global warming below 20C in order to avoid the most dangerous consequences of climate change (Article 2 of the UNFCCC). The need for a transformational shift to low carbon development pathways in order to achieve global warming stabilization is highlighted, and possible future roles for the GEF in this context are presented.

Climate change projections, impacts and resilience

To stabilize atmospheric GHG concentrations at levels low enough to avoid mean global temperatures rising above 2°C, individual incremental reductions in GHG emissions through numerous technological mitigation interventions will be inadequate. A transformational shift, leading towards a significantly lower energy demand and the decarbonization of energy supply and economic systems, will be required. This shift must be closely linked with the sustainable development aims and objectives of developing countries and Economies in Transition (EIT).

Normally, the focus of discussion on impacts of climate change is restricted to natural resources, food production systems, and water resources. However, since a significant amount of GEF support for mitigation is through the energy sector, it should be noted that implications of projected climate change and extreme weather events are also important for this sector. Both energy supply chains and energy demand are already being affected by increasing climate variability and temperature extremes, examples being less reliable hydropower storage reservoir levels, periods of insufficient cooling capacity for thermal and nuclear power stations, and increasing air-conditioning demands.

The highlights of climate change projections, impacts and the need for resilience are presented below:

- Concomitant with our improved understanding of climate change and its impacts, global GHG emissions and the related impacts continue to reach new highs. During the year 2010, carbon dioxide emissions from fossil fuel combustion exceeded 33 billion tonnes (33 GtCO₂ or 9 GtC) for the first time.
- There is international agreement that the maximum global temperature increase should be limited to <2°C. The world has already warmed by 0.8°C since pre-industrial times, and a further 0.6°C warming is already locked into the future climate system due to elevated GHG concentrations in the atmosphere. New research suggests that a warming of 2°C could be achieved as early as by 2030s. The International Energy Agency (IEA) warns that if we continue on the current emissions path based mainly on fossil fuel combustion, the world will head towards a warming of 6°C or more towards the end of this century.
- Observed sea level rise has been higher than the AR4 model projections. However it should be noted that AR4 models do not include the contributions from large ice sheets. **New research projects that sea level could rise between 0.5 to 2m towards the end of this century**, while AR4 projected a sea level rise of 0.18 to 0.59m over the same period.
- Limiting mean global warming to roughly 2°C by the end of this century is now appearing as increasingly unlikely to be achieved, since it requires an immediate ramp down of emissions accompanied by enhanced carbon sequestration.
- Land and water resources are already critically stressed, and climate change will have an adverse impact on agricultural productivity in the coming decades. Areas currently suffering from food insecurity are expected to witness disproportionately negative effects. According to AR4 (IPCC, 2007a), climate change is expected to exacerbate current stresses on water resources from population growth, land-use change (including urbanization), along with inadequate soil conservation and management.
- The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (IPCC, 2012) concluded that there is evidence of some weather extremes changing as a result of the atmospheric build-up of GHGs. It projected that by the end of the 21st century there will be a substantial rise in temperature extremes in many regions of the world. The frequency of heavy rainfall events will likely increase, and there is medium confidence that droughts will intensify in some seasons and areas due to reduced rainfall and/or increased evapotranspiration.
- Climate change could adversely impact net primary productivity and carbon stocks of forests. Forests and other terrestrial ecosystems could undergo large-scale change, from being a net carbon sink to a carbon source. There is a risk of substantial restructuring of the global terrestrial biosphere with approximately half of the Earth's land surface area likely undergoing significant plant community changes, and over one-third of terrestrial ecosystems undergoing biome-scale changes by the end of this century.

- Existing stresses of climate change impacts on hundreds of eco-regions of exceptional biodiversity around the world will increase the likelihood of habitat loss and species extinction over this century. **Traditional conservation practices may prove insufficient for the continuation of many eco-regions.** The actual biodiversity loss could be higher than thought previously as by 2080, more than 80% of genetic diversity within species may disappear in certain groups of organisms.

Recent observations and modeling clearly suggest that the threats from climate change are more immediate and severe than those projected by the AR4. This underscores the need for pursuing urgent mitigation strategies to limit warming below 2°C.

The GEF should continue to recognize the severity of the threats posed by climate change and its impact on the delivery of global environmental benefits across focal areas. Thus, the GEF should adopt strategies to screen for climate risks through the use of appropriate indicators and incorporate resilience enhancement measures in all of its programs.

Energy Efficiency

Most assessments of mitigation opportunities agree that improved energy efficiency (EE) should be the highest priority option for achieving climate goals. This is especially true for developing countries where improved EE also brings significant social and economic co-benefits such as poverty alleviation, improved health and air quality, increased social welfare, energy security, and reduced stress on the need to expand energy system capacities. While there is a broad portfolio of low-cost mitigation options which vary by climate, level of economic development and culture, a number of options stand out as potential “leap-frog” strategies or key opportunities (Table ES.1).

Due to the diversity of energy end-uses, rather than supporting single technologies, the main interventions that the GEF should consider relate to policies that ensure a broad proliferation of EE technologies. Several key policies are applicable in developing countries and EITs to unlock these potentials (Chapter 4). The most relevant policy instruments are energy efficiency regulations, most notably EE performance standards for appliances, lighting¹, vehicle fuel economy standards, building codes, and energy management systems.

TABLE ES.1. Key leap-frogging mitigation opportunities in energy-efficiency in the building, industry and transport end-use sectors.

Applicability	Low investment cost	High investment cost	Social relevance (e.g., energy access)
Developing countries	White roofs, light surfaces.	Urban greening. Very low or zero energy commercial buildings (heat resistant designs, shading, natural ventilation). Novel cooling systems.	Efficient, clean cookstoves
EITs	Thermostatic valves.	Very high performance new buildings (insulation, air tightness, heat recovery, solar gains). High-performance building retrofits.	Energy-efficient retrofits of social housing.
Both	Phase-out of incandescent lighting. Light-emitting diodes. Energy-efficient appliances. Reduction of standby losses. Solar or heat pump water heating. Industry and building energy management systems. High-efficiency electric motors and optimization of driven systems. Energy-efficiency improvements in cement, steel, and chemical industries. High-efficiency two and four wheel vehicles. Low-steam shipping.	Heat energy cascading (including co-generation). High-efficiency vehicles. Transport planning and management systems. Intermodal transport. Promotion of information and communication technology (ICT) Promotion of IT infrastructure enabling system optimization opportunities. Energy efficiency design.	Infrastructure and facilities enabling non-motorized and two and four wheeled motorized transport.

¹ Although “lighting” is used specifically here, in this report as in the majority of relevant literature, the term “appliances” refers to ‘lighting’ as well.

TABLE ES.2. Key leap-frogging renewable energy technology based mitigation opportunities in the electricity, heat, and transport fuel supply sectors for developing countries and EITs.

Sector	Low investment cost	High investment cost	Socially relevant, such as for energy access	Comments
Electricity and heating (either as stand-alone systems or as cogeneration combined with power generation).	Hydropower -medium and small-scales. On-shore wind power. Geothermal power and heat. Bioenergy systems using biomass from wastes and residues.	Solar PV systems- small and large- scales. Concentrating solar power (CSP). Distributed energy systems, using small-scale RE technologies and mini-grids. Bioenergy + Carbon Capture and Storage (CCS).	Most RE systems have social co-benefits (such as energy access, improved health, employment).	The viability of a RE project partly depends on the local RE resources. Wide energy cost ranges therefore exist. RE resource availability first needs to be assessed.
Transport	1 st -generation biofuels from food crops but can have low potential due to land use competition.	Advanced biofuels, mainly using ligno-cellulosic and algal feedstocks.	Small scale biofuel systems could provide mobility access in developing countries and overcome dependence on imported oil products.	Liquid or gaseous biofuels should be produced sustainably with net GHG benefits, including when taking indirect land use change into account.

Such regulations can ensure broad adoption of many of the most relevant technologies. In order for these standards to be transformational and to avoid lock-in (especially of infrastructure-related technologies), EE regulations need to be set at ambitious performance levels, be properly enforced and regularly updated.

Renewable Energy

The recent growth of renewable energy (RE) technologies to provide electricity, heating, cooling and transport fuels has been significant, but the share of total global primary energy remains low (when traditional biomass is excluded). Many RE technologies continue to mature, and significant reductions in costs are becoming evident. Most countries have abundant RE resources available for capture and use. Where these resources are particularly good government support may not be required, as renewables may already compete with conventional fossil fuel energy systems.

The co-benefits resulting from the deployment of RE technologies include energy security, improved health, employment, training opportunities through capacity building, improved social cohesion of communities, increased mobility of people and freight, and local community pride. These should all be considered when developing policies and formulating assistance programs for developing countries. Some potential RE mitigation options and leap-frogging technologies, such as Bioenergy-Carbon Capture

and Storage (BCCS) and advanced biofuels for transport are summarized in Table ES.2.

- Recent growth in 1st-generation liquid biofuel production from sugar, starch and oil crops has leveled off, partly due to concerns over competition for land and water with food and fiber production, possible loss of biodiversity, loss of livelihoods of small landholders, and poor cost competitiveness without subsidies. Ethanol production from sugarcane varies with the sugar commodity price.
- Advanced biofuel options tend to have lower life-cycle emissions than 1st-generation biofuels if forest and wood processing wastes, crop residues, or animal wastes are used as feedstocks. Where purpose-grown energy crops are used, the aim should be to obtain high yields (in terms of GJ/ha) with low inputs of irrigation, fertilizers, agro-chemicals, etc. Although life-cycle analyses of some advanced biofuels show GHG emissions to be relatively low, data remains uncertain. When indirect land-use change impacts are included, in specific cases, emissions per km travelled might exceed those using petroleum-based fuels. Overall, for the GEF to fund large-scale commercial projects, the biofuels need to be based on biomass feedstocks that are sustainably produced. Most of the advanced biofuels, with the possible exception of hydrogenated vegetable oils, have not sufficiently proven themselves commercially for the GEF to consider supporting them other than as demonstration projects. To promote

renewables the GEF could focus on market-based policy mechanisms for addressing incremental costs, and testing business models for off-grid renewable electrification.

- Agriculture, fishing, food processing, transport, storage, retailing and cooking of food are increasingly becoming fossil fuel dependent. There is therefore a need to develop opportunities from shared land use to increase renewable energy when combined with food production, as well as using biomass arising from food and fiber processing. In addition, energy efficiency should be improved at each stage along the entire food supply chain: encouraging food systems and diets that minimize GHG emissions per capita; optimizing food transport and processing needs to meet local demands in ways that minimize total GHG emissions; and reducing food wastage at the production, storage and consumption stages.
 - To be acceptable, any approved RE project should clearly demonstrate GHG reductions on a life-cycle basis and, in addition, it should not lead to loss of biodiversity, food production and local livelihoods.
 - The GEF should continue to monitor trends in market-based policy mechanisms that support the incremental costs of renewables even though their capital costs are declining and evaluate business models for off-grid renewable electrification.

Urban energy, transport and infrastructure

Urban areas require large and concentrated energy supplies for lighting, heating and cooling, food and water supplies, waste treatment, information, communication, entertainment and mobility services. They are, therefore, responsible for large shares of global GHG emissions. Energy use in cities produced 71% of global energy-related CO₂ emissions in 2006, with an expected increase to 76% in 2030 (IEA, 2008). Due to the integrated governance structures of most urban areas, cities offer numerous opportunities to scale up responses to climate challenges in an integrated manner, combining energy efficiency, renewable energy, and broader development issues.

- Climate change policy responses in urban areas can be designed and implemented utilizing the governance opportunities that cities provide in key sectors: transport, land use zoning, buildings, energy, waste treatment, water and food.

- Opportunities for the transport sector include eliminating long commutes and encumbered traffic by re-designing the physical dimensions of cities, shifting to more environmentally efficient modes of transport such as walking, cycling or public transport, and by improving vehicle and fuel technologies.
- Sustainable low-carbon transport policies can help improve local air quality, reduce congestion, reduce travel time, and increase the efficiency and capabilities of transport services, including freight.
- Combining technology solutions in the energy domain and physical sectors such as buildings and transport together with broader development issues related to urban functions, as well as water and food supply, and waste treatment remains a challenge to the planning and development of sustainable urban areas.
- Lack of appropriate climate governance institutions or necessary authority, insufficient expertise, and a lack of funding or central government support are key barriers to climate integrated urban policies (OECD, 2010).

Mitigation opportunities associated with risks

Several technologies are considered controversial and/or unproven, yet they may prove to be critical to achieve stabilization of warming at <2°C.

- **Short-lived climate forcers:** Mitigation of short-lived emissions can bring significant and immediate climate benefits, along with bestowing human health and agricultural co-benefits. However, focusing on the mitigation of black carbon and organic aerosols should not postpone the existing need for reduction of long-lived GHGs. Rather, it must be viewed as a complementary strategy.
- **AFOLU/REDD+:** Avoiding deforestation and forest degradation can provide immediate opportunities in mitigating climate change, and therefore should form an integral part of any strategy to stabilize atmospheric CO₂ concentrations. If implemented effectively and combined with adequate safeguards, REDD+ could provide multiple environmental and socioeconomic benefits including biodiversity conservation, improved livelihoods, security to local rural communities, and increased revenues to forest-dependent communities. The GEF already covers

SFM/ REDD+ and LULUCF (Land Use, Land-Use Change and Forestry) programs, so it could consider including “Climate-smart agriculture” and the opportunities for reducing methane and nitrous oxide emissions. In addition, the GEF could adopt the AFOLU (Agriculture, Forest and Other Land Use) approach used by the IPCC-2006 GHG inventory guidelines as well as the IPCC Fifth Assessment Report. AFOLU includes all six production land categories as well as non-CO₂ emissions from livestock and rice production. The addition of the AFOLU approach as a conceptual framework would enable supporting mitigation projects through agricultural soil carbon enhancement and methane emission reduction from livestock and rice production, in addition to LULUCF and REDD+ projects.

- **Geoengineering:** Solar Radiation Management (SRM) projects have high risks and uncertainties, and should therefore not receive GEF support until specific technologies and approaches are more clearly defined. Geoengineering will remain a potential option in the context of reaching (or crossing) tipping point thresholds that could lead to abrupt climate impacts, particularly if other GHG reduction approaches deliver less mitigation potential than expected. One problem for GEF would be that geoengineering projects would probably involve regional agreements and funding rather than individual country initiatives. Large-scale biological atmospheric CO₂ removal projects have lower risks, and the GEF could consider supporting these once potential trade-offs in these initiatives are better understood. Increasing the carbon content of soils, for example by the addition of biochar, can help significantly reduce atmospheric CO₂ concentrations.
- **Carbon dioxide capture and storage:** These could become an integral component of any deep GHG emission reduction strategy, provided current and future risks are addressed. Carbon Capture and Storage (CCS) projects are now under the umbrella of the Clean Development Mechanism (CDM). CCS, combined with biomass combustion (such as when co-fired with coal) or gasification could have negative emissions if the biomass is sustainably grown; it then offers a very high mitigation potential. Therefore, within its future strategies, the GEF should consider including rigorous monitoring and ongoing project evaluation of CCS projects during demonstration and implementation stages.

- **Nuclear energy:** This low-carbon technology already contributes significantly to global electricity demands (currently contributing approximately 13% of the total generation mix), and several scenarios show it could further contribute to GHG emission reduction strategies. However, the unsubsidized costs as well as risks of accidents and weapons proliferations are high, and public acceptance is often a controversial issue. It is therefore unlikely that nuclear energy will be a viable option for GEF to support the foreseeable future. Hence, GEF support may not be advantageous.

Achieving <2°C stabilization, mitigating climate change, and promoting the green economy: Recommendations for the GEF

The UNEP 2011 synthesis report, *Bridging the Emissions Gap* (UNEP, 2011a), suggested that if global emissions do not exceed 44 Gt CO₂-eq in 2020, and emissions are sharply reduced thereafter, then there is a 66% probability that the politically agreed target of 2°C global temperature rise can be met. Early “peaking” of emissions below 44-46 Gt CO₂ by 2020 is a necessary pre-condition. The International Energy Agency (IEA) stated that it is **feasible to reduce GHG emissions using existing technologies in order to be on the 450 ppm stabilization pathway, but non-OECD countries will have to play a critical role, given their share of current and projected global GHG emissions** (IEA, 2011a).

As an implementing mechanism of UNFCCC, the GEF has acquired extensive experience over its 20 years of promoting climate change mitigation in a large number of developing countries and EITs at different levels of economic development. The GEF has attempted to adapt its climate change mitigation strategies and implementation arrangements over this period. As the markets for low-carbon technologies grow and the related technology prices decline, the GEF strategy should continue to be reviewed.

Recent scientific analysis shows that climate change impacts are projected to be more immediate and severe than was previously thought. **The GEF, therefore, should re-evaluate its approach and strategies in the context of recent UNFCCC agreements based upon emerging scientific evidence on the need to stabilize GHG concentrations in the atmosphere to limit warming at below 2°C.** This will likely require an alternate but complementary approach

to the present GEF strategies that tend to be sector or technology-based. Recommendations for future consideration by the GEF are as follows:

1. Shift away from promoting single technology and single sector approaches recognizing that the key mitigation opportunities are increasingly focusing on system optimization to gain further mitigation benefits rather than making improvements to individual technologies because: improvements in mature technologies are approaching their efficient thermodynamic, technical or cost-effective limits; and recent improvements in ICT have already led to its increasingly widespread use even in poor regions.
 - However, this may not be the case for all countries, and consider only those leading the technology transition. GEF should initially commence such an approach only with the leading countries and covering selected topics such as industrial systems, urban systems and helping smart-grids to improve electricity demand management.
2. National and international experiences widely agree that while improving the efficiency of individual components might yield minor gains, only system optimization can result in significant gains with payback periods of less than two years. In general, the recycling of materials and the optimization of whole systems offer profitable investment opportunities. Assist developing countries and EITs to produce short and long-term low-carbon development strategies to help achieve the <2°C stabilization target consistent with their national economic development goals. There is a need to go beyond the National Communication reports to develop investment plans, prioritizing the interventions needed.
3. Support countries by enabling them to analyze, evaluate and identify options for achieving transformational shifts in energy supply and mitigation strategies for forests and agriculture.
4. Support “leap-frogging” opportunities for transformational change in energy systems to enable developing countries and EITs to shift to low carbon pathways. Additional effort may be required to assist poorer countries improve energy access in a climate friendly way.
5. Assist the higher GHG emitters (such as Brazil, Russia, India, China and South Africa) to evaluate and pursue transformational shifts through energy efficiency improvements and renewable energy deployment in the industry, building, and transport sectors, as well as mitigation options in the forest and agricultural sectors. These countries could then significantly contribute, along with OECD countries, to early peaking of annual GHG emissions and deep GHG emission reductions through large, cost-effective interventions from which economies of scale could derive. How GEF might usefully engage in the economic development debate in an innovative and efficient way needs consideration.
6. Promote demonstrations of selected cutting-edge and emerging mitigation technologies such as very high performance building designs (both new and retrofit), novel and alternative cooling systems for commercial buildings (such as desiccant dehumidification), very high-efficiency appliances, and bioenergy and CCS.
7. Encourage policies that set ambitious appliance standards, building codes, and fuel economy norms. Promote minimum efficiency performance standards because of their cost-effectiveness and high policy acceptability in most jurisdictions. Promote deployment of energy management systems that can overcome non-technical barriers to organizational and continual energy efficiency improvements. Support “feebates” and proactive utility regulations that provide real mitigation opportunities, as well as significant social and economic co-benefits.
8. Promote the development of carefully designed policy mechanisms which have the potential to increase the uptake of renewable energy power systems more cost-effectively than, for example, traditional feed-in-tariffs which are being modified by governments as technologies evolve.
9. Support projects that have the potential to overcome the challenges of RE deployment by encouraging commercial scale-up to reduce costs, and enable integration into present and future energy supply systems.
10. Support development of new state and national policies that remove subsidies for fossil fuels, and promote the carefully designed transfer of subsidies to renewable energy technologies.
11. Build and sustain strategies that reduce the present fossil fuel dependence of the agri-food supply chain, and reduce agricultural-related GHG emissions through efficiency improvements and shifts to renewable energy and reductions in methane and nitrous oxide emissions as the various technologies develop to the commercial stage.

12. Adopt sustainable integration of agricultural production systems that reduce GHG emissions and other negative environmental impacts from agriculture. Discourage the development of peat-lands (they already contribute about 2 GtCO₂ emissions annually) for energy crop production.
13. Respond to climate change in urban systems by developing an integrated, continuous, and long-term strategy based on combined approaches in transport, buildings, water supply, waste treatment, food supply and land use zoning. Such an integrated approach should adequately address other challenges that have interfaces at the urban level, such as management of chemicals, coastal management (where appropriate), and development goals for overall human well-being.
14. Support urban-level policies, measures and practices. Policies and actions by national and state governments can often be difficult to negotiate and implement, whereas local governments can act sooner and in more flexible ways. This has been demonstrated in many countries where even though national climate-related actions are paused, cities have been dynamically transforming. Local and regional authorities provide the governance opportunities, the decisiveness, and the scale to approach the climate change challenge in an integrated manner combining energy efficiency, renewable energy, and broader development issues. The innovations in sustainable urban management could be hierarchical, starting with large cities and slowly shifting to smaller urban centres.
15. Adopt the AFOLU approach covering REDD+, LULUCF, soil carbon enhancement, and methane emission reduction options (from livestock and rice production). These can provide low cost and immediate GHG mitigation opportunities, as well as provide biodiversity conservation, land reclamation, and livelihood improvement benefits when implemented with adequate environmental and social safeguards.
16. Identify climate risks (and mitigation opportunities) throughout the GEF portfolio, across all sectors, and mainstream resilience enhancement measures to combat projected climate change impacts.
17. Overall, the GEF should assist recipient countries to assess, select and evaluate technologies, policies, measures, regulations, financial incentives and disincentives, financial needs, technology transfer mechanisms, and institutional capacity that will enable them to shift more rapidly and comprehensively to a low-carbon pathway that is consistent with national sustainable development goals.

Principles for defining the GEF strategy towards GEF-6 and a green economy

Reducing the carbon footprint of key economic sectors (energy supply, industry, transport, buildings, waste, forestry and agriculture) in order to achieve sustainable levels is possible, but will require substantial resources and innovative, transformative ways of addressing climate change mitigation. In the long term, low-carbon technologies will improve economic performance and global wealth whilst enhancing natural capital. These approaches will also make a significant contribution to poverty alleviation.

Towards GEF-6 and a Green Economy. The GEF's approach to climate mitigation through market transformation and investment in environmentally sound, climate-friendly technologies remains highly relevant in the context of a future green economy, and the need for keeping global temperature increase below 2°C. Within this context, the GEF could consider the following principles to achieve maximum impact in future strategy development.

Undertaking an optimization approach to provide systemic solutions should become the focus for GEF-6 project support. Rather than supporting single, low-carbon technologies or improving the performance of individual components, the GEF should consider supporting more complete systems that could encompass a combination of energy demand reductions, low-carbon option deployment, innovative IT systems, capacity building, energy security, and policy development whilst leading towards sustainable development. Monitoring of such integrated projects and assessing their success will present challenges, so careful consideration will need to be given as to how this may best be achieved.

Principle 1: Have a common goal but with differential delivery approaches. Focus on the more rapidly urbanizing economies and major GHG emitting countries to enable deep emission reductions, and in low GHG emitting countries, to focus on energy access for all. A common goal towards reducing GHG emissions and supporting low-carbon development paths should be implemented, taking into account differing geographies and levels of national development.

Principle 2: Enhance leverage of available global climate financing. Existing barriers to leveraging a range of public and private sector resources for GEF projects should be significantly relaxed. To make a transformational impact, private sector financing for GEF projects should be increased significantly.

Principle 3: Utilize economies of scale and potential synergies between sectors and GEF focal areas². In GEF-6 and beyond (assuming similar or higher levels of funding becomes available), a strong focus on systemic and programmatic approaches to energy production and consumption would utilize economies of scale, and produce multiple benefits from several sectors and focal areas. There is a need to explore and promote mitigation and adaptation synergies when addressing climate change.

Principle 4: Account for climate risks and increase the resilience of GEF climate mitigation projects. Climate change risks have to be recognized so that every GEF program and project addresses these risks and achieves climate resilience wherever possible.

Principle 5: Assure transparency, accountability and global learning. Higher levels of transparency, GHG accountability, and support for global learning should become essential ingredients of GEF funding support for climate change mitigation initiatives.

ORGANIZATION OF REPORT AND CHAPTERS

This report, "Climate Change: A Scientific Assessment for the GEF," is organized into eight chapters covering the following topics:

Chapter 1 presents an introduction to the GEF and the evolution of GEF support to the climate change portfolio.

Chapter 2 outlines the science of climate change projections, possible impacts of climate change, and adaptation strategies to cope with climate change in the context of GEF portfolios.

Chapter 3 highlights the global agreement on the need for stabilization of global warming at $<2^{\circ}\text{C}$.

Chapter 4 describes mitigation opportunities through energy efficiency.

Chapter 5 presents mitigation alternatives through renewable energy (including biofuels).

Chapter 6 describes mitigation options in the transport and urban sectors.

Chapter 7 outlines some of the emerging and controversial mitigation opportunities such as reduction of short-lived climate forcers, REDD+, geoengineering, CCS, and nuclear power.

Chapter 8 in closing discusses the need for a transformational shift to low carbon development strategies and the unique role of the GEF in promoting and supporting this shift to achieve stabilization of global temperature increases below 2°C .

² These are Biodiversity, Climate Change, International Waters, Land Degradation (Desertification and Deforestation), Chemicals, and Sustainable Forest Management (SFM/REDD-PLUS).



GLOBAL ENVIRONMENT FACILITY

gef

INVESTING IN OUR PLANET

CHAPTER 1

The Global Environment Facility - a financial mechanism for the UNFCCC

Climate change is a global environmental concern and requires action at all levels, particularly at the global level. The Intergovernmental Panel on Climate Change (IPCC) prepares periodic assessment reports on the science of climate change, impacts, adaptation and mitigation. IPCC reports provide an important basis upon which the UNFCCC takes decisions on addressing climate change. The Global Environment Facility (GEF) is the financial mechanism of the UNFCCC to address climate change. The GEF also uses the IPCC assessments for policy formulation and designing mitigation and adaptation programs. The IPCC Working Group III submitted its Fourth Assessment Report (AR4) on *Mitigation of Climate Change* in 2007 (IPCC, 2007b), covering the literature up to 2006; the next report is due in 2014.

The science of climate change is continuously evolving. The GEF will soon start planning for GEF-6 replenishment cycle (2014 to 2018); however, the findings from the IPCC 5th Assessment Report will not be available for the GEF policy formulation process to address climate change. Therefore, an updated overview of climate change mitigation options is needed. The aim of this report is to provide an analysis of recent scientific findings in order to assist the GEF to formulate its strategies and priorities in the context of GEF-6, and hence to support its efforts in helping the world move towards a low-carbon green economy.

This report is focused on updating knowledge on mitigation of climate change. It highlights climate change projections, impacts, and needs for adaptation, and presents the key mitigation technologies, policies and opportunities, particularly those relating to energy efficiency, renewable energy, transport, and urban systems. Strategies for stabilizing atmospheric GHG concentrations are described, as are other technology options. Some of the mitigation options can be characterized by higher uncertainties, such as reducing short-lived climate forcing agents (including black carbon), geo-engineering proposals, carbon dioxide capture and storage (CCS), and nuclear power. Reducing emissions from deforestation and forest degradation (REDD+) is also presented. **Finally, the report presents a strategy for the transformational change required to reduce GHG emissions in order to mitigate climate change, and outlines the potential role for the GEF in realizing this goal.**

1.1. The Global Environment Facility

As an operating entity of the financial mechanism of the UNFCCC since 1991, the GEF has been supporting eligible mitigation, adaptation, and enabling (National Communications of non-Annex I countries) activities in the climate change focal area. The overall immediate goal of the GEF in this focal area is to support developing countries, and countries with Economies in Transition (EITs), toward a low-carbon development path. The GEF's long-term impact should be measured in how successful it is in slowing the growth of GHG emissions into the atmosphere from GEF recipient countries.

As of October 15, 2012, since its inception, the GEF has supported a comprehensive set of activities on climate change mitigation, and financed

569 projects worth 3.6 billion in 156 developing countries and EITs (GEF/C.43/Inf.05). These projects attracted co-financing of 23.7 billion and covered enabling activities, energy efficiency, renewable energy, sustainable transport and urban systems, land use, land-use change and forests (LULUCF), SFM/REDD+, technology transfer, and Small Grants Program. Projects on energy efficiency and renewable energy account for more than 60% of the entire GEF mitigation portfolio. On adaptation, since the approval of the first regional and global Stage II initiatives to build the capacity of vulnerable countries, the GEF Trust Fund (Strategic Priority on Adaptation or SPA), the Least Developed Countries Fund (LDCF), and the Special Climate Change Fund (SCCF) financed climate change adaptation projects. Since the inception, LDCF and adaptation window of the SCCF fund (SCCF-A) have supported 117 adaptation projects with \$480 million and mobilized \$2.8 billion in co-financing (GEF/C.43/Inf.05³).

Development of the climate change mitigation focal area in the GEF-5 strategy was guided by three principles: (i) responsiveness to UNFCCC (Convention) guidance; (ii) consideration of national circumstances of recipient countries; and (iii) cost-effectiveness in achieving global environmental benefits (GEBs). The GEF approach to climate change mitigation at this replenishment cycle aimed to help recipient countries move towards a low-carbon development path through market transformation of, and investment in, environmentally sound, climate-friendly technologies.



1.2. Strategies for climate change mitigation and adaptation

The GEF-5 climate change strategy takes into account different national circumstances to tackle climate change mitigation, while supporting sustainable development. It has six strategic objectives:

³ Report of the Global Environment Facility to the Eighteenth Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change. Available at: http://www.thegef.org/gef/council_document/report-global-environment-facility-eighteenth-session-conference-parties-united-nat

CCM-1: TECHNOLOGY TRANSFER: TO PROMOTE THE DEMONSTRATION, DEPLOYMENT, AND TRANSFER OF INNOVATIVE LOW-CARBON TECHNOLOGIES.

- Outcome 1.1: Technologies successfully demonstrated, deployed, and transferred.
- Outcome 1.2: Enabling policy environment and mechanisms created for technology transfer.

CCM-2: ENERGY EFFICIENCY: TO PROMOTE MARKET TRANSFORMATION FOR ENERGY EFFICIENCY IN INDUSTRY AND THE BUILDING SECTOR.

- Outcome 2.1: Appropriate policy, legal and regulatory frameworks adopted and enforced.
- Outcome 2.2: Sustainable financing and delivery mechanisms established and operational.

CCM-3: RENEWABLE ENERGY: TO PROMOTE INVESTMENT IN RENEWABLE ENERGY TECHNOLOGIES (RETS).

- Outcome 3.1: Favorable policy and regulatory environment created for renewable energy investments.
- Outcome 3.2: Investment in renewable energy technologies increased.

CCM-4: TRANSPORT/ URBAN: TO PROMOTE ENERGY EFFICIENT, LOW-CARBON TRANSPORT AND URBAN SYSTEMS.

- Outcome 4.1: Sustainable transport and urban policy and regulatory frameworks adopted and implemented.
- Outcome 4.2: Increased investment in less-GHG intensive transport and urban systems.

CCM-5: LULUCF: TO PROMOTE CONSERVATION AND ENHANCEMENT OF CARBON STOCKS THROUGH SUSTAINABLE MANAGEMENT OF LAND USE, LAND-USE CHANGE, AND FORESTRY.

- Outcome 5.1: Good management practices in LULUCF adopted both within the forest land and in the wider landscape.
- Outcome 5.2: Restoration and enhancement of carbon stocks in forests and non-forest lands, including peatland.

CCM-6: ENABLING ACTIVITIES: TO SUPPORT ENABLING ACTIVITIES AND CAPACITY BUILDING UNDER THE CONVENTION (UNFCCC).

- Outcome 6.1: Adequate resources allocated to support enabling activities under the Convention.
- Outcome 6.2: Strength of human and institutional capacities of recipient countries.

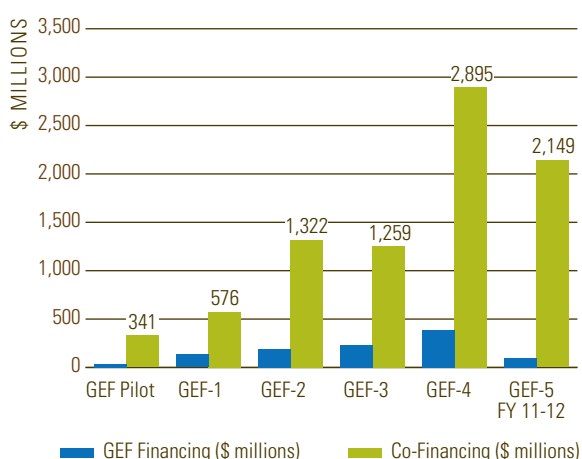
CCM-1. The first objective focuses on innovative technologies at the stage of market demonstration or commercialization where technology push is still critical. The second to fifth objectives (CCM-2 to CCM-5) focus on technologies that are commercially available in a recipient country, but face barriers and require market pull to achieve widespread adoption

and diffusion. The last objective (CCM-6) is devoted to supporting enabling activities and capacity building under the Convention.

CCM-2. During the GEF Pilot Phase and GEF-1 (1994–1998), the energy efficiency portfolio focused on technology demonstration and policy, and

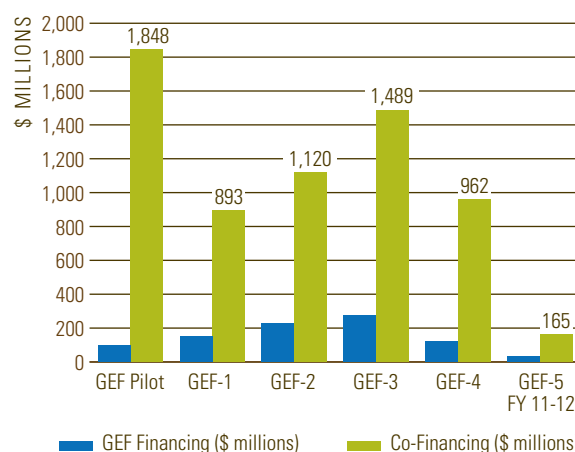
regulatory transformation (Figure 1.1). Under GEF-2 (1998–2002), the distribution was tipped toward technology transfer, standards and labeling, and financial instrument interventions. GEF-3 (2002–2006) was marked by a prevalence of market-based solutions and policy, and regulatory transformations. In GEF-4 and GEF-5, the portfolio focused on (a) establishing regulatory frameworks, comprehensive standards, and labeling programs, and (b) demonstrating and deploying energy efficient technologies. In addition, the GEF is expanding the scope of its assistance to encompass more integrated systems approaches, particularly for standards and labeling programs in the industrial and residential sectors.

FIGURE 1.1: GEF financing and co-financing of energy efficiency.



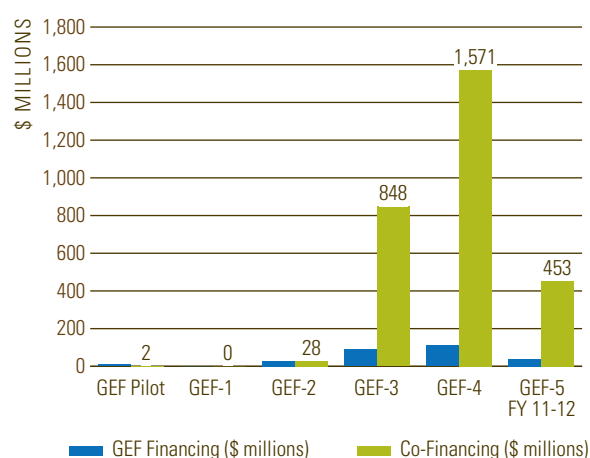
CCM-3. Funding for the renewable energy portfolio increased from the GEF Pilot Phase to GEF-3 (Figure 1.2). However, it decreased in GEF-4 a) in order to expand the energy efficiency and other portfolios; b) due to the high amount of funding directed to renewable energy, such as concentrating solar power projects, approved under GEF-3 that are still under implementation; and c) the decision not to pursue the strategic objective for the promotion of off-grid renewable energy technologies (RETs) in GEF-4. The catalytic approach by the GEF to the promotion of RETs is multi-dimensional, mixing interventions ranging from “soft” actions (barrier removal and capacity building) to tangible actions (direct investments in RETs). Current portfolio focuses particularly on biomass-based electricity and heat generation, support of RET in industries and on decentralized RE systems.

FIGURE 1.2: GEF financing and co-financing of renewable energy.



CCM-4. From GEF-2 to GEF-5, and as of July 2012, the GEF has supported 46 projects which include components on sustainable transport and urban systems (Figure 1.3). Prior to GEF-5, projects under this category focused on sustainable transport. Under the GEF-5 climate change strategic objective CCM-4, the focus was expanded to include integrated approaches that promote energy efficient, low-carbon cities. During GEF-2, the GEF’s portfolio focused on technological solutions. Since GEF-3, the focus has shifted to comprehensive strategy options including land use and transport planning, public transit systems, energy-efficient fleet improvement, transport demand management, and non-motorized transport.

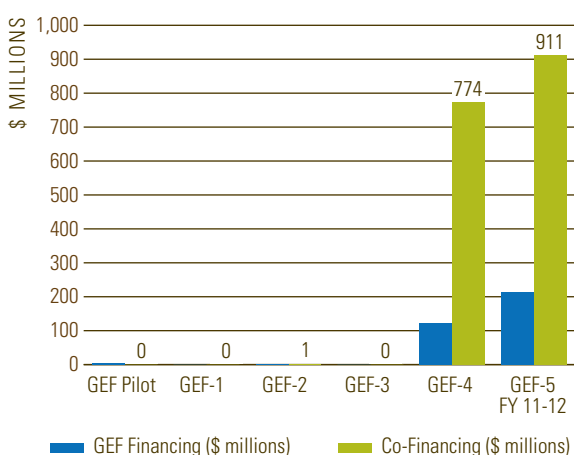
FIGURE 1.3: GEF financing and co-financing of sustainable transport and urban systems.



CCM-5. Since its inception in 1991, the GEF has supported more than 340 projects and programs in the field of sustainable forest management (SFM); although climate change mitigation benefits were generally not formally recognized until GEF-4. Overall, the GEF has allocated approximately \$1.7 billion to forest initiatives, supplemented by more than \$5.7 billion in co-financing⁴.

Historically, most investments by the GEF were dedicated to forest conservation for biological diversity, with projects directed toward land degradation objectives beginning about the year 2000. Land degradation projects also began to include carbon sequestration benefits. Under GEF-5, SFM has been expanded to the SFM/REDD+⁵ incentive program (Figure 1.4), and further multi-focal area projects producing multiple global environmental benefits (GEBs) are being encouraged.

FIGURE 1.4: GEF financing and co-financing of LULUCF and SFM/REDD+.



GEF-5 LULUCF projects span and link landscapes, economic sectors, and people with the land. LULUCF activities include developing national systems to measure and monitor forest carbon stocks and changes, reduce deforestation and degradation, increase forestland, and adopt good management practices. In the first year of GEF-5, the projects funded served to demonstrate the widespread

applicability for LULUCF and SFM/REDD. Coupling LULUCF and other GEF focal area objectives, such as biodiversity and land degradation, captures synergies in multiple GEBs. Additional benefits are generated through SFM/REDD+ funding.

As the financial mechanism of the UNFCCC, the GEF also plays a key role in financing adaptation. The GEF strategic goal for adaptation is to support developing countries in their endeavors to become climate resilient by promoting both immediate and longer-term adaptation measures in development policies, plans, programs, projects and actions. These efforts will result in reduced economic losses due to climate change and variability at country level. The GEF provides adaptation finance through the LDCF and the SCCF; in response to UNFCCC guidance, the GEF was entrusted with the management of the two Funds in 2001 (Decisions 5 and 7, CP.7). While the SCCF has four financing windows, adaptation constitutes the priority area for both the LDCF and the SCCF. The LDCF was designed to support the special needs of the LDCs under the UNFCCC with the priority of preparing and implementing National Adaptation Programs of Action (NAPAs). The SCCF was established under the UNFCCC in 2001 to finance activities, programs, and measures relating to climate change that are complementary to those funded by the climate change focal area of the GEF Trust Fund, and by bilateral and multilateral sources. While the SCCF has four financing windows, adaptation was given top priority in accordance with UNFCCC guidance (Decision 5/CP.9).

Towards GEF-6

GEF-5 replenishment cycle will end in 2014; the GEF will therefore be preparing a strategy for the climate change focal area for GEF-6 for the period 2014-2018. This scientific assessment is aimed at assisting the GEF in preparing the GEF-6 climate change mitigation strategy based on the latest scientific advancement.

⁴ The data are available as of June 2011.

⁵ Reducing emissions from deforestation and forest degradation with later additions of sustainable forest management, conservation, and enhancement of carbon stocks to become REDD+.



CHAPTER 2

Need for urgent mitigation and adaptation actions

In 2007, IPCC published its most recent 4th Assessment Report (AR4) reviewing climate science (Solomon *et al.*, 2007) and the impacts of climate change on key ecosystems (Parry *et al.*, 2007). Both assessments considered scientific literature published till 2006. Hence, the understanding of climate science as projected by IPCC-2007 is about 6 years old.

This chapter attempts to review and present the advances made in climate science since the AR4, using recent scientific literature documenting observations and projections relating to climate change and its impacts. These are presented in the context of the GEF's focal areas of Biodiversity, Land Degradation, International Waters, and Sustainable Forest Management. The implications of advances in climate science, impact assessments and vulnerabilities are explored in the two other focal areas of the GEF: Climate Change Mitigation and Adaptation. Unlike the detailed and rigorous IPCC Report Chapters, this chapter presents a limited and preliminary review of the science of climate change.

2.1. New evidence on observed and projected climate change

New studies strengthen the conclusion that the climate is changing and that the main cause is human induced GHG emissions. Higher temperatures are predicted towards the end of the 21st century than those projected in the AR4 Report (IPCC, 2007a).

The AR4 Report identified a linear trend in the observed temperature rise at 0.74°C over the 100 year period of 1906-2005. New research suggests that the observed temperature has increased to 0.79°C between the periods 1850-59 and 2000-2009 (Huber and Knutti, 2011).

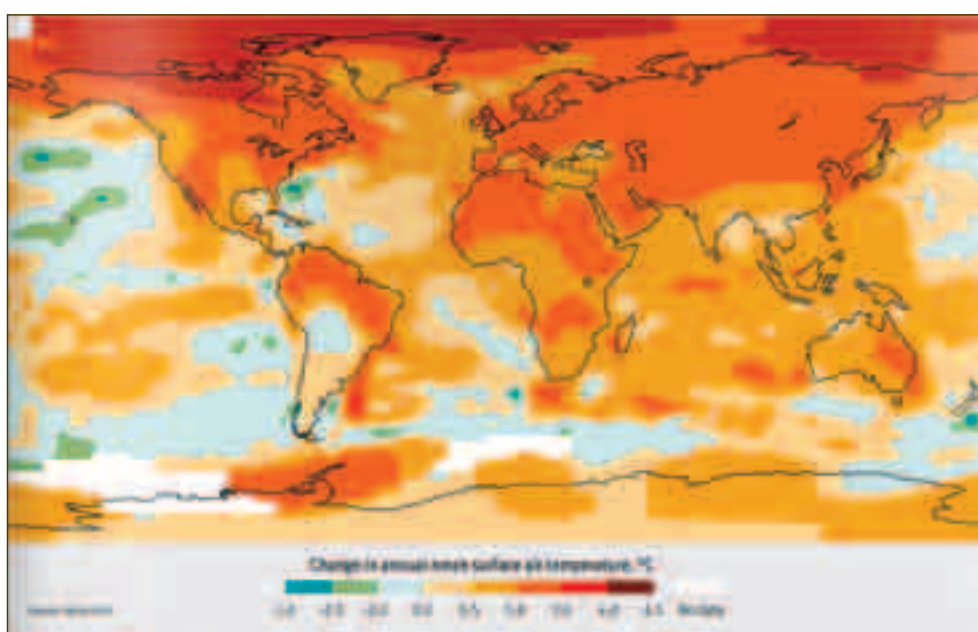
Global annual mean surface air temperatures often mask the regional variations in the range of 0.2 to >4°C that were assessed by NASA during the period 1960-2009 (Fig. 2.1).

There is no uniform trend in observed precipitation. IPCC (2007a) suggested that over the period 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, northern Europe, and northern and central Asia. However, over the same period it had declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has 'likely' increased since the 1970s.

The IPCC (2007a) concluded that "most of the observed increase in global average temperatures since the mid-20th century is very likely (i.e. >90% probability) due to the observed increase in anthropogenic GHG concentrations." New research further increases confidence in the fact that the anthropogenic GHG emissions constitute the dominant cause of observed climate change. For example, a study by Huber and Knutti (2011) concluded that "it is extremely likely (>95% probability) that 'anthropogenic forcings' were by far the dominant cause of warming. The contribution of natural forcing since 1950 is near zero". Another study by the US National Academy of Sciences (NAS, 2010) concluded that "the Earth system is warming and that much of this warming is very likely due to human activities", and describes this conclusion as a "settled fact".

Solomon *et al.* (2007) projected a temperature rise of 3.2°C towards the end of the 21st century under the business as usual (BAU) scenario. Under the current emission scenario, global temperatures could rise up to 6°C by the end of the century (IEA, 2011a). A study by MIT has revised its median surface warming estimates up from 2.4°C to 5.1°C by 2091-2100 (Sokolov *et al.*, 2009). A recent study by MIT's joint program on the Science Policy and Policy of Global Climate Change concluded that global energy use could double by 2050, which

FIGURE 2.1: Change in global annual mean surface air temperatures, 1960–2009 (NASA-GISS).



could result in approximately 64% rise in GHG emissions. The study further concluded that by 2100, as a result of this GHG increase, global mean surface temperature could rise by 3.5 to 6.7°C (median value 4.3°C) above the present level (MIT, 2012). The British Meteorological Office projected a warming of 4°C by as early as the 2060s (Betts *et al.*, 2011). Rowlands *et al.*, (2012) using an observationally constrained large climate model ensemble, projected a warming of 1.4 to 3°C by the 2050s, relative to the 1960-1990 baseline.

Representative concentration pathways and temperature projections

Compared to an earlier practice, where emission scenarios were developed by the IPCC, the scientific community has developed new emission scenarios termed as “representative concentration pathways” (RCPs). The four RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) represent the full range of stabilization, mitigation and baseline emission scenarios available in the literature (Hibbard *et al.*, 2011). The naming convention reflects socio-economic pathways that reach a particular radiative forcing by the year 2100. For example, RCP 8.5 leads to a radiative forcing of 8.5 W/m². Unlike IPCC scenarios (A1B, A2, B2, etc.), RCPs represent pathways of radiative forcing and not detailed socioeconomic narratives. They also include the crucial possibilities of climate change mitigation and adaptation (Moss *et al.*, 2010).

Using the Canadian earth system model CanESM2, Arora *et al.*, (2011) projected that by 2100, compared with 1850, the global temperature would/ could rise to 2.3 to 5.8°C under the scenarios RCP 2.6 and RCP 8.5 respectively.

Although the scientific understanding that ‘rising concentrations of GHGs cause climate change’ has become stronger, GHG emissions are reaching ‘unprecedented’ highs.

Observed CO₂ emissions from fossil fuels are increasing at an ever faster rate. An unprecedented increase of 5.9% in global fossil fuel emissions was measured in 2010, compared to an average of 3.1% per year over the period 2000-2010. For the first time, carbon emissions surpassed 9 GtC (33 GtCO₂) in 2010 (Peters *et al.*, 2012). In addition, observed

CO₂ emissions from fossil fuels over the last decade have surpassed many of the levels projected by the IPCC’s high emission scenarios. Burning of fossil fuels and deforestation are the two key contributors to human induced GHG emissions (Fig. 2.2).

FIGURE 2.2a: CO₂ emissions from fossil fuels and land use change sectors.

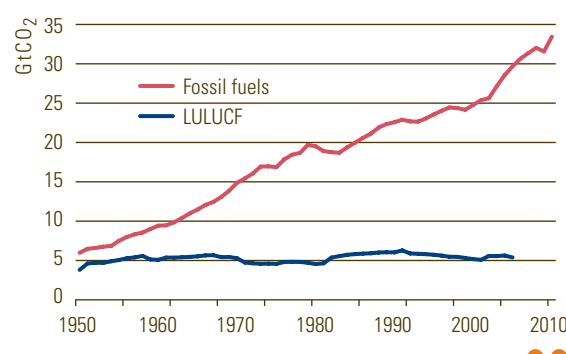
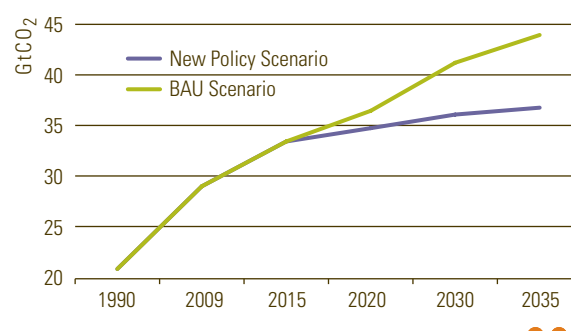


FIGURE 2.2b: CO₂ emission projections until 2035 (IEA, 2011a).



Looking to the future, IEA (2011a) projected that under the BAU scenario, global fossil fuel related CO₂ emissions will increase by more than 50%, from the 2009 emissions of 28.84 GtCO₂ per year to 43.3 GtCO₂ in 2035. Even under the new policy scenario⁶, fossil fuel CO₂ emissions increase by 26% over the same period.

New studies provide evidence to show that some weather extremes have already changed as a result of observed climate change, and these could increase further towards the end of this century.

“It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent” (IPCC, 2007a). The new IPCC Special Report (SREX; IPCC, 2012) concluded that “There is

⁶ This scenario incorporates the broad national policy commitments and plans that had been announced up until mid-2009 to tackle energy insecurity, climate change and local pollution, and other pressing energy-related challenges, even where the specific measures to implement these commitments have yet to be announced.

evidence that some extremes have changed as a result of anthropogenic influences, including increases in atmospheric concentrations of GHGs. It is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures on the global scale.

There is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation on the global scale. It is likely that there has been an anthropogenic influence on increasing extreme coastal high water due to increase in mean sea level".

Pall *et al.* (2011) investigated the links between climate change and the UK floods of October-November 2000, the wettest autumn on record since 1766. They concluded that "the precise magnitude of the anthropogenic contribution to this event 'remains uncertain'", but "in nine out of ten cases model results indicate that 20th century anthropogenic GHG emissions increased the risk of floods occurring in England and Wales in autumn 2000 by more than 20%, and in two out of three cases by more than 90%".

Min *et al.* (2011) showed that "human-induced increases in GHGs have contributed to the observed intensification of heavy precipitation events observed over approximately two-thirds of data-covered parts of Northern Hemisphere land areas".

Coumou and Rahmstorf (2012) reviewed the evidence linking weather related extreme events to climate change. They argued that "for some type

of extremes — notably heat waves, but also precipitation extremes — there is now strong evidence linking specific events or an increase in their numbers to the human influence on climate. For other type of extremes, such as storms, the available

evidence is less conclusive, but based on observed trends and basic physical concepts it is nevertheless plausible to expect an increase."



The SREX (IPCC, 2012) projected a substantial rise in temperature extremes by the end of the 21st century and suggested that "it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe". It concluded that there is "medium confidence that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration".

2.2. How serious are the impacts of climate change in the context of GEF focal areas?

This section reviews recent studies assessing the impact of climate change on mitigation (through the energy sector), biodiversity, land degradation, international waters and sustainable forest management.

2.2.1. Biodiversity

New research suggests that projected biodiversity loss due to climate change could be higher than previously thought.

The IPCC (2007a) concluded that “the resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances and other global change drivers”, and “approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction, if increases in global average temperature exceeds 1.5 to 2.5°C”.

Balint *et al.* (2011) suggested that the projected biodiversity loss due to climate change could be higher than previously thought, as by 2080, more than 80% of genetic diversity within species may disappear in certain groups of organisms. Heyder *et al.*, (2011) project “a risk of substantial restructuring of the global land biosphere on current trajectories of climate change”. They concluded that “considerable ecosystem changes can be expected above 3°C local temperature change in cold and tropical climates and above 4°C in the temperate zone”. They further suggested that “sensitivity to temperature change increases with decreasing precipitation in tropical and temperate ecosystems”.

Beaumont *et al.* (2011) investigated the impact of climate change on 238 eco-regions of exceptional biodiversity around the world. They concluded that projected climate change over the coming decades may place substantial strain on the integrity and survival of some of these biologically important eco-regions. Existing stresses combined with climate change impacts will increase the likelihood of their loss over the 21st century. Based on Williams *et al.*, (2007), standard conservation practices such as assisted migration and networked reserves may be insufficient for the continuation of many of these eco-regions. Key risks associated with projected climate change for the 21st century include possibilities of future climate states with no current climate analog.

Based on 20 to 30 year data for 60 protected areas in tropical forests, William *et al.* (2012) estimate that about half of all tropical forest protected areas are experiencing an erosion of biodiversity. “Tropical protected areas are often intimately linked ecologically to their surrounding habitats, and a failure to stem broad-scale loss and degradation of such habitats could sharply increase the likelihood of serious biodiversity declines.” The Global Environment Outlook (GEO-5) (UNEP, 2012) concluded that since 1970 vertebrate populations have fallen by 30%, and land conversion and degradation has resulted in

a 20% decline of some natural habitats. It concluded that climate change will have profound impacts on biodiversity, particularly in combination with other threats. However, according to the Convention on Biological Diversity (2010), “with adequate resources and political will, tools exist for loss of biodiversity to be reduced at wider scales”.

2.2.2. Land degradation, water and food security

Land and water resources are already critically stressed, and climate change has already started impacting on global food yields. These impacts are likely to rise in future, thus seriously compromising future global food security.

Using 20 years of data, FAO (2011a) concluded that land degradation is increasing in severity and extent in many parts of the world with more than 20% of all cultivated areas, 30% of forests, and 10% of grasslands undergoing degradation. An estimated 1.5 billion people, nearly a quarter of the world’s population, directly depend on the land that is being degraded.

Changes in precipitation and temperature lead to changes in runoff and water availability. Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanization. “The negative impacts of climate change on freshwater systems outweigh its benefits” (IPCC, 2007a).

Vorosmarty *et al.* (2010) presented a worldwide synthesis quantifying multiple stressors on freshwater security, and jointly considering human and biodiversity perspectives. Nearly 80% of the world’s population is currently exposed to high levels of threat to water security, with habitats associated with 65% of the continental discharge classified as moderately to highly threatened.

McDonald *et al.* (2011) investigated the impact of demographic growth and climate change on water availability in urban areas of the developing world. Currently 150 million people live in cities that have perennial water shortage, defined as having less than 100 liters per person per day of sustainable surface and groundwater flow within their urban extent. This number could rise to almost 1 billion by 2050 due to demographic growth. Linked to land degradation, water stress is the key question of food security.

- IPCC projected a decrease in food productivity at lower latitudes for even small local temperature increases (1 to 2°C), particularly in seasonally dry and tropical regions. In mid-to-high latitudes, the projections are a marginal increase in crop productivity for up to 1 to 3°C, and a decrease in crop productivity beyond this point.
- On global food security, Foley *et al.* (2011) estimated that “approximately a billion people today are chronically malnourished while our agricultural systems are concurrently degrading land, water, biodiversity and climate on a global scale”.
- Lobell *et al.* (2011) suggested that climate change is already affecting the global food production. Based on the models that link yields of the four largest commodity crops to weather, they concluded that “global maize and wheat production over the period 1988-2008 declined by 3.8% and 5.5%, respectively.” On a more comforting note, “for soybeans and rice, winners and losers largely balanced out.”
- A study by the International Food Production Research Institute projected a loss of up to 13% in global wheat production, 12% in maize production, and 12.1% in rice production by 2050 compared to the 2000 climate (Nelson *et al.*, 2010).
- Beddington (2012a and 2012b) concluded that climate change will have an adverse impact on agricultural production in the coming decades. Areas currently suffering from food insecurity are expected to witness disproportionately negative effects. For example, “recent droughts and floods in the Horn of Africa, Russia, Pakistan and Australia affected food production and prices”. “The frequency of such extreme weather events will increase, which, when combined with poverty, weak governance, conflict, and poor market access, can result in hunger and famine” (IPCC, 2012).
- Nevo *et al.* (2012) examined if the wild cereal progenitors of wheat and barley are undergoing evolutionary changes due to climate change, as “the best hope to secure staple food for humans and animal feed by future crop improvement depends on wild progenitors”. Over a period of 28 years, the study witnessed profound changes in ‘flowering time’ and ‘genetic makeup’ of these wild cereals. It concluded that “the revealed evolutionary changes imply unrealized risks present in genetic resources for crop improvement and human food production”.

2.2.3. Sustainable management of forests and other terrestrial ecosystems

Climate change could adversely impact net primary productivity and carbon stocks of forests. Forests and other terrestrial ecosystems could undergo large scale changes, from being a sink of carbon to a source.

“Over the course of this century, net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse, thus amplifying climate change” (IPCC, 2007a). “For increases in global average temperature exceeding 1.5 to 2.5°C, major changes are projected in ecosystem structure and function, species’ ecological interactions and shifts in species’ geographical ranges.”

New studies documenting the observed impacts of climate change on terrestrial ecosystems, especially forests, are becoming increasingly common. Recent global carbon budget studies suggest the global terrestrial ecosystem to be a sink of carbon in recent decades despite the deforestation related flux of CO₂ to the atmosphere (Le Quere *et al.*, 2009; Yude *et al.* 2011). However, Carnicer *et al.* (2011) suggested that “climate change is progressively increasing severe drought events in the Northern Hemisphere, causing regional tree die-off events contributing to global reduction of carbon sink efficiency of forests”. For example, a study by Potter *et al.* (2011) estimated the impacts of the 2010 drought on carbon uptake of the Amazon forest. The study estimates that net primary production declined by an average of 7% in 2010 compared to 2008, representing a loss of vegetation CO₂ uptake of nearly 0.5 MtC in 2010.

Building on forest inventory data from USDA Forest Service, Woodall *et al.* (2009) showed that tree species in the Eastern US are migrating northward at rates approaching 100 km per century for many species. This is in line with climate change adaptation expectations. However, Zhu *et al.* (2012) used the same dataset, but improved the methodology for capturing tree range shifts to demonstrate that climate change is occurring more rapidly than trees can adapt. It analyzed 92 species in more than 43,000 forest plots in 31 states of the US, and found that more than half of the tree species are not adapting to climate change as quickly or consistently as predicted. Nearly 59% of species showed signs that their geographic ranges are contracting from both the north and south. Only about 21% of species appeared to be shifting northward as predicted. Thus, instead of the expected northward expansion, tree species are actually contracting in their habitat. Trees are having difficulty in adapting even to the current rates of climate change, and it will still be harder in higher temperature regimes in future.

Bergengren *et al.* (2011) projected 49% of the Earth's land surface area to undergo plant community changes, and 37% of the world's terrestrial ecosystems to undergo biome-scale changes by the end of the 21st century.

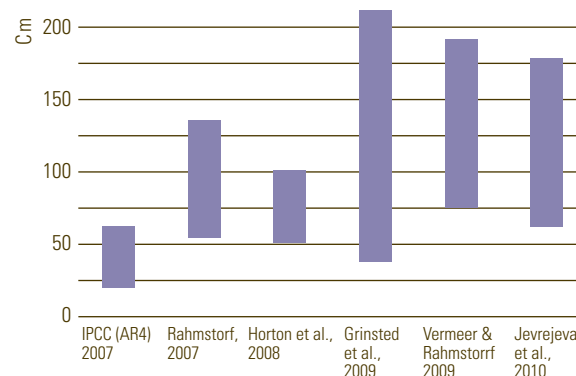
Fenner and Freeman (2011) projected the impact of climate change on peatlands which contain about 550 Gt of carbon. Climate change is expected to increase the frequency and severity of droughts in many of the world's peatlands which, in turn, will release far more carbon dioxide than had previously been assumed. The subsequent effects from a period of severe drought on peat-land will last long past the drought itself. Furthermore, the carbon dioxide release continues and may even increase after the drought. It was previously assumed that most of the carbon dioxide from peat-lands was released immediately in the event of a drought.

2.2.4. International waters

Observed sea level rise has been much higher than IPCC model projections. IPCC (2007a) projected a sea level rise of 0.18 to 0.59m towards the end of this century. New research projects much higher levels ranging from 0.5 to 2m over the same period.

Rahmstorf (2010) suggested that "since the beginning of satellite measurements, sea level has risen about 80% faster, at 3.4 mm per year, than the average IPCC model projection of 1.9 mm per year".

FIGURE 2.3: Estimates for 21st century sea level rise from semi-empirical models as compared to the IPCC Fourth Assessment Report (Rahmstorf, 2010).



IPCC (2007a) projected a sea level rise of 0.18-0.59 m towards the end of the century, plus an unspecified amount that could come from changes in the large ice sheets covering Greenland and Antarctica. In Figure 2.3, new sea level rise estimates made by the respective studies using semi-empirical approaches, are compared. The projection of sea level rises is higher than the IPCC (2007a) predictions, largely in the range of 0.5 to 2m by the end of the century. For example, Vermeer and Rahmstorf (2009) projected a sea level rise of 0.75 to 1.9m by the end of the century, with the best estimate ranging from 1.04 to 1.43 m.

A considerable degree of uncertainty remains on global sea level rise projections, much of which comes from the uncertainty of how ice-sheets, such as those in Greenland and Antarctica, will ultimately respond to climate change.

New estimates based on satellite observations from 1992-2010 suggest that losses in Greenland and Antarctica ice sheets are accelerating at a much faster pace than thought by IPCC (2007a). Rignot *et al.* (2011) estimated a combined acceleration in melting at 36.3 ± 2 Gt/yr, of which Greenland is experiencing losses at 21.9 ± 1 Gt/yr and Antarctica at 14.5 ± 2 Gt/yr. Losses from ice sheets are 3 times larger than the losses from mountain glaciers and ice caps. A new study by Tedesco

et al. (2011) estimated that Greenland witnessed record melting in 2010.

The precise future behavior of Greenland and Antarctica ice sheets is not known. "The magnitude of the acceleration suggests that ice sheets will be the dominant contributors to sea level rise in forthcoming decades, and will likely exceed the IPCC projections for the contribution of ice sheets to sea level rise in the 21st century" (Rignot et al., 2011).

On the threats of ocean acidification and its impact on marine life, Makarow et al. (2009) suggested that, at current CO₂ emission trends, oceans could become 150% more acidic by 2100 than they were at the beginning of the 'Anthropocene'. As a result "by 2100 around 70% of all cold water corals, especially in higher latitudes, will live in waters undersaturated in carbonate due to ocean acidification".

Pace of climate change and its impact on marine species: Burrows et al., (2011) analyzed the pace of climate change over land and oceans over the period 1960-2009. The study documents the pace of climate change shifts in geographical isotherms over time, and the shift in seasonal timing of temperatures over lands and oceans. Both measures are higher in oceans than on lands at some latitudes, despite slower warming over oceans. These trends are cause for particular concern as areas of high marine biodiversity often have greater velocities of climate change and seasonal shifts.

2.2.5. Impact of climate change on energy resources, infrastructure and services

Normally, the focus of discussion of the impact of climate change is restricted to natural resources, and at most to food production and water resources. However, implications of projected climate change and extreme weather events to the energy sector are also important, and need to be considered by the GEF since the bulk of its support for mitigation is through energy sector improvement. Both the energy supply chain and energy demand are already vulnerable to the impacts of current climate variability and extreme weather events in many parts of the world, and it is projected that energy services and resources will increasingly be affected by increasing climate variability and greater extremes (Ebinger and Vergara, 2011).

Climate change can also have direct effects on energy endowment, infrastructure and transport, and indirect effects through other economic sectors. Naswa and Garg (2011) suggested that climate change-related natural disasters represent an additional stress on India's infrastructure as temperature, precipitation, sea level rise and extreme events pose direct and indirect threats to infrastructure assets. Coastal infrastructure assets are additionally vulnerable as these are directly exposed to sea level rise and weather extremes. Significant impacts on energy supply infrastructure are projected due to higher temperatures, increased precipitation, sea level rise, extreme events and increased demand for energy (Sathaye et al., 2012). A detailed list of energy system vulnerabilities to climate change can be seen in Table 2.1.

2.3. Urgency of mitigation and adaptation

Urgency of mitigation arises as global warming could intersect 2°C by 2030s, and 4°C by 2060s. Holding warming below 2°C, though feasible, is becoming increasingly doubtful, and further delay in implementation could lead to excessive costs.

The UNFCCC aimed to "achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Durban (2011) and Cancun agreements (2010) (see Chapter 3) recognized the need for deep cuts in global GHG emissions, and identified a goal of reducing global GHG emissions so as to hold the increase in global average temperature below 2°C, above pre-industrial levels. Dangerous anthropogenic interference with the climate system refers to the risks arising from tipping elements (Fig.2.4). One of the most dangerous impacts is likely to come from the melting of the Greenland ice-sheet, which is likely to reach its tipping threshold around 2°C warming (Lenton et al., 2008). Robinson et al., (2012) suggested that dangerous climate change could set in much faster and earlier than thought. The Greenland ice-sheet could reach a threshold within the warming range of 0.8 to 3.2°C, leading to an ice-free state. The current scientific understanding puts this threshold at 1.9 to 5.1°C (Lenton et al., 2008).

TABLE 2.1. Vulnerability of energy systems to climate change impacts (Ebinger and Vergara, 2011).

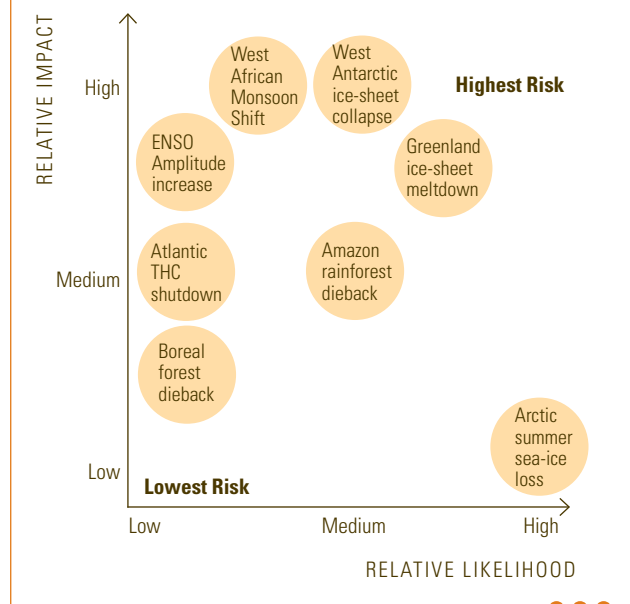
	Relevant climate impacts			
Energy system	General	Specific	Additional	Impacts on the energy sector
Impacts on renewable energy resource endowment				
Hydro	Runoff	Water volumes (+/-), seasonal flows; highs and low extreme events	Erosion and siltation	Reduced firm energy, increased variability, increased uncertainty.
Wind	Wind field characteristics; changes in wind resource.	Changes in density, wind speed; increased wind variability.	Changes in vegetation (might change roughness and available wind).	Increased uncertainty
Biomass	Crop response to climate change	Crop-yields; agro-ecological zone shift	Pests, water demand, drought, frost, fires, storms	Increased uncertainty; increased frequency of extreme events.
Solar	Atmospheric transmissivity	Water content; cloudiness; cloud characteristics.	Pollution/dust and humidity absorb part of the solar spectrum.	Positive/negative impacts.
Wave and tidal	Ocean climate	Wave field characteristics; no effect on tides	Strong non-linearity between wind speed and wave power	Increased uncertainty; increased frequency of extreme events.
Impacts on energy supply				
Hydropower	Water availability and seasonality	Water resource variability; increased uncertainty of expected energy output.	Impact on grid; wasting excessive generation; extreme events.	Increased uncertainty; revision of system reliability; revision of transmission needs.
Wind power	Alteration in wind speed frequency distribution.	Increased uncertainty of energy output	Short life span reduces risk associated with climate change; extreme event.	Increased uncertainty on energy output
Bioenergy	Reduced transformation efficiency	High temperatures reduce thermal generation efficiency	Extreme events.	Reduced energy generated; increased uncertainty.
Impacts on transmission, distribution and transfers				
Transmission, distribution, and transfers	Increased frequency of extreme events; sea level rise (SLR).	Wind and ice, landslides; flooding, coastal erosion, SLR	Erosion and siltation; weather conditions that prevent transport.	Increased vulnerability of existing assets
Impacts on design and operations				
Siting infrastructure	SLR; increased extreme events	Flooding from SLR; coastal erosion; increased frequency of extreme events.	Water availability; permafrost melting; geomorpho-dynamic equilibrium.	Increased vulnerability of existing assets; increased demand for new good siting locations.
Energy trade	Increased vulnerability to extreme events	Cold spells and heat waves	Increased stress on transmission, distribution, and transfer infrastructures	Increased uncertainty; increased peak demand on energy systems

The world has already warmed by 0.8°C, and a further minimum warming of about 0.6°C (0.3°C to 0.9°C) is already built into the system due to emissions already in the atmosphere (Matthews and Weaver, 2010; and Solomon *et al.* 2007). According to Smith *et al.* (2011), a warming of 2°C could be achieved as early as the 2030s, and a warming of

4°C by the 2060s (Betts *et al.* 2011). Ironically, as the urgency to mitigate emissions is mounting, GHG emissions have witnessed record increments in recent years. Arora *et al.* (2011) projected global temperature by using the Canadian earth system model (CanESM2), and concluded that “limiting warming to roughly 2°C by the end of this century

is unlikely since it requires an immediate ramp down of emissions followed by ongoing carbon sequestration in the second half of this century”.

FIGURE 2.4: A ‘straw-man’ risk matrix for climate tipping points (Lenton, 2011).



Observed CO₂ emissions are now higher than many of the IPCC high emission scenarios. The IEA (2011a) warned that with current emission paths, the world is headed towards a 6°C or more temperature rise towards the end of the century. The opportunity for limiting the warming below 2°C is fast closing, and “without further action by 2017, all CO₂ permitted in the 450 scenario will be locked in by existing power plants, factories, buildings, etc.” (IEA, 2011a).

According to Stern (2007), “the benefits of strong and early action far outweigh the economic costs of not acting”. Almost all of the GEF focal area objectives and expected outputs are prone to the risks of climate change. Therefore, the GEF needs to clearly and urgently recognize that the threats posed by climate change are a multi-focal area challenge, requiring multi-focal approaches and actions within each focal area project.

2.4. Resilience in the GEF focal areas

As was seen in earlier sections, the global environmental benefits of all GEF focal areas are projected to be impacted by climate change, with

some of the ecosystems already being impacted by recent observed climate changes. The science of climate change has progressed sufficiently to make an assessment of climate change impacts and vulnerability at regional levels, and perhaps at individual project levels. Thus, projects in all focal areas of the GEF may require enhancing resilience to climate risks. The GEF could adopt a simple climate change risk assessment and resilience tool.

Climate change impacts in GEF projects could be considered at three levels:

- **Impacts on natural resources.** Studies are available describing the potential impacts of climate variability/climate change on the natural resources included in the projects related to forests, biodiversity, wetlands, semi-arid/arid cropland, water availability/stream flow and crop yields.
- **Impacts on objectives or outputs of the project.** Climate change could potentially impact the outputs of the project such as reclaimed degraded land, increased crop yields, moisture conserved, power generated from micro-hydro/windmill systems, carbon stocks in afforested/reforested area, biodiversity of wetlands/mountain ecosystems/tropical forests conserved.
- **Impacts on project interventions.** Climate change could potentially impact the interventions proposed in a GEF project, such as wind turbines or micro-hydro system installations, land area afforested/reforested, soil and water conservation structures, shelter belts grown, alternate livelihoods planned for reducing degradation of biodiversity.

GEF investments, to deliver global environmental benefits, are best protected by adopting approaches that simultaneously address climate risks and the objectives of focal areas. Enhancing ecosystem and community resilience is the entry point for delivering co-benefits for all GEF focal areas, while also contributing to sustainable development. There is a strategic imperative to identify the specific risks of climate change and possible technical, policy and institutional interventions

in GEF focal area strategies, and to include the climate risks in results-based management frameworks. The GEF is encouraged to allocate resources using a pro-active approach aimed at increased climate resilience across the portfolios. This may be achieved, *inter alia*, through mainstreaming climate risks into its projects and programs, identifying opportunities in each focal area, adopting ecosystem-based adaptation, and explicitly linking with climate change.

Resilience enhancement options, practices and policies: Scientific knowledge, information and practical experience are available to enhance resilience to climate change in most environment, conservation and development projects. Most efforts to cope with current climate risks and extremes will also help build resilience to projected climate change. The World Bank, the Asian Development Bank, UNDP, DFID, GIZ, etc., already have guidelines to mainstream adaptation to climate change in all developmental projects. There are multiple approaches to climate change adaptation. Two of the potential approaches are 1) ecosystems-based and 2) community-based. According to UNFCCC (2008), "ecosystem-based adaptation includes a range of local and landscape scale strategies for managing ecosystems to increase resilience and maintain essential ecosystem services and reduce the vulnerability of people, their livelihoods and nature in the face of climate change." On the other hand, community based adaptation approaches place the emphasis on empowering local communities to reduce their vulnerabilities.



2.5. Conclusions

The understanding that climate change is happening due to human induced GHG emissions has increased substantially since the publication of AR4 (IPCC, 2007a). Climate change is now recognized as one of the most pressing global issues of our planet (El Sioufi, 2010). Unfortunately, as the understanding that 'GHGs cause climate change' is increasing, GHG emissions are reaching new highs. Observations at the global and regional levels show higher observed and projected impacts of climate change on many key ecosystem elements such as sea level rise (Rahmstorf, 2010), biodiversity (Beaumont et al., 2011), ice sheets (Tedesco et al., 2011), Arctic sea ice (Wang and Overland, 2009), and ecosystem changes (Zhu et al., 2012) than considered by the AR4 (IPCC, 2007a).

Thus, observations and model simulations clearly suggest that the threats from climate change are much more immediate and severe than projected by AR4. This underscores the need for pursuing urgent mitigation strategies to limit the warming below 2°C and cope with the observed impacts of climate change, and to build resilience to cope with future impacts. The GEF should recognize that climate change could impact the anticipated delivery of environmental benefits from different focal areas, and therefore develop strategies to screen for climate risks and incorporate resilience enhancement measures in all GEF programs.



CHAPTER 3

UNFCCC agreement on <2°C and CO_{2-eq} stabilization targets to avoid dangerous climate change

In 2010, the average concentration of CO₂ in the atmosphere was 388.5 ppm. In 2009, the total emission of GHGs from fossil fuel use and land use change was estimated at 49.5 GtCO_{2-eq} (Montzka *et al.*, 2011). At the Sixteenth UNFCCC Conference of Parties (COP 16) held in Cancun in December 2010, the international community agreed to deep cuts in global GHG emissions, with a view to limit global average temperature rise below 2°C. The most recent UNEP synthesis report, "Bridging the Emissions Gap" (UNEP, 2011a), suggested that if global emissions do not exceed 44 GtCO_{2-eq} in 2020 and emissions are sharply reduced afterwards, there is a 66% probability that global warming can be limited to this politically agreed target of 2°C (Table 3.1).

TABLE 3.1. Overview of key characteristics of GHG emission reduction pathways reviewed.

Number of pathways	Peaking decade (year)*	Total GHG emissions in 2020(GtCO _{2-eq})		Total GHG emissions in 2050(GtCO _{2-eq})		Average energy and industry-related CO ₂ emission reduction rates between 2020 and 2050 (% of 2000 emissions/year)	
		Median	Range**	Median	Range**	Median	Range**
"Likely" chance (>66%) to limit global temperature increase to below 2°C during 21 st century							
23	2010-2020	44	26-(41-46)-49	21	12-(18-23)-32	2.6	0.6-(2.3-3.1)-3.6
"Medium" chance (50to 66%) to limit global temperature increase to below 2°C during 21st century							
17	2010-2020	46	42-(45-49)-50	26	20-(24-29)-32	2.5	2.0-(2.2-2.9)-3.6

Notes:

* Because IAM pathways provide emissions data only for 5-year or 10-year increments, the encompassing period in which the peak in global emissions occurs is given. The peak year period given here reflects the 20th-80th percentile range. Note that pathways with a "likely" chance show peaks earlier in the decade, whilst those with a 'medium' chance are spread across the whole decade.

** Range is presented as the minimum value (20th percentile – 80th percentile) maximum value.

Keeping emissions to a certain level in 2020 is not sufficient to assure global warming of <2°C above pre-industrial levels in the 21st century. Global temperature increase will be particularly determined by emissions after 2020. However, the early “peaking” of emissions below 44-46 GtCO_{2-eq} in the decade 2010-2020 is a necessary condition to limit global temperatures to <2°C, and in agreement with all models (UNEP, 2011a).



Following agreements reached in Copenhagen at COP 15 in 2009, 42 industrialized countries and 44 developing countries submitted their pledges to limit GHG emissions to certain levels by 2020. However, these pledges made in association with the Copenhagen Accord (in 2009) and later confirmed in the Cancun Agreement (2010), are not sufficient to put the world on a climate-sustainable path (see Chapter 8). In the “New Policies Scenario” of the IEA World Energy Outlook (IEA, 2011a) (which incorporates the existing commitments and plans announced by countries around the world to tackle climate change, energy insecurity, and atmospheric pollution, including the Cancun Agreements and G-20 and the Asia-Pacific Economic Cooperation country initiatives), energy-related CO₂ emissions continue to increase (Table 3.2), rising to 34.4Gt CO₂ in 2020 and to 36.4Gt CO₂ in 2035. This could lead to a global long-term temperature increase of more than 3.5°C. The WEO 2011 “Current Policies Scenario”, that assumes no change in government policies and measures beyond those enacted or adopted by mid-2011, suggests that long-term temperatures will rise above 6°C. In contrast, the “WEO 2011 450 ppm Scenario” (IEA, 2011a) shows total GHG emissions from energy sectors in 2020 should roughly be equal to the level of emissions in 2009 (28.8 GtCO₂), and decline to 21.6 GtCO₂ by 2035 in order to maintain a long-term temperature increase below 2°C. The 450 ppm scenario requires lower GHG emissions (35%) by 2035 than the New Policy Scenario, even lower (nearly 50%) than the Current

TABLE 3.2. World anthropogenic greenhouse gas emissions by scenario (GtCO_{2-eq}) (IEA, 2011a).

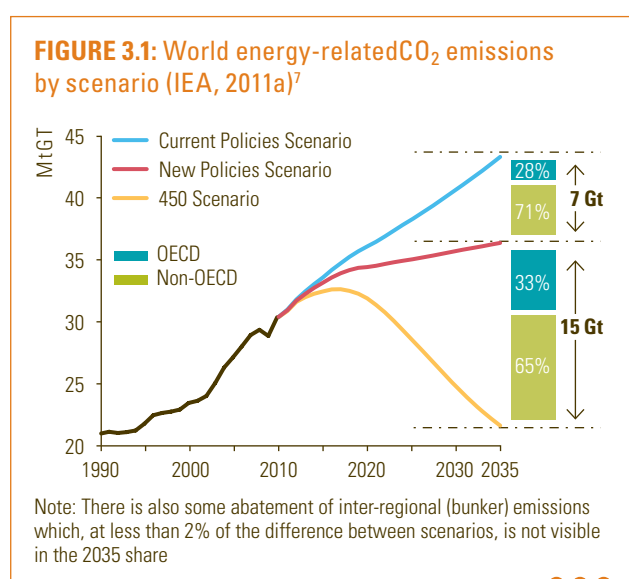
	2009	New Policies Scenario		Current Policies Scenario		450 Scenario	
		2020	2035	2020	2035	2020	2035
CO ₂ energy	28.8	34.4	36.4	36.1	43.3	31.9	21.6
CO ₂ other	1.4	1.2	1.1	1.7	1.9	1.0	0.8
CH ₄	7.7	7.2	7.1	9.3	1.07	6.4	5.1
N ₂ O	3.2	3.2	3.2	3.8	4.2	3.0	2.7
F-gases	0.7	0.7	0.9	1.4	2.3	0.5	0.5
LULUCF	5.2	4.3	1.9	4.3	1.9	4.3	1.9
	47.1	50.9	50.6	56.5	64.4	47.1	32.6

Notes:

F-gases include hexafluorocarbons (HFC's), perfluorocarbons (PFC's) and sulphur hexafluoride (SF₆) from several sectors, mainly industry. CO₂-other includes CO₂ emissions from industrial processes; LULUCF refers to land use, land use change and forestry. Emissions from peat-lands are not included.

Policies Scenario. Thus, there is a large emissions gap between the Current Policies Scenario and the 450 ppm Scenario as deep cuts are needed to have a chance of stabilizing temperatures below 2°C.

The share of total global GHG emissions for non-OECD countries in 2010 was 65% (GCP, 2011). The 35% share of OECD is projected to decline by 2020 under the BAU scenario and may continue to decline in coming years. Energy-related CO₂ emissions of non-OECD countries may have to play a major role in reducing CO₂ emissions to be on a 450 ppm scenario trajectory (Fig. 3.1). The emission reduction share of non-OECD countries may have to be around 65% of the projected decline of 15 GtCO₂, based on the New Policies Scenario.



Depending on conditional and unconditional pledges and compliance rules, the gap between business-as-usual emissions (with no pledges implemented) and emissions consistent with a 66% chance to stay <2°C target is between 9 and

18 GtCO_{2-eq} (median 12GtCO_{2-eq}) (UNEP, 2011a). In theory, this gap can be reduced without major new technological breakthroughs by reducing emissions in the power, industry, transport (including aviation and marine), buildings, waste, forestry and agricultural sectors (summarized in sections 8.1 and 8.3).

Beyond the energy sector, a range of mitigation options are available for abatement of agricultural emissions, short-lived black carbon and organic aerosols, and emissions arising from deforestation and forest degradation (REDD+), particularly in developing countries (see chapter 7). Key mitigation opportunities include improved energy efficiency (chapter 4), renewable heat and power generation (chapter 5), transport options and urban systems (chapter 6), and agriculture and forest management (chapter 7) (IEA, 2011a; UNEP, 2011a).

It is thus feasible to reduce GHG emissions using the existing technologies to be on the 450 ppm scenario and potentially hold global warming to <2°C (IEA, 2011a; UNEP, 2011a; UNEP, 2011b). Non-OECD countries, which form the majority of GEF recipient countries, may have to play a critical role given their growing share of future global GHG emissions, and shift to a low carbon emission path.

The peaking of annual emissions should happen soon. Thus, there is a need to assist developing countries and EITs to assess various pathways that ensure economic development occurs in a synergistic way with low carbon development. The GEF can potentially play a critical role in assessing the potential to shift to a low carbon development path while supporting such a shift. The following chapters present mitigation opportunities in different sectors for the GEF to consider when formulating future strategies towards GEF-6.

⁷ In 2009, energy-related CO₂ emissions contributed 61% to total greenhouse-gas emissions.



CHAPTER 4

Energy efficiency technologies for mitigation in developing countries and economies in transition

A uniform conclusion in the vast majority of mitigation assessments (Riahi *et al.*, 2012; IEA 2011a; Edenhofer *et al.*, 2009; Bouwman *et al.*, 2005; Mitchell *et al.*, 2011) is that energy efficiency has a key role – “while there is no silver bullet, improved energy efficiency comes the closest to being one”⁸. Beyond its climate change mitigation benefits, improving energy efficiency has a critical role in contributing to many of the other strategic goals of nations, including improved energy security, a broad range of environmental benefits, poverty alleviation and improved consumer welfare, net employment and productivity gains, increased competitiveness, and reduced investment needs in energy infrastructure, while increasing the value of other capital stock. Furthermore, according to IEA (2011a), energy efficiency accounts for nearly 65% of the strategy that will keep us on a pathway to hold global warming at <2°C. Energy efficiency has always been, and will continue to be, a crucial opportunity for the GEF to support.

⁸ Originally stated by a senior BP official, in a keynote speech on climate change mitigation.

Improving efficiency is also the prime option for reaching ambitious climate goals. For instance, as Riahi *et al.* (2012) have demonstrated in the GEA (Global Energy Assessment), one of the most robust findings in the pathway analysis for how a low warming 2°C target can still be reached, is that lost opportunities in efficiency improvement make more controversial solutions necessary. While such goals can be reached through many pathways, approaches involving the highest level of improved efficiency are the least costly and the most flexible. Even targets under 2°C can be reached by employing more controversial options such as CCS and nuclear power, while pathways that compromise a push towards improved energy efficiency also have to rely on these options to reach such goals.

In this chapter, after a brief cross-sectoral review, the industrial, transport and building sectors are analyzed in detail. Even without including the consumption of electricity in these sectors, they are expected to provide an approximate 45% share of the total global greenhouse gas mitigation potential until 2020 (UNEP, 2011a).

4.1. Cross-cutting technologies and issues

Improving the efficiency of energy use⁹ involves a large number of activities (from heating and cooling to air travel to cement production). Each covers a broad range of technologies, with each one having energy-efficient options. This chapter presents a few opportunities that either account for a large quantity of energy use and associated mitigation potential¹⁰, or provide cost-effective energy savings and mitigation opportunities. These options are reviewed on a sectoral basis¹¹, largely from the perspective of developing countries. A few important mitigation opportunities and trends presented cut across sectors. The key findings relating to energy efficiency are as follows:

- i) Electric motor systems account for about 40% of the world's total electricity demand, and about 20 – 30% of this could be saved (i.e., up to 12% of total world electricity use) (IEA, 2011g). The IEA expects that widespread, harmonized, minimum efficiency performance standards for motor driven electricity systems, combined with regulatory measures for gears and transmissions are expected to save 5% of global electricity use by 2030.
- ii) Key mitigation opportunities are increasingly moving away from a focus on improvements in individual technologies to systemic optimization (Riahi *et al.*, 2012). This is mainly because:

- improvements in individual technologies are often near their thermodynamic or cost-effective limits; and
- recent improvements in information and communication technology (ICT) and its increasingly widespread use even in poor regions (such as mobile telephones).

4.2. Industry

The industrial sector's energy savings potential is estimated to be around 40 EJ by 2030, about a 30% reduction from a BAU scenario (Banerjee *et al.*, 2012). Approximately three-quarters of the sector's energy saving potential is located in developing countries where the estimated improvement potentials - between 30 and 35% - are higher than world-wide (Banerjee *et al.*, 2012). Due to the sector's diversity, the mitigation potential of different options varies with location. That being said, the most important elements of an effective industrial policy package are usually common: namely energy reduction targets, energy management systems, energy efficiency standards, and system optimization training (UNIDO, 2008 and 2011). Some of the key opportunities are as follows:

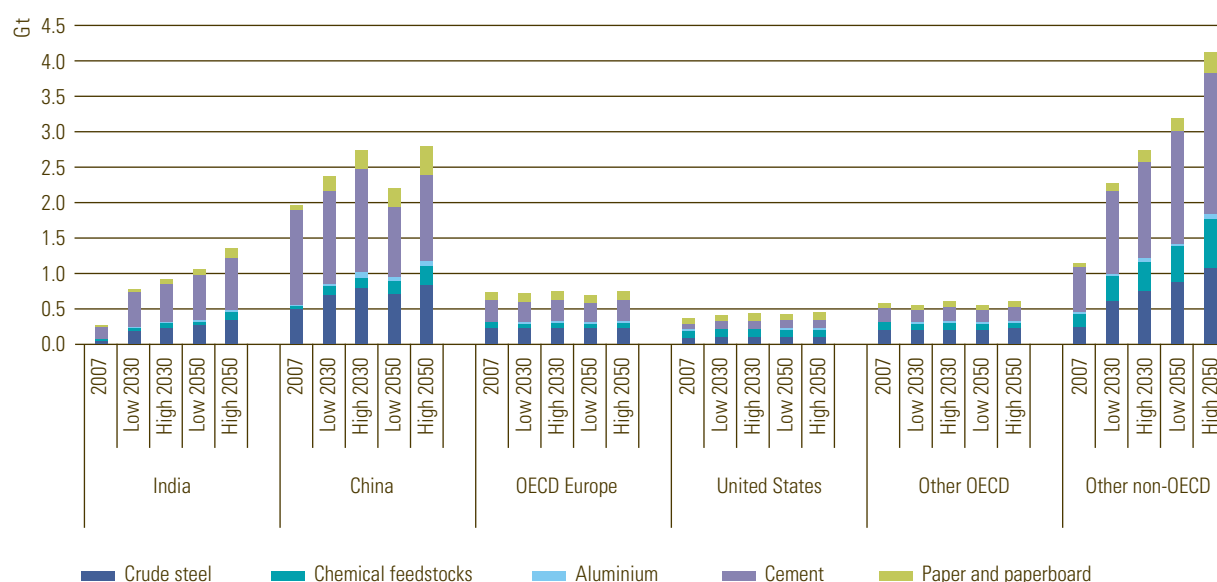
⁹ Improving the efficiency of energy supply and electricity generation is covered elsewhere.

¹⁰ The focus here is on energy use reduction potentials rather than GHG potentials because the latter highly depend on the carbon intensity of energy supply, and this is covered in Chapter 5.

¹¹ Sector-integrated renewable energy opportunities, such as biomass for transport, industry and buildings are discussed in Chapters 5 and 7.

- There are some generic and sector wide opportunities to avoid energy losses. National and international experiences widely agree that while improving the efficiency of components might yield minor gains in industry, **systemic optimization can result in more significant gains, up to 20–30% (GEA, 2012), with payback periods of less than two years (UNIDO, 2011).**
 - Motor systems account for about 60% of industrial electricity use (13.6 EJ/yr), and 20% of this energy could be saved by commercially available technologies and good engineering practices.
 - Compressed air systems are frequent targets of cost-effective improvement projects.
 - The efficiency of steam and process heat systems (accounting for 33 EJ/yr and 11 EJ/yr respectively) could be improved by 10-20%, by using, for example, excess steam for on-site power generation (Banerjee *et al.*, 2012).
 - In general, the recycling of materials, and hence the embedded energy, and the optimization of whole systems, offer profitable investment opportunities (Riahi *et al.*, 2012).
 - Energy-intensive industries (iron and steel, non-ferrous metals, mineral mining and processing, cement, chemicals and fertilizers, petroleum refining, pulp and paper) offer the largest opportunities as they have an 85% share of industrial direct energy consumption (Banerjee *et al.*, 2012). Therefore, any energy saving opportunities in these industries is especially important in developing countries, primarily for cement and steel production. China, for example, currently produces over 70 times as much cement per unit of GDP as the USA, and this trend will continue for decades in developing countries.
- Differences between CO₂ emissions in various energy scenarios vary by region, and can be larger than the differences between low and high demand values due to efficiency improvements (shown in Fig. 4.1). Examples include:
- the use of direct reduced iron in the steel industry (Banerjee *et al.*, 2012);
 - integrated fluid catalytic cracking in the chemical industry (Liu *et al.*, 2007); and
 - the blending of fly ash or other materials in the cement industry (Banerjee *et al.*, 2012).

FIGURE 4.1: Materials production by region in low- and high-demand scenarios (IEA, 2011h).





From a carbon savings perspective, the iron and steel and cement industries provide the largest potential. A breakdown by technology (Fig. 4.2) shows that energy efficiency is important mitigation option in iron and steel and cement industries (as well as for chemicals, pulp and paper and aluminum, not shown in Fig. 4.2) (IEA 2011g).

In spite of progressive achievements in all relevant technologies and processes, the energy intensity of manufacturing is not expected to decrease much

further (Banerjee *et al.*, 2012; UNIDO, 2011). As Riahi *et al.* (2012) stated, “the large gains will not come from [single technologies or] narrow process efficiency improvements but from the application of broader systems optimization strategies. The only way to cut energy consumption by industry more than marginally is to consume much less of the products of industry and to sharply increase the rate of product re-use, renovation, re-manufacturing and recycling.” In other words, the best option to significantly reduce industrial energy consumption by far is to avoid unnecessary production. Producing durable and repairable products, recycling and reusing, as well as dematerializing goods and services are among the most important options.

Regulations on warranty and durability, eco-design specifications, standardization of components and repair services, and recycling programs are relatively cheap and cost-effective instruments that limit material consumption without curtailing consumption itself. Some of the key mitigation opportunities in the industrial sector are listed in Table 4.1.

FIGURE 4.2a: Global direct emissions reduction by technology option in iron and steel

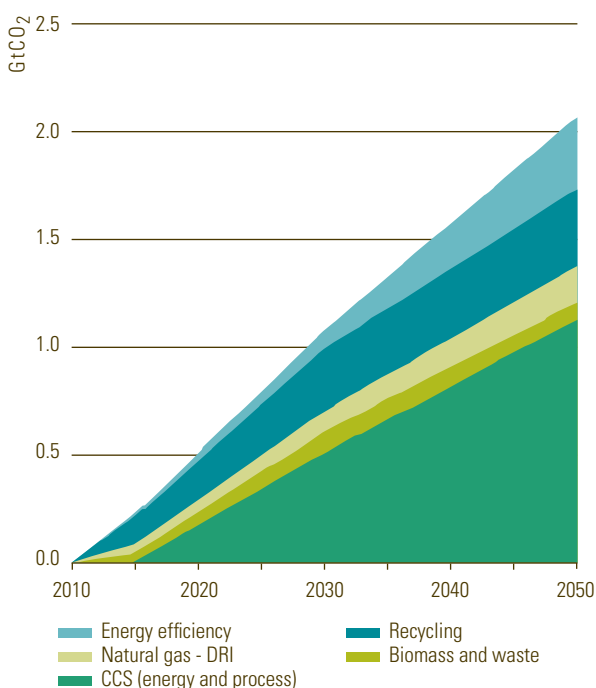


FIGURE 4.2b: Global direct emissions reduction by technology option in cement

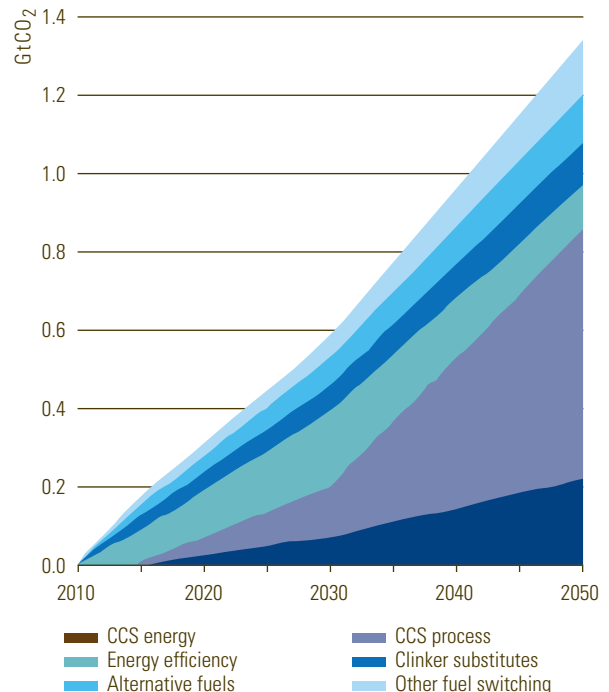


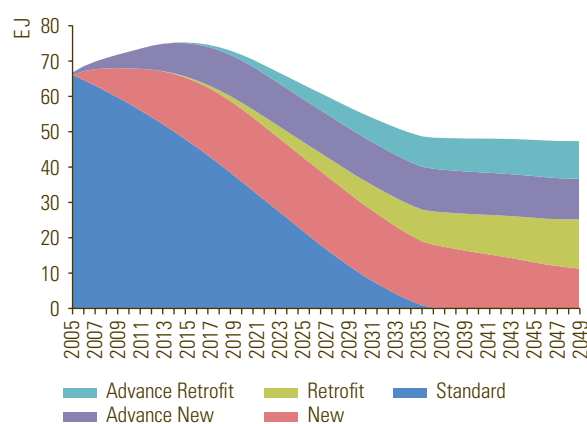
TABLE 4.1. Mitigation opportunities in the industrial sector.

	Mitigation option	Mitigation potential	Policy/regulatory/institutional/financial arrangements to promote the option
Avoid unnecessary consumption of products and raw materials	Consumption reduction; reuse; dematerialization and substitution; eco-design of products and services including durability; recycling.	High High High High	Recycling mandates and waste regulations; refuse collection pricing; eco-design specifications including durability; warranty regulations; standardization of components and repair services.
Improve efficiency in energy intensive industries	Energy savings in the - iron and steel industry: - cement industry: - chemical industry: - pulp and paper industry:	(Based on IEA, 2010a) 420 Mt 520 Mt 300 Mt 80 Mt	Benchmarking; auditing; recognition programs; tax and fiscal policies; carbon offset programs; demand-side management (UNIDO, 2008; UNIDO, 2011).
Improve systemic performance	System assessment and system optimization; benchmarking; energy management systems.	10-20% of the total energy consumption of industrial facilities	Energy management standards; target setting agreements; system optimization libraries; capacity building; national energy management programs.

Many industrial energy efficiency opportunities are extremely cost-effective: For instance, UNIDO (2011) found that most interventions examined in developing countries had an internal rate of return well over the market rates. Better use of infrastructure, pipe and insulation improvements, and waste reuse are the most profitable.

4.3. Buildings and appliances

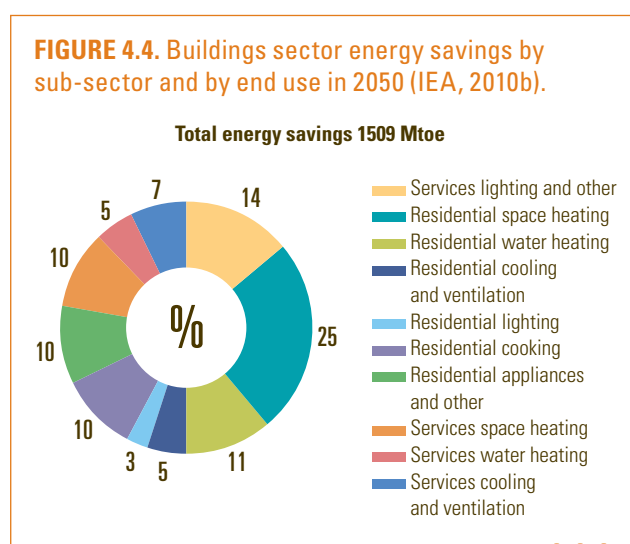
The building sector's share of total energy consumption is very high in developing countries. For instance, in India buildings are responsible for over half of all primary energy use (IEA 2010a). The sector's energy and carbon savings potentials are huge. Modeling results show that **global final thermal energy use for water and space heating can be reduced by 40-50% by 2050 as compared to 2005**, despite the over 120% increase in total floor area projected during the same period (Fig. 4.3).

FIGURE 4.3: Thermal energy use from 2005 to 2050, under the "deep" scenario (Urge-Vorsatz *et al.* 2012b).

Note: Due to the very different climatic, economic, and cultural conditions, the emission reduction potentials of countries and climatic zones vary considerably.

Well over half of global building energy use is for space heating and cooling, and if water heating is included, thermal energy use accounts for over two-thirds of building final energy use. Therefore, it is recommended that these end uses be the highest priority to be targeted. Space heating accounts for 40-50% of the savings in energy in the IEA ACT scenario in the commercial/residential sector by 2050 (IEA 2006a). Nevertheless, the use of appliances, information and communication technologies (ICT) and consumer electronics (CE) is increasing dynamically. In addition, lighting, appliances and air conditioning account for over half of the total CO₂ emissions reduction in the sector by 2050 in the ACT scenario. Different end-uses in energy saving potentials by 2050 have been projected (IEA 2010b) (Fig. 4.4). However, these global shares differ significantly by region due to the vast diversity in climatic, economic, and cultural conditions.

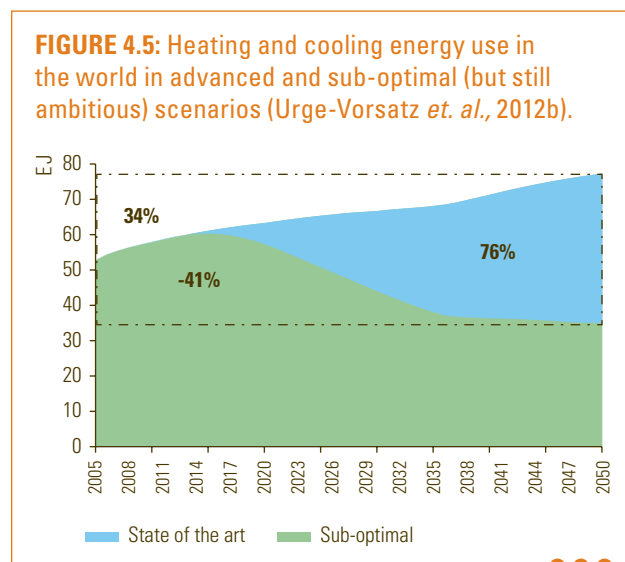
FIGURE 4.4. Buildings sector energy savings by sub-sector and by end use in 2050 (IEA, 2010b).



The sector is extremely diverse in end uses, technologies, alternatives and non-technological opportunities. Table 4.2 provides a systematic review of a selection of key opportunities.

In moderate and cold climates, it has become feasible and cost-effective¹², for both new buildings and retrofits¹³, to reduce heating energy needs by 70 – 90% compared to standard practice, while providing full comfort and uncompromised services. This is possible when buildings are considered as systems rather than as sums of individual components. This integrated design principle, together with advanced IT systems used for optimization, and the reliance on relevant vernacular design elements to reduce local climate-related loads, can yield major mitigation potentials. This is also the case in hot/warm and humid climates. However, significant amounts of energy (about 36 EJ or over 70% of 2005 total sectoral final energy) can be wasted if sub-optimal new construction and retrofit buildings, that can lock-in GHG emissions for decades, are allowed (Figure 4.5).

FIGURE 4.5: Heating and cooling energy use in the world in advanced and sub-optimal (but still ambitious) scenarios (Urge-Vorsatz *et. al.*, 2012b).



In the more prosperous regions of warm and tropical climate zones, cooling and dehumidification are the main concerns, as well as electricity supply for appliances. In these regions, a 50% reduction potential in cooling load is feasible through the use of cool roofs, vegetation and increased albedos (Akbari *et al.*, 2009).

¹² At less than 10% marginal cost (Schnieders and Hermelink, 2006)

¹³ The economics of retrofits tend to be less attractive than for new construction.

TABLE 4.2. Overview of key mitigation opportunities for developing countries and EITs in the building sector, with the size of the potential and most relevant policy options.

	Mitigation options	Mitigation potential	Applicability	Policy/regulatory/institutional/financial arrangements to promote the option	Reference
Avoid: reduce service demands	Smart metering	15 – 20% of household energy use.	More affluent population segments.	Mandatory smart metering	Ürge-Vorsatz et al., 2012a
Avoid: reduce load	Low energy buildings; passive houses; deep retrofits.	50-95% of current energy consumption in buildings.	Most regions, especially cold and moderate climates.	Building codes and standards; building certification; utility revenue decoupling.	Schnieders and Hermelink, 2006
Avoid: mitigate urban heat islands	White roofs; lighter surfaces; urban greening.	Up to 50% of cooling loads	Warm climates	Regulations; urban planning.	Akbari et al., 2009 Xu, et al., 2012
Shift: to non-fossil heat sources	Renewable solutions; heat pumps.	Appliances for 70% of water heating energy; high potentials for heating, cooling, power.	All regions (climate specific solutions).	Tax credits; Feed in tariffs; Quota systems;	Reid et al., 2010
Shift: to emerging technologies (further assessment needed)	Desiccant dehumidification; PV/T solar system; seasonal heat and cool storage:	Potentially high, yet unknown	Humid regions; all regions; moderate and cold regions;	R&D	
Shift/Improve: new stoves	Replace inefficient traditional cooking stoves	1-9 t CO ₂ /year per stove; 0.6-2.4 Gt/year total.	Primarily Africa, India, Latin America, and Asia	Scale up clean cookstove initiatives.	Ürge-Vorsatz et al., 2012a
Improve: lighting	Incandescent and mercury vapor lamps to be replaced by CFLs and LEDs; high-efficiency ballasts; fuel-based lighting to be replaced by solar-powered solid-state lighting; time switches, occupancy sensors; day lighting and dimming	0.7 Gt/year(very large emission reduction potentials in the case of fuel-based lighting~0,2 Gt/yr; above average savings potentials in residential lighting)	First priority: replace fuel based lighting; then: for all regions and building types.	Banning inefficient lighting equipment; energy performance or eco-design regulations; labeling (products) and certification (buildings, outdoors); sustainable lighting programs for the poor.	IEA, 2006b
Improve: heating and cooling equipment	High-efficiency boilers; heat pumps; solar thermal systems; thermal storage; CHP	Up to 2GtCO ₂ -eq reduction by 2050.	All regions; climate specific solutions.	Energy performance standards; labeling; maintenance; regulations, other regulations,	IEA, 2010c IEA, 2011g
Improve: appliances	Energy efficient appliances; optimized power management in ICT and CE improved durability	40-90% of appliances; energy use lowest lifecycle cost ICT and CE reduce its global energy use by 1/3 rd , BAT by over ½	all regions	Appliance standards, labeling programs, rebates/feebates. harmonized test procedures, eco-design regulations.	IEA, 2009b
Improve: water heating	Waste heat recovery (e.g. from drain water); improved technologies (e.g. tankless heaters; condensing boilers; solar systems; heat pumps.	30-40% of water heating energy needs; 20-80% of current needs	Heat recovery in cold regions, especially in commercial and multi-family buildings.	Labeling programs; tax credits; bans on inefficient heaters.	Sachs, Talbot, and Kaufman, 2011
Improve: district heating (where it still makes economic sense with very high efficiency buildings)	Increase CHP; reduce distribution losses; increase the efficiency of final energy use, such as meter-based billing; thermostatic valves; programmable thermostats.	Appliances, 20% in distribution; high in the production and consumption phase	EITs; Central and Eastern Europe; Asia	Appropriate cost allocation (i.e. make cogenerated heat cheaper); assistance with financing; best-practice programs; tax incentives; mandatory requirements or standards.	IEA, 2004

In all world regions, ICT and CE will play a major role in emissions mitigation. At present, these account for about 15% of global residential electricity use, but they are expected to grow from less than 50 TWh in 2012 to over 800 TWh in 2030 in non-OECD countries alone (IEA, 2009b). Using lowest life-cycle cost technologies could cut this by 30%, and today's best available technologies would increase the cuts by over half.

Appliance standards represent a powerful tool to drive the transition toward energy efficiency.

The effectiveness of these instruments has been widely proven, and further savings potentials are substantial (Ürge-Vorsatz et al., 2012a).

Lighting is undergoing a major transformation. By 2012, most OECD countries, as well as many non-OECD countries, will have introduced legislation to phase out incandescent lamps (IEA, 2010b). The GEF, together with many other multi-lateral institutions, has supported market transformation programs away from the incandescent lamp. The remaining developing country governments need assistance in introducing incandescent phase-out legislation, ideally as part of comprehensive appliance standards or eco-design regulations.

In addition to heating, cooling and lighting mitigation options, there are immediate, non-negotiable priorities with readily available solutions (including efficient and clean cookstoves, which have evolved significantly in the past few years, and now offer

many new innovative prototypes (Ürge-Vorsatz et al., 2012a). Efficient and clean cooking devices are essential to reduce indoor air pollution, black carbon emissions and their related health toll (Martin et al., 2011). Each advanced stove can avoid the equivalent of 1-9 t CO₂/year, so scaling up clean cookstove initiatives could not only save 2 million lives a year, but also reduce GHG emissions by 0.6-2.4 GtCO₂-eq a year (Ürge-Vorsatz et al., 2012a).

In addition to technological measures that reduce energy consumption during the life of a building, low-GHG construction materials and the reduction of the energy payback time of advanced equipment, are also key concerns (Ürge-Vorsatz et al., 2012a). Furthermore, urban planning can also have a significant effect on building energy performance; it determines shading, surface to volume ratios, the heat island effect, and opportunities for district heating/cooling systems, as well as cogeneration.

In the building sector, barriers play a critical role in the spread of efficient technologies. Regulatory instruments have proven to be most effective in removing or overcoming them. New standards and building codes need to set ambitious levels of energy efficiency in new buildings in order to avoid long-term lock-in.

A summary of key energy efficiency mitigation opportunities in the developing countries and EITs is listed in Table 4.3.

TABLE 4.3. Summary of key mitigation opportunities through energy efficiency in buildings, industry and transport in either developing countries, EITs, or both.

Applicability	Low cost and high mitigation potential	High cost and high mitigation potential	Socially relevant and energy access
Developing countries	White roofs, light surfaces	Urban greening; Very low energy commercial buildings (heat resistant design, shading, natural ventilation); Novel cooling systems.	Efficient, clean cookstoves
EITs	Thermostatic valves.	Very high performance new buildings (insulation, air tightness, heat recovery, solar gains). High-performance building retrofits.	Energy-efficient retrofits of social housing.
Both	Phase-out of incandescent lighting; Energy-efficient appliances; elimination of standby losses; Solar water heating; High-efficiency electric motors; High-efficiency two-wheelers; Industry energy management systems; Low-steam shipping; Energy-efficiency improvements in cement, steel, and chemical industries.	High-efficiency vehicles; Transport planning and management systems; Intermodal transport; Energy cascading (co-generation); Promotion of IT infrastructure enabling system optimization opportunities; Energy efficiency design.	Infrastructure and facilities enabling non-motorized and two-wheeled motorized transport.

4.4. Transport

The transportation sector's energy consumption (currently around 91 EJ/yr) is projected to increase substantially in the coming decades, especially in developing countries, as demand for personal mobility and freight grows significantly with increasing affluence. Minimizing energy use is crucial since the difference in transport-related CO₂ emissions between different future scenarios reaches 1.7-2.5 GtCO₂ by 2020 (UNEP, 2011d). Reducing demand, modal shift, and the efficiency enhancement of both individual vehicles and systems of transportation are essential.

Together with the systemic transformation brought on by demand reduction and shifting service modes, it is crucial to improve the efficiency of individual vehicles. Opportunities and priorities

can differ significantly depending on the transport mode, the type of vehicle used, and the geographic location. For road vehicles, new fuels and fuel efficiency standards for petroleum fuels are important. The improvement of several components of motorcycles, cars, trucks, and buses can also substantially increase the overall efficiency of the vehicle (California Energy Commission, 2011). In shipping, speed reduction and fleet planning are the biggest opportunities to reduce energy use and emissions (Ribeiro *et al.*, 2012). In the case of air and rail transport, a combination of several smaller steps (including technological, systemic, and management improvements) can achieve at least 2% annual energy efficiency improvement (Ribeiro *et al.*, 2012). Table 4.4 provides a systematic review of key mitigation opportunities in transport.

TABLE 4.4. Overview of key mitigation strategies in transport, with their mitigation potentials and key policy implications.

	Mitigation option	Mitigation potential	Policy/regulatory/institutional/financial arrangements to promote the option
Avoid: Excessive travel demands	- Preventing excessive demand - Urban planning: smart zoning with mixed use zones - E-services, telecommuting	- High - Medium	- Fuel pricing; provision of alternatives; taxes on externalities; - Zoning regulations; - Infrastructure; e-services.
Avoid: Too large vehicles	- Prevent the shift to larger vehicles	- High	- Feebate programs; car weight taxes.
Avoid: Unnecessary fuel consumption	- Better maintenance of vehicles	- Medium (10-20% of vehicle fuel consumption)	- Educational programs; regulations on regular vehicle maintenance.
Shift: Modal shifts	- Road and air freight to rail, shipping, and intermodal transport. - Air and road passenger transport to rail - Urban passenger transport to non-motorized transport; - Clean and efficient two-wheelers and public transport; - Bus rapid transport (+light rail transit)	- High - High - High - More than 50% (compared to LDVs)	- Provision of appropriate infrastructure and facilities for alternatives (road structures accommodating two-wheelers and walking, interconnectedness of modes, etc.). - Access restrictions - Usage proportional road fees
Shift/Improve: New fuels	- Hybrid and all-electric vehicles - Biofuels	- High (35-50% for two-wheelers in India) - High (e.g. in Brazil)	- NiMH or Li-ion battery programs to substitute lead-acid batteries. - Life-cycle assessment of fuels before use (Weinert <i>et al.</i>, 2008; Amjad <i>et al.</i>, 2011)
Improve: Road transport	- Increased fuel efficiency; - urban vehicles → minimal idling losses → integrated starter/generator systems; - regenerative braking → supply power to the vehicle's electrical system; - efficient two-wheelers; - road system planning and optimization.	- High - ~10% - ~10% - 10-20% (of individual vehicle consumption)	- Fuel efficiency standards + feebate programs; - Technological specifications inspection and maintenance programs.
Improve: Shipping	- Slow steaming (speed reduction); - fleet planning.	- ~30% - ~5-40% (of individual vehicle consumption).	- Mandatory speed limits; - capacity building.



The mitigation potential for the transport sector is presented in Chapter 6 together with related urban designs and infrastructure. Biofuels are covered in Chapter 5 under renewable energy.

4.5. Policy, institutional and regulatory options

In conclusion, the GEF should consider supporting *fewer individual (energy efficient) technologies*, and instead *focus on*

- a) the policies that ensure the broad proliferation of already proven technologies;
- b) systemic solutions and optimization as well as management opportunities; and
- c) examine the viability of supporting local ICT infrastructure options that can enable specific optimization opportunities or electronic alternatives to energy-using activities.

While there is a very broad array of technologies that offer large mitigation opportunities, many of them can be effectively promoted through single or simple overarching policies. A selection of key policies available to promote EE can be identified (Table 4.5). The GEF can effectively promote many cutting-edge mitigation options by supporting the introduction of these policies. While there is no silver bullet or one-size-fits-all solution from a policy perspective, the promotion of minimum efficiency performance standards (fuel economy for vehicles, appliance standards, building codes) is probably the most cost-effective policy with the highest potential and applicability in the majority of jurisdictions. Standards can capture a very large share of the available cost-effective potential at little cost and at significant societal net benefits.

4.6. Key mitigation options, leapfrogging opportunities and promising policies

In developing countries key mitigation opportunities occur through improved energy efficiency (Table 4.3). Leap-frogging opportunities include very high performance buildings (new and retrofit), novel and alternative cooling systems for commercial buildings (such as desiccant dehumidification), very high-efficiency appliances, and solar water heating. However, it is important to note that the most important leap-frogging interventions that the GEF can support will come from policy options since these can encompass several, if not many, key mitigation technologies. Policy leap-frogging such as through setting ubiquitous and ambitious appliance standards, building codes and fuel economy norms, introducing feebates, and proactive utility regulation, can provide both real mitigation leap-frogging opportunities as well as significant social and economic co-benefits. While there is a broad portfolio of promising policy opportunities, by far the largest mitigation potential can be unlocked through ubiquitous energy-efficiency regulations (appliance and fuel economy minimum efficiency performance standards, building codes, industry management systems standards, etc.).

TABLE 4.5. Summary of key policies available to promote energy efficiency most effectively for developing countries and EITs.

Broad policies	Specific policies
Policies and regulations	Eco-design regulations (including minimum efficiency performance standards, fuel economy and appliance standards, building codes, durability specifications). Waste/recycling regulations. Energy management system standards. Energy-efficiency obligations and quotas. Utility regulations decoupling profits from sales. Road speed limits; car access restrictions.
Financial incentives and taxes	Non-subsidized energy pricing (where feasible). Proportional road fees. Traffic congestion charges. Vehicle "feebates".
Voluntary actions	Public leadership programs. Public procurement policies. Negotiated industry agreements.
Information-based program	Information disclosure mandates/programs (requirements for certification and labeling, auditing, training). Capacity building and training programs. Benchmarking (industry).
Institutional	Setting industry sectoral targets. Promotion of energy service companies (ESCOs). Demand-side management programs.



CHAPTER 5

Renewable energy technologies, policies and measures

"NEW AND RENEWABLE SOURCES OF ENERGY STAND AT THE CENTER OF GLOBAL EFFORTS TO INDUCE A PARADIGM SHIFT TOWARDS GREEN ECONOMIES, POVERTY ERADICATION AND, ULTIMATELY, SUSTAINABLE DEVELOPMENT."

UN Secretary General, 22 August, 2011.

The transition away from fossil fuels to renewable energy (RE) systems has begun. RE systems have the potential to meet the ever growing demand for the full range of future energy services; however, in many countries it will take time before they can reach full effect. RE currently meets over 13% of global primary energy demand, although almost half of this share comes from traditional biomass, a resource which is not always truly renewable and sustainable. There is real potential, over the next two to three decades, to displace a significant share of the large volumes of traditional biomass currently being consumed by 2 to 3 billion people for cooking and heating, with more modern energy systems. The increased deployment of improved, more energy efficient designs of cookstoves would reduce biomass demand, as would the continuing uptake of biogas, ethanol gels, DME (di-methyl ether that can substitute for liquefied petroleum gas), and RE electricity. The resulting efficient, clean energy services and improved health could benefit subsistence farmers, rural communities and peri-urban inhabitants. In 2009 alone, approximately \$9.1 billion was invested to provide 20 million people with access to electricity and 7 million people with advanced cookstoves (IEA, 2011a, Chapter 13).

RE can be used either *directly* to provide energy supplies on-site or *indirectly* as a result of being integrated into an existing conventional energy supply system, such as an electricity network or a natural gas grid (Figure 5.1). In addition, isolated communities, especially in EIT and developing countries, can benefit from the development of RE projects feeding into local mini-networks. Such “leapfrogging technologies” are often preferable to the long wait most rural regions experience, while high cost government investment extends the main transmission and distribution lines to their communities.

This chapter outlines promising RE technologies and their costs and mitigation potentials, and also discusses policy measures that, in many countries, could result in more rapid deployment. A summary of the costs, barriers and mitigation potentials for each of the main RE technologies by 2030 and 2050 is given in Table 5.1.

5.1. Modern renewable energy technologies

The Global Energy Assessment analysis (GEA, 2012) indicated that a significant increase in RE technologies is technically feasible, would give high overall benefits, and is a relatively low cost energy transition development route. Global investment in RE projects could reach \$7 trillion in the next 20 years

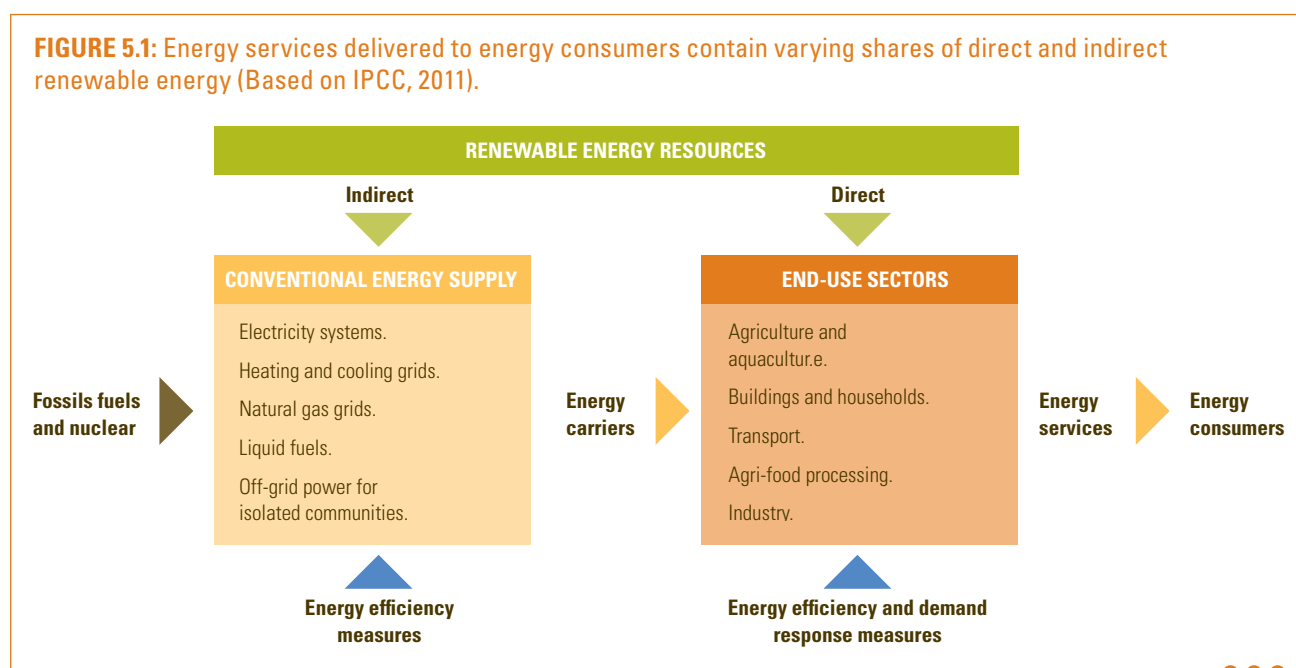
to meet the rapidly growing demand (Bloomberg New Energy Finance, 2011). The \$195 billion that was invested in RE in 2010 could more than double in 2030 with over half of the total investment mostly shared equally between Europe, North America and China, and one quarter by developing countries.

5.1.1. Centralized renewable electricity systems

RE resources provided 19.5% of total electricity generation in 2009 using 1253 GW of installed capacity, accounting for 25.3% of total global capacity (IPCC, 2011). Large hydro plants make up approximately 80% of this capacity. Most of the non-hydro RE power plant technologies are variable and have relatively low capacity factors;¹⁴ in 2009 they generated approximately 250 GW, which accounts for only 3% of total global electricity. This is projected to increase 5 or 10 fold by 2035, (Bloomberg New Energy Finance, 2011; IPCC, 2011; Deng *et al.*, 2011; Krewitt *et al.*, 2009) although government incentives, at around \$66 billion per year, may have to triple to drive this increase (IEA, 2011b).

Over the years, electricity supply systems have been developed to give high reliability whilst managing demand loads that vary over seconds, days, weeks, and years. These systems are complex but continuously evolving so as to accommodate increasing shares of variable generation from wind, wave and solar PV. In the future, electricity grids will need to

FIGURE 5.1: Energy services delivered to energy consumers contain varying shares of direct and indirect renewable energy (Based on IPCC, 2011).



¹⁴ Average output of a power plant as a percentage of its maximum output (the rated capacity in kW or MW).

become more flexible as a result of additional investment in advanced sensing and control capabilities, accurate and timely forecasting of weather and load, demand-side response management, and energy storage. Recent experience has confirmed that approximately 20% of variable RE generation can be accommodated in most existing energy systems for a relatively low additional cost (GEA, 2012; IPCC, 2011 Chapter 8). Having a portfolio of RE technologies can accommodate higher shares of RE electricity in the mix. In addition, Concentrating Solar Power (CSP) plants, currently at the demonstration stage with several plants operating or under construction (IPCC, 2011; IEA, 2010c), have the ability to store solar heat, and hence enable electricity to be dispatched even after sunset or on cloudy days.

5.1.2. Decentralized renewable energy systems

Decentralized RE-based power generation systems, including solar PV, biomass combustion and gasification, biogas production, and wind power at the 5 to 500 kW scale, have real potential to meet the energy needs of rural communities, particularly in Africa, South Asia, South-east Asia and South America. These RE systems can replace imported fossil fuel based sources and promote self-reliance of communities, as well as create local jobs and improve health.

In 2010, overall investment in small-scale RE projects increased 91% from the previous year to reach around \$60 billion (UNEP, 2011b). Local city, town and rural district governments are often in a position to successfully encourage development of decentralized RE projects by their residents and businesses (IEA, 2009a). In many remote rural areas of developing countries and EITs, these distributed generation and mini-grids, as leapfrog technologies, have good potential to provide energy services whilst avoiding high investment costs for transmission line infrastructure.

Distributed electricity systems, also known as “smart-grids” or “digital energy systems”, are not yet clearly defined in the sector, but in essence can be either large- or small-scale systems (including generation plants, transmission and distribution lines, end-use appliances and the end-users) that have been optimized by using digital electronic

controls. The system communicates continuously along the entire electricity delivery infrastructure in order to integrate a range of energy carriers, and maintain system balance at all times (Schock *et al.*, 2012). Distributed heat energy supplies (such as solar thermal water heating) and load-demand response services (such as cool-stores and domestic refrigerators) are key components.

Several small-scale demonstration smart-grids have been implemented, and the private sector (including large corporations such as Siemens¹⁵, Intel, Vodafone and Mitsubishi) has shown a growing interest. International standards for key components, such as time-of-use meters, are under development.¹⁶ Battery electric two-, three- and four-wheel vehicles are rapidly gaining in popularity, and can also act as a storage component of RE systems. However, they only give significant GHG mitigation potential per km travelled when RE electricity is available for off-peak recharging.

5.1.3. Heating and cooling

The application of solar thermal, biomass, direct geothermal or ground source heat pumps to provide heat for hot water, building space or high-temperature industrial processes is well understood. **The immediate large-scale, low cost mitigation opportunity is through the promotion and deployment of solar water heaters for domestic and industrial uses, thereby displacing electricity or traditional biomass.**

Local unavailability of biomass can be overcome, for instance, by sustainably producing biomass feedstock in degraded lands and by using wood pellets, 13 Mt of which were exported worldwide in 2009 (Chum *et al.*, 2011), rising to 15.6 Mt in 2010 (REN21, 2012) with continued projected growth. The use of solar water heating continues to increase, with “combi-systems” (that heat and cool both building space and water) growing in popularity. Large-scale solar thermal systems for district heating schemes, with seasonal storage, are being developed. In addition, several million ground source heat pumps, that provide both heating and cooling services, are successfully operating in countries such as Sweden; however, most need subsidies in order to compete with conventional natural gas heating systems.

¹⁵ See for example <http://www.energy.siemens.com/hq/en/energy-topics/smart-grid/>

¹⁶ See for example http://www.sisconet.com/cimservices.htm?gclid=CMG--oOo_qwCFQ2DpAodGRspRw

Solar air-conditioning and cooling technologies (absorption and desiccation) continue to be developed and improved upon, their advantage being that cooling demand is often linked with periods of high solar radiation levels (IEA, 2009a). Cost reductions are needed before these technologies can be widely deployed. In addition, the use of natural waterways for district cooling systems has been well proven, and has high potential for replication (Sims *et al.*, 2011).

5.1.4. Biofuels for transport

Recent growth in 1st-generation liquid biofuel production from sugar, starch and oil crops has leveled off, partly due to concerns over sustainable biomass production, including competition for land and water with food and fiber production, loss of biodiversity and loss of livelihoods of small land-holders. In order to reach high levels of sustainability, advanced biofuel pathways can use new feed-stock types, such as algae and ligno-cellulosic materials, that can be produced in locations not in direct competition with food production, and that do not adversely impact on natural habitats. Continuing opportunities for advanced biofuels exist by improving process efficiency (for example, by using more effective enzymes) and transport logistics and storage; also by decreasing the costs of ethanol distillation, and adding value through commercializing the various co-products.

Co-products such as dried distiller grains with solubles from corn, high protein meals from oilseed crops, and glycerin, can provide additional revenue, as can using process residues such as bagasse and lignin for heat and electricity generation.

Multi-product bio-refineries could produce a wider variety of co-products to enhance the economics of the overall process (IEA, 2011c).

Advanced “drop-in” fuels, such as iso-butanol or synthetic aviation kerosene, can be derived through a number of possible conversion routes, such as hydrotreatment of vegetable oils (HVO), which is being commercialized in Singapore, Finland and elsewhere (Bacovsky *et al.*, 2010). Other routes have reached the demonstration stage with full-scale commercial production becoming possible towards the end of this decade, at current oil prices (Chum *et al.*, 2011). Given that drop-in fuels

are relatively energy dense and can handle rigorous operating conditions, several private and public sector consortia are evaluating their potential use for marine fuels and aviation purposes (ICAO, 2011).

Advanced biofuels have lower life-cycle emissions than 1st-generation biofuels where forest and wood processing wastes or crop residues are used.

Where purpose-grown energy crops are produced as feedstocks, obtaining high yields (in terms of GJ/ha) with low inputs (irrigation, fertilizers, agri-chemicals etc.) should be the aim. Life-cycle GHG emissions of advanced biofuels are uncertain; in extreme cases they can exceed those of petroleum fuels, when indirect land-use change is included.

Infrastructure development for biofuels is relatively low cost needing a parallel delivery, storage and dispensing system similar to the existing infrastructure for petroleum fuels. The advent of drop-in biofuels will reduce the need for developing new infrastructure.



IEA (2010a) estimated that if a modest 10% of global biomass residues could be made available for the biochemical production of ethanol, it could yield about 155 billion liters of gasoline equivalent (lge), or approximately half the total biofuel demand in 2030, which is about 4.1% of the projected transport fuel demand.

The costs of producing 1st-generation biofuels are largely based on the costs of the feedstocks which typically make up 45-70% of the overall production costs. The capital costs of advanced biofuel production systems are generally higher than those of 1st-generation; therefore, feedstocks typically make up a slightly lower proportion of the total production costs. However, the costs of these non-food feedstocks are less susceptible to variability than are food commodity dependent feedstocks (such as corn, sugarcane, rapeseed oil and palm oil).

At present, without government subsidies or other supporting policies, bioethanol and biodiesel are not always cost-competitive with gasoline or diesel, even at oil prices of around \$80-100/bbl. The exceptions are markets where production costs are low, notably for Brazilian sugar cane ethanol (IEA, 2011c). Various advanced biofuel production routes have progressed technically and may be able to compete at oil prices around \$60-70/bbl (\$0.33-0.44/lge) (Chum *et al.*, 2011). With further R&D investment, by 2020 they could fully compete depending on future oil and carbon prices.

Biomethane (produced from scrubbed biogas or landfill gas) can also be used as a transport fuel similar to compressed natural gas with which it can be blended or used directly in engines, both in vehicles or stationary applications. In addition, liquefied natural gas has future potential as a fuel for heavy duty and marine vehicles.

For the GEF to fund commercial initiatives, 1st generation biofuel projects would need to be based on sustainably produced biomass that do not lead to losses of biodiversity and local livelihoods, and result in net GHG reductions on a life-cycle basis. Advanced biofuels are probably not yet sufficiently proven or well advanced commercially to receive support other than for demonstration plants, with the possible exception of hydrogenated vegetable oils (HVO).

5.2. Opportunities for developing countries and economies in transition

For many developing countries, goals to improve social and economic development can outweigh concerns of GHG emission increases, though having sustained and secure supplies of energy in the future will be indispensable for sustainable development. The availability of a reliable and affordable supply of RE in low-GDP countries can be an essential component for the provision of much needed basic energy services, particularly in rural areas. In locations where good RE resources exist, residents, businesses and municipalities have the opportunity to install technologies to provide heating, cooling, electricity and liquid or gaseous fuels.

Present funding to improve energy access is mainly targeted at extending centralized electricity grids, but these do not usually reach the poorest households (IEA, 2011a). Therefore, additional funding to support energy access initiatives is also required at the local level. This includes building up technical and financial capacities to stimulate RE project development. Low income levels, unequal income distribution, inequitable distribution of modern forms of energy, a lack of financial resources to build the necessary infrastructure, weak institutional and legal frameworks, and a lack of political commitment, all contribute to limiting access to modern energy systems for hundreds of millions. **For remote rural areas and small islands, the “smart-grid” concept could possibly be deployed as a leapfrogging technology to displace diesel-powered generation and provide electricity access, using mini-grids and RE resources** (5.1.2). Many examples already exist, such as on the small Pacific Island of Tokelau.¹⁷

Approximately 40% of the world's population are in need of universal access to electricity and cleaner cooking methods using alternative fuels and/or advanced biomass stove designs. Recent analysis (GEA, 2012) found that universal access to modern energy services can be achieved by 2030 if new institutions and national enabling mechanisms are developed. These include appropriate subsidies and financing to help people living below the poverty line embark on a pathway towards sustainable development.

¹⁷ <http://www.bbc.co.uk/news/science-environment-16109449>

The IEA (2011a) estimated that providing universal basic energy access by 2030 would increase global electricity generation by 2.5%. If this energy was based mainly on fossil fuel-based thermal generation, global primary demand would increase by 0.8% and GHG emissions by 0.7%. Utilizing RE sources can achieve energy access and security as well as be climate neutral, and may even lead to other benefits – such as reduced local air pollution – due to the avoidance of black carbon (a short-lived climate forcers consisting of dangerous particulates from incomplete combustion and unburned hydrocarbons – see Chapter 7).

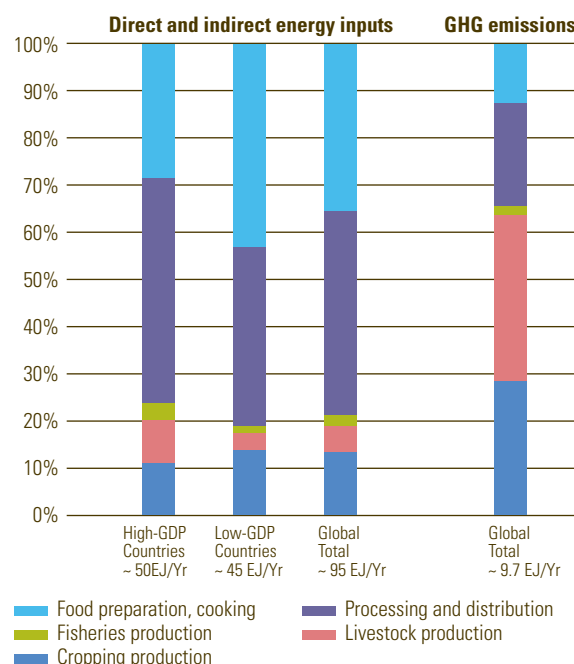
The IEA (2011a) estimated that, from now until 2030, investments of around \$1 trillion will be required to achieve energy access goals. This will involve increasing the present average investment level of around \$50 bn/yr by over five times, although the GEA (2012) analysis showed global investments of around \$40 bn/yr would suffice to achieve this goal. Either projection would be a relatively small fraction of the total energy infrastructural investments anticipated over this period. As households gain access to modern energy services, it is expected that this will support improved standards of living and thereby the ability to pay for these energy services.

The correlation between food prices and oil/gas prices and the future dependence of the agri-food supply chain on fossil fuels is of growing concern as demand for food continues to increase (FAO, 2011b). Decoupling the food supply chain from fossil fuel inputs can be achieved by increasingly displacing them with RE resources by such means as integrated food-energy systems (IFES) on farms and at food processing companies. Many successful examples of IFES exist globally at both large and small scales.

5.2.1. Energy-smart food

The global agri-food supply chain is responsible for approximately 32% of global energy end-use demand. In low-GDP countries, a greater share of energy is used for cooking, while in high-GDP countries, more energy is used for processing and distribution (transport) (Fig. 5.2). Roughly 22% of total global greenhouse gas emissions result from the food supply sector, yet one third of all the food we produce fails to be consumed, meaning much energy, water and use of land is wasted (Gustavsson *et al.*, 2011).

FIGURE 5.2: Indicative shares of final energy consumption for high- and low-GDP countries, the global total and total associated global GHG emissions for the food sector (FAO, 2011b).



Food demand is projected to rise by 70% by 2050 due to increased population and increased demand for protein. The current high dependence on fossil fuel inputs for food production, processing, distribution, storage and preparation is a significant concern.

Furthermore, it is increasingly recognized that food supply systems are a major contributor to GHG emissions, as they presently represent over 20% of total global GHG emissions (FAO, 2011b). This share can be reduced by the uptake of improved energy efficiency measures along the entire food supply chain using such technologies as reduced tillage, irrigation monitoring, improved refrigeration, more efficient transport systems, and also by increasing the deployment of RE systems on farms and in food processing plants. It can also be supported by lowering methane emissions from ruminants and rice paddy fields, by reducing nitrous oxide emissions through precision nitrogenous fertilizer application and animal waste management (Smith *et al.*, 2008), and by eliminating the various sources of food losses.

Food commodity prices appear to be closely linked with oil and gas prices (FAO, 2011b). The costs of decoupling the food supply chain from fossil fuel dependence vary widely for any given situation, but it is well understood that improving energy efficiency offers many cost reduction

opportunities. These include tractor operation, irrigation scheduling, engine maintenance, electric motor drive selection, cool room insulation, etc. The costs of renewable energy systems on farms and in food processing plants depend on local resources, the scale of energy demand, and capital investment costs. Wide ranges exist (IPCC, 2011), but when all co-benefits are taken into account there is high potential to provide improved energy security and lower fossil fuel dependence.

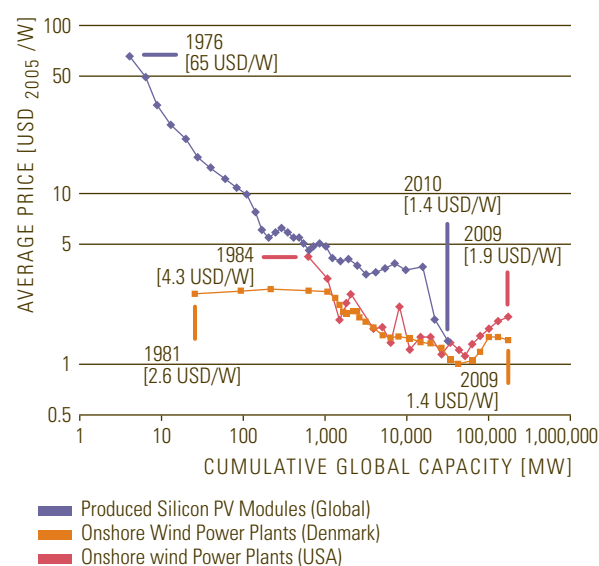
It is possible to reduce the current dependence of food production on high fossil fuel demands in developing countries through increased renewable energy uptake and energy efficiency improvements throughout the entire food supply chain, particularly when combined with food production and land use. Sustainable development could also be an additional outcome. Reducing food waste through improved optimization throughout the food supply system, including during consumption, is necessary. Although food waste at the point of consumption is less of an issue for low-income end-users in developing countries, food loss in storage accounts for over 30% of waste. Promoting a low-meat diet (avoiding red meats in particular) and avoidance of obesity are policy measures that should be considered. A meal with equal nutritional value, eaten by residents of low-GDP countries as opposed to high-GDP countries, has a carbon footprint with a difference as high as a factor of four. This clearly implies that substantial opportunities exist to lower GHG diets in high-GDP countries (Harvey, 2010).

5.3. Cost effectiveness of renewable energy technologies in the short term (2020/2030)

Renewable energy technologies are often not competitive with equivalent fossil fuel technologies when supplying wholesale energy markets such as district heating schemes, centralized electricity grids and transport fuels. However, where sources are particularly good or projects are developed to directly supply local markets, RE can often compete with the present retail prices for electricity, heat or petroleum fuels. Domestic wood burners, building-integrated solar PV, and biomethane-powered vehicle fuels are examples of cost-competitive local energy markets. There has been an attempt to categorize RE technologies into low/high cost and low/high mitigation potential (Table 5.1). However, there are many exceptions due to variations in specific

local resources and costs. For example, as delivered diesel fuel prices have increased, the continued cost reductions in solar PV technologies (Fig. 5.3) has made them competitive with small diesel-powered generation plants in remote areas.

FIGURE 5.3: Long-term price trend for solar and wind (IPCC, 2011).



In 2010, the total investment in new wind projects was \$94.7 bn, up 30% from 2009 (UNEP, 2011b). That year, investment in solar, including small-scale projects, was \$86 bn, up 52% from the previous year. Approximately \$11 billion was invested in biomass and waste-to-energy projects, with biofuels at \$5.5 bn, down dramatically from the 2006 boom when \$20.4 bn was invested in new plants. The overall growth in RE projects has been partly achieved through the introduction of new policies and institutional mechanisms that reduce risks and increase the attractiveness of early, sustained, capital-intensive investments.

The GEA (2012) analysis indicated that in order to replace old plants while meeting increasing energy demands, global investments in energy supply systems will have to increase to between USD 1.7 and 2.2 trillion/yr in the coming decades, with about US\$300–550 billion of that required for demand-side efficiency. The present investment level of approximately USD 1.3 trillion dollars/year represents about 2% of current world GDP. This could increase to 3% by 2050, based on projected economic growth. The challenge will be to attract investment flows for RE projects, given that they are predominantly up-front capital costs giving low short-term rates of return. However, in the long-term, they have low fuel and operating costs.

TABLE 5.1. Assessment of costs (shown for electricity (kWh) or as primary energy (GJ)), cost reduction potential by 2050, technical potential, deployment potential and mitigation potential by 2050 for a range of RE electricity and heat systems (based on IEA, 2011a, c, d and Fishedick et al., 2011)

Technology Present levels of supply	Present levelized cost range of energy (USD/kWh). Future cost reduction potential by 2050	Resource variability. Dispatchability for power generation. Typical capacity factor	Mitigation potential by 2050	Technical potential. Deployment potential by 2050. Mitigation potential in 2050 from displacing coal and gas plant mix. Most suitable regions.
ELECTRICITY				
Bioenergy, landfill gas, biogas, CHP, municipal solid waste. 0.3 PWh (~2EJ incl. CHP heat)	\$0.02-38 /kWh Low. Key components are mature (e.g. boilers, steam turbines, CHP) so limited scope for cost reductions. More competitive opportunities are likely as markets grow and more efficient biomass fuel supply chains develop. Good potential for further decentralized and centralized deployment especially in EITs. Medium-high. Gasification of biomass, mainly small-scale, has reached around 1.4 GW th installed capacity (Kirkels and Verbong, 2011). Only a few large-scale demonstration power plants in operation.	Seasonal. Good dispatchability. Capacity factor 50-90%	High. Biogas and landfill gas projects can reduce non-CO2 GHG emissions. Use of agricultural and forest residues are near carbon neutral but soil nutrient recycling needs consideration. Energy crop production gives possible direct and indirect GHG emissions resulting from land use change.	50-150 EJ 1.4-1.8 PWh (5 – 7 EJ); 800-1000 Mt CO ₂ Africa, South America.
Solar PV 0.026 PWh	\$0.08-0.90 /kWh High. Numerous small-scale installations and several grid-connected plants operating at the 1-5 MW scale. Module costs continue to decline, but labor for installation costs can remain a constraint in OECD countries as can energy storage. Can compete in remote locations or with retail power prices. Could become more competitive with wholesale electricity prices in an increasing number of regions and countries by 2030.	Minutes. Low dispatchability. Capacity factor 10-25%. Needs energy storage.	Low – medium. Small share of generation mix but growing slowly. Displacing small diesel-powered generation in rural areas is promising. Building-integrated PV good, especially if displacing coal-fired power generation.	>1200 EJ 1-1.5 PWh (3.6-5.4 EJ) 600-900 Mt CO ₂ Lower latitude regions
CSP 1.5 GW (mainly demonstrations)	\$0.20-0.50 /kWh High. Heat at >150°C converted to electricity via heat engine and generator. Cost, demand for water, and land competition can be constraints. Future opportunities especially in low latitudes with high solar radiation levels (e.g. North Africa). With technology improvements, potential investment cost reductions could be 30-40% in the next decade. Investment costs expected to decrease with scale-up (IEA, 2010c).	Hours. Partially dispatchable if coupled with thermal storage. Capacity factor 35-40%.	Medium. Deployment just starting so limited by 2030. Dependent on electricity generation source being displaced	>300 EJ 0.5-1 PWh (1.8 – 3.6 EJ) 300-600Mt CO ₂ Deserts and high latitudes



Technology Present levels of supply	Present levelized cost range of energy (USD/kWh). Future cost reduction potential by 2050	Resource variability. Dispatchability for power generation. Typical capacity factor	Mitigation potential by 2050	Technical potential. Deployment potential by 2050. Mitigation potential in 2050 from displacing coal and gas plant mix. Most suitable regions.
Geothermal Steam: 0.07 PWh Enhanced geothermal systems (EGS): 0 PWh	\$0.04-17 /kWh (EGS, uncertain) Low-Medium. Hydrothermal, high temperature reservoirs mature. Costs may continue to fall with more learning experience. Costs of binary plants using lower-temperature resources could become fully competitive by 2030 (IEA, 2011d). High. EGS being demonstrated as heat transfer mechanisms. Could be widely deployed but constraints of drilling costs and possible small localized earthquakes. Future cost reductions likely but uncertain.	Years. Good dispatchability. Usually baseload. Capacity factor 60-90%	Low-medium. Some CO ₂ can be released during drilling and heat extraction. Deployment of hydrothermal limited to locations where natural resource exists (Goldstein <i>et al.</i> , 2011).	20-40 PWh: EGS, 110-1000 EJ 1-2 PWh 3.6-7.2 EJ): EGS, uncertain 600-1200 Mt CO₂: EGS, uncertain Hydrothermal limited by steam resource. EGS: most places
Hydropower Large: 3.2 PWh <10MW: <0.1 PWh	\$0.02-14 /kWh Low. Supplies around 20% of global electricity (IEA, 2011a) with potential to expand, but limited by site locations and social and environmental impacts from damming rivers. Enables increasing shares of variable RE systems to be better integrated since output can be ramped up and down rapidly. Installing more efficient turbines can be a more cost-effective option than construction of new plants (IEA, 2010a). Medium. Small run-of-river projects (<10 MW) have good potential for cost reductions as do low-head systems under development.	Reservoir: Days to seasonal Good dispatchability. Peaking power potential. Capacity factor 30-80%. Run-of-river: Hours to seasonal. Partial dispatchability. Capacity factor 20-95%.	High. Wide deployment potential at centralized and decentralized locations. Low GHG life-cycle emissions except for reservoirs in warmer regions where methane emissions can possibly result from decaying flooded vegetation.	14-15 PWh; [<10 MW scale: 1-2PWh] 5-7 PWh (18-25EJ) [<10 MW scale: <1 PWh] 3000-4000 Mt CO₂: [<10 M scale: 200-300 Mt CO ₂] Africa, Asia, South America.
Ocean energy Tidal range: 0.5 GW Currents: 0 Wave: 0 OTEC: 0	\$12-32 /kWh (uncertain) High. Pre-commercial stage, (except 240 MW tidal barrage at La Rance, France and Sihwa, S Korea). Several devices demonstrated with mixed results (Lewis <i>et al.</i> , 2011). Devices built to withstand extreme conditions tend to be high cost. Investment and maintenance costs could decline as experience is gained.	Tidal range: Hours to days Ocean currents: Hours - days. Wave: Minutes Low dispatchability Capacity factors 20-30%	Low. Rate of deployment hard to predict but only slow progress to date.	Tidal <1TW: Currents 0.5-1EJ Wave 10-30 EJ: OTEC >100 EJ Unavailable Unavailable Currents: Europe, SE Asia, South America. Wave: Worldwide
Wind On-shore: 0.25 PWh Off-shore: 0.05PWh	\$0.04-23 /kWh Low. Mature. Grid-connected increasing in number and individual capacity with lower price per installed Watt (Fig. 5.3) and improved reliability (Wiser <i>et al.</i> , 2011). Developments moving off-shore due to landscape objections in spite of higher installation and maintenance costs. Medium. Small turbines off-grid less mature and need storage.	Minutes Low dispatchability. Typical capacity factor 20-40% on-shore and 30-45% off-shore but can reach 50% on good sites.	High. Recent rapid growth rate likely to continue.	On-: 20-125 PWh Off-: 4 -35 PWh On-: 6 -12 PWh (21-42 EJ) Off-: 1-4 PWh (3.6 – 14 EJ) On-: 3500-8000 Mt CO₂ Off-: 600- 3000 Mt CO₂ Worldwide



TABLE 5.1.

Technology Present levels of supply	Present levelized cost range of energy (USD/kWh). Future cost reduction potential by 2050	Resource variability. Dispatchability for power generation. Typical capacity factor	Mitigation potential by 2050	Technical potential. Deployment potential by 2050. Mitigation potential in 2050 from displacing coal and gas plant mix. Most suitable regions.
HEAT				
Modern bioenergy, biogas 3.3 EJ	\$2 - 80 /GJ Low. Cost reduction potential limited, other than in markets with growing capacities that could stimulate larger-scale equipment and more competitive biomass supply chains (IEA, 2011b). During the market development phase, capital cost reductions of around 25% are predicted. Cheaper domestic cook stove designs improving. Future fuel cost reductions likely including DME and ethanol gels. Biogas at small- and medium-scales mature but opportunity for cost reductions for operation and maintenance.	Seasonal. Availability varies with resource. Solid biomass residues cheap and easy to store. Animal dung and human wastes for biogas limited volumes.	High. Good potential for increased deployment at large/medium scales. Avoidance of unsustainable firewood supply for traditional woody biomass from deforestation.	200 – 300 EJ 20-40 EJ 1500-4000 Mt CO₂ Worldwide
Solar thermal 0.6 EJ (180 GWth)	\$5 - 200 /GJ Medium. Up-front capital costs for solar water heaters higher than for electric or gas water heaters, but average annual lifetime cost can be considerably lower.	Daily. Some form of back-up heat source usually required	Medium. Good deployment potential but limited GHG savings per unit.	>1500 EJ 2-3 EJ 200-300 Mt CO₂ Worldwide
Geothermal Steam and ground source heat pumps 0.45 EJ EGS: 0 EJ	\$10-80 /GJ High. Competitive where high, continuous heat demand exists such as district heating or for some local heat supply (such as heated greenhouses) (IEA, 2011d). Ground source heat pumps gaining greater market share. Cost reductions likely especially for drilling of bores.	Years. Reliable source.	Medium. Increased deployment likely but presently constrained in some regions by costs.	100-300 EJ EGS: 10-300 EJ 5-10 EJ EGS: 5-50 EJ 400-1000 Mt CO₂ EGS: 400-5000 Mt CO ₂ EGS and heat pumps: worldwide
TRANSPORT				
Biofuels 3.1 EJ (90 bn l)	\$3 - 50 /GJ (~\$0.15 – 2.5 /l) High. Mature 1 st generation biofuels (except sugarcane ethanol) not competitive without support at oil prices <\$100/bbl. Novel advanced processes offer scope for cost reductions through improvements in efficiency and product yield. May compete better with gasoline, diesel and 1 st generation biofuels between 2030 and 2040 (IEA, 2011c, Section 8.1).	Seasonal. Biofuel production from crops varies with prevailing conditions. Ligno-cellulosic feedstocks from residues less variable.	Low to medium. Varies with indirect and direct emissions as a result of land use changes. Competition with food and fiber crops could be a constraint.	~100 EJ 10-30 EJ 600-3000 Mt CO₂ Worldwide

PWh - Watthour*10¹⁵.

EGS - enhanced geothermal systems.

OTEC - ocean thermal energy conversion

Mitigation potentials are indicative only, varying widely with the mix of coal and gas plants displaced and scale and type of technology.

5.4. Policy, institutional and regulatory options for promoting renewable energy

There is a need for an integrated approach to ensure both universal and clean energy for sustainable development. Coordinating energy policies with policies from other sectors could lead to mutual support. Policies relating to agriculture, rural development, industry, buildings, urbanization, transport, health, environment, climate, and energy security can all be linked with RE deployment policies. The use of appropriate policy instruments and institutions can help foster a rapid diffusion and scale-up of advanced RE technologies in all sectors in order to meet the multiple present and future societal challenges related to energy.

The development of new state and national policies could eliminate fossil fuel subsidies (\$409 bn in 2010; IEA, 2011a chapter 14). These policies could also encourage the internalization of the economic externalities resulting from fossil fuel use as well as reduce RE costs by encouraging technology uptake. Renewable energy subsidies for biofuels and RE electricity amounted to \$66 bn in 2010. These subsidies may decline per unit of energy due to government austerity measures, and a lower need for subsidies should electricity and transport fuel prices continue to increase, hence making RE energy more competitive. Feed-in-tariffs (FITs) tend to result in greater uptake and be more cost-effective than tradable RE certificate schemes. However, as a result of recent austerity measures many states and countries are reviewing their overall costs to support FITs, with a tendency toward reducing these subsidies (REN 21, 2011; REN21, 2012). The average differences between various economic support systems tend to be smaller than the average differences between countries that have variations in their overall policy packages (IEA, 2011b). Having a broad policy package that includes RE and its various co-benefits is therefore recommended.

5.5. Conclusions

Renewable energy systems are simple and easily adoptable, and the global RE industry is growing rapidly. Using agricultural land and waterways for both food production and energy generation, for instance, is feasible wherever good RE resources are available. Innovative schemes regarding institutional arrangements are required when several types of partners (landowners, utilities, developers, municipalities etc.) are involved.

By 2050, the global RE shares of primary energy could increase to between 30 and 75%, and in some regions it could exceed 90% (GEA, 2012; IPCC, 2011). The main challenges to RE deployment are cost reductions, commercial scale-ups, and integrating RE into present and future energy supply systems. With careful policy development, RE can provide multiple benefits including employment, energy security, improved human health, and reduced environmental impacts such as through climate change mitigation. These co-benefits justify the rapid deployment of RE.

International mechanisms, such as the CDM and GEF project support, provide opportunities to develop a broad range of RE technologies and encourage international co-operation to bring new technologies to market. Developing countries with good RE resources could benefit from further collaboration with countries that could help provide the funding, capacity building, and technology transfer needed to develop these resources. These objectives are included in the proposed UNFCCC Green Climate Fund (GCF). Care is needed to ensure that low-GDP countries willing to host RE projects funded by high-GDP countries benefit from sustainable development and economic growth, but without dependency on permanent funding.

Mobilization of finance necessary for deploying RE technologies, particularly in emerging and developing countries, could be encouraged by the GEF, GCF, multilateral banks, and national governments, by giving higher priority to the RE sector (IEA, 2011b).

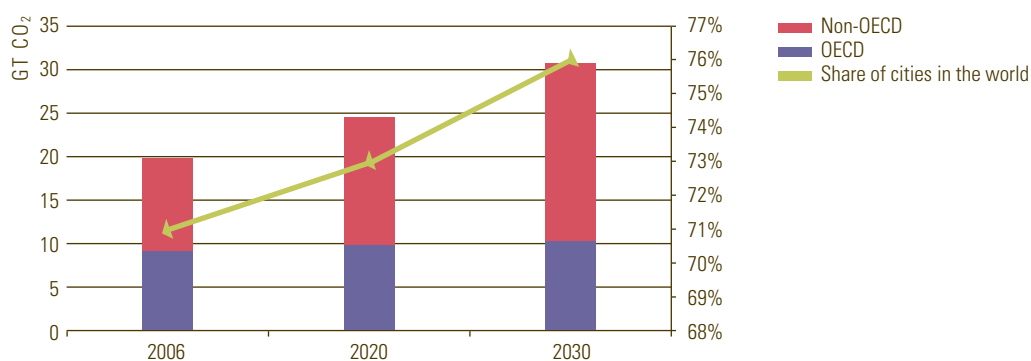


CHAPTER 6

Urban systems and infrastructure: technologies, policies and tools for mitigation

Urban areas, which are driven by the concentrated energy services required for lighting, heating and cooling, appliance use, electronics use, and mobility are responsible for large shares of global GHG emissions. In 2006, energy use in cities produced 71% of global energy-related CO₂ emissions, with an expected increase to 76% in 2030 (Fig. 6.1) (IEA, 2008). In the IEA Reference Scenario, non-OECD countries produce 89% of CO₂-emissions growth in cities and are expected to account for two-thirds of the global CO₂ emissions in 2030, up from 53% in 2006 (IEA, 2008).

FIGURE 6.1: Energy related CO₂ emissions in cities by region in a business as usual scenario (IEA, 2008).

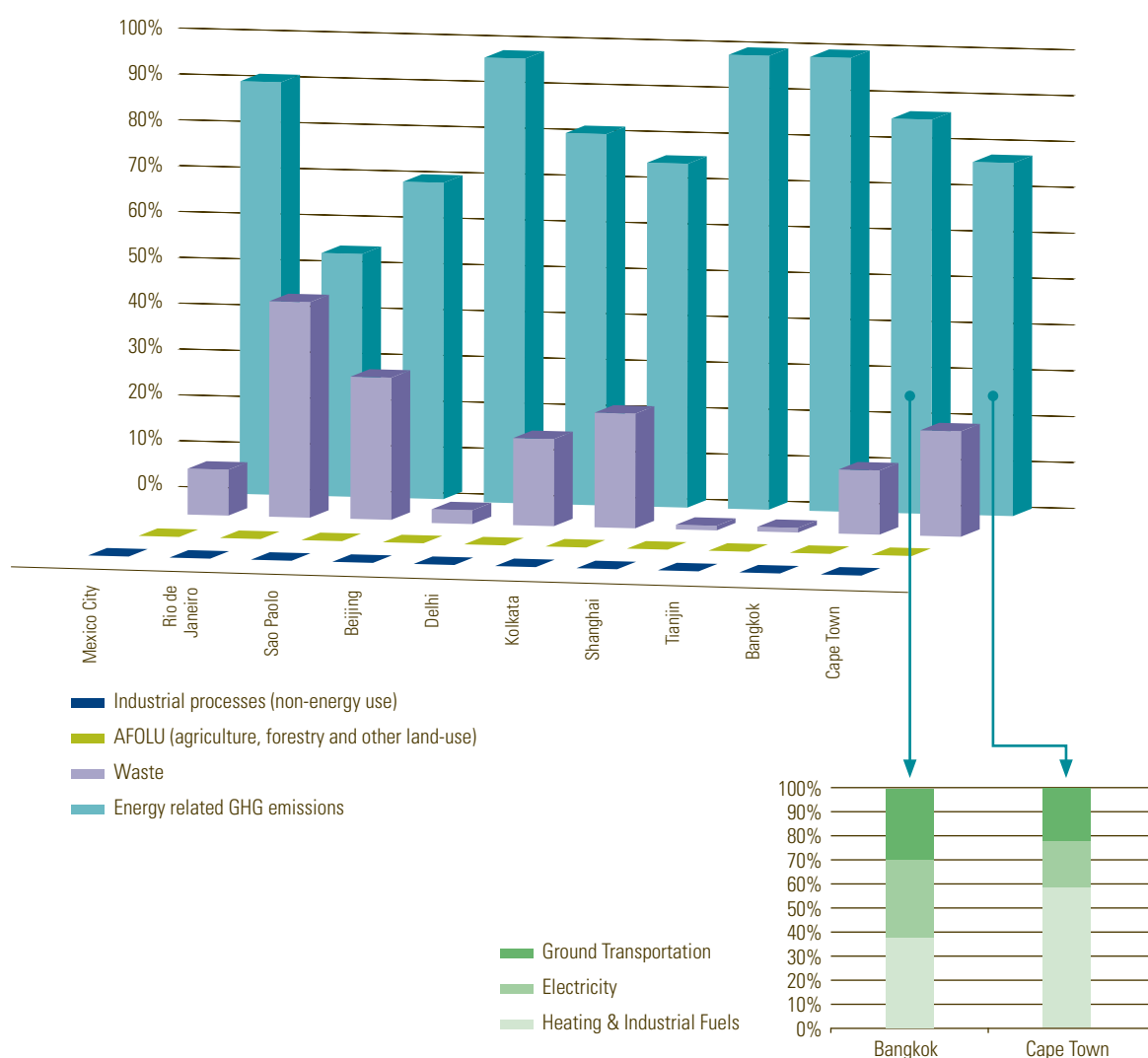


Acceleration of urbanization will predominantly occur in Asia and Africa. Urban areas concentrate people, goods, capital investments, infrastructure and knowledge, and are thus core engines of national economies. Whereas OECD countries, Latin America and the Caribbean already have levels of urbanization between 70% and 82%, Africa and Asia are presently at 40% which is expected to increase to 60% by 2050. On a global level, urbanization is expected to rise from 50.5% of total population in 2010 to 67% in 2050, when 6.25 billion people will be living in urban areas (UN, 2012).

In the absence of an open, global protocol compatible with UNFCCC guidelines for quantifying GHG emissions attributed to urban areas, several

assessment methodologies have been developed and are in use. However, multiple non-standardized methodologies complicate comparison of results of GHG emission assessments in urban areas¹⁸. An inventory of several studies analyzing GHG emissions in 44 cities, 10 of which are in non-OECD countries, allows for a rough analysis of GHG emissions (Fig. 6.2). **Energy related GHG emissions are largely responsible for total emissions in urban areas.** For example, among energy related GHG emissions in Bangkok and Cape Town, the shares per sector differ on the basis of current electricity production technologies, heating degree days and urban population density, with transportation energy use being inversely correlated to the latter (Kennedy *et al.*, 2009b).

FIGURE 6.2: GHG emissions in 10 cities per sector (analysis based on Kennedy *et al.*, 2009a)



¹⁸ In particular, the definition of boundaries and scopes, and cross-boundary emissions such as those embodied in materials, food, and fuel consumed in cities, allow for differences in assessment of GHG emissions attributable to urban areas. As a consequence, data illustrating shares of GHG emitting sectors in urban systems are scarce.

6.1. Mitigation technologies, policies and tools in urban and transport systems

On an urban scale, climate change policy responses (such as EE, Chapter 4 and RE, Chapter 5) can be designed and implemented through the governance opportunities that cities offer, particularly in the key urban sectors of transport, land use zoning, buildings, energy, waste, water, and food/carbon sequestration. Table 6.1 summarizes potential mitigation technologies classified according to their scale of engagement. The strategies with higher scales of engagement generally entail higher investments and produce higher GHG reductions (Kennedy, 2009c).

In addition to individual technological solutions, cities can offer additional leverage (chapters 4 and 5) via their role as energy consumers, their

use of strategic urban planning, and their unique role in a number of key sectors. Cities also have the ability to combine policies that target separate technologies in order to enhance their effectiveness. Additional opportunities for the transport sector exist through the so called “Avoid-Shift-Improve” approach (Bellagio Declaration, 2009¹⁹):

- **Avoid** the need to travel by adjusting how cities are designed;
- Support modal **shifts** to more environmentally efficient forms of transport such as public transport, walking or cycling; and
- **Improve** energy efficiency of motorized transport by improving vehicle and fuel technology in public transport (UNEP, 2011d).

TABLE 6.1. Mitigation technologies, level of engagement and related costs and GHG emission reduction potential (Adjusted from Kennedy, 2009c).

	Low cost GHG emission reduction low Minor engagement	Medium cost GHG emission reduction medium Medium engagement	High cost GHG emission reduction high Major engagement
Transportation / Land use zoning	High occupancy vehicle lanes; smart commute; car-pool networks; car share Natural gas vehicles (e.g. municipal buses) Bus rapid transit On road bike lanes; bike share	Financial penalties for auto use (e.g. tolls, congestion charges) Incentives for use of low-emission vehicles Light rail transit Segregated bike lanes	Pedestrianization of city centers Infrastructure for plug-in-hybrid vehicles Subways Bicycle highways
Buildings	Building energy retrofits Green roofs Energy star buildings	Improved building operations Renewable electricity (PV) or renewable heating/cooling (solar hot water, geothermal, biomass, ground source heat pumps) technologies	Demolition and reconstruction with high energy efficiency green buildings
Energy		District energy systems Borehole or aquifer thermal storage	Combined heat and power plans
Solid waste	Landfill methane capture Vacuum collection of solid waste	Solid waste gasification	Increased recycling Greening supply chains
Water / waste water	Reduced demand through low-flush toilets or low-flow shower heads	Reduced demand through grey water systems	Anaerobic waste water treatment plants
Food / Carbon sequestration	Planting of urban forestry	Residential scale urban agriculture (in CO ₂ enriched greenhouses)	Industrial scale urban agriculture (in CO ₂ enriched greenhouses)

¹⁹ <http://www.sutp.org/bellagio-declaration/>

Electricity from renewable energy systems can be used in electric rail systems; hydrogen fuel cell vehicles can use hydrogen produced from RE; biofuels can be used in public transport, fleet vehicles, or blended in retail service stations (IEA, 2009a). Sustainable low-carbon transport policies also improve local air quality, reduce congestion, improve travel time, and increase the offerings of transport services (GEF-STAP, 2010).

Modal shifts²⁰ have considerable potential to reduce or moderate the growth of transport-related GHG emissions. For example, **air and road** transport can be shifted **to rail, water or intermodal** transport. In cities, careful planning of road systems and the development of infrastructure and facilities for **non-motorized²¹ and public transport** can reduce demand growth for light duty vehicle (LDV) use. A possible way to moderate this would be through congestion charges in busy urban areas. In rapidly developing cities it is essential to promote urban development that enables safe non-motorized and two-wheeled transport (Schipper et al., 2008). To **discourage car ownership and unnecessary use**, car taxes, fees and the improvement of safe and comfortable alternative public transport options are necessary. The shift to smaller, lighter and more efficient vehicles can be facilitated by **feebate programs** (i.e. rebates for small, light and efficient vehicles; fees for large, heavy and inefficient ones) (Greene, 2010; Schipper, 2007).

Cities usually rely on energy sources beyond their boundaries. However, distributed small-scale energy technologies have the potential to reduce fossil fuel consumption on an urban scale. Cities and regions can help create stronger markets for renewable energy and energy efficient products through many levels such as:

- selective public purchasing,
- integrating environmental targets in transportation and planning,
- retrofitting programs or increasing the share of renewable sources in energy supplies, e.g. through local utilities.

One challenge in creating sustainable urban areas is how to combine technology solutions in the energy domain and physical sectors, such as buildings and transport, with broader development issues related

to water, food and waste. Many people, particularly in less developed regions, do not have a secure food supply, and their access to clean water, sanitation and modern sources of energy are limited. **Creating synergies between urban energy system management and other urban policy goals will require systematic, multi-sectoral strategic plans that implement policy packages that enhance each other's effectiveness** (OECD, 2010).

There is a connection between waste, food and energy where combined strategies lead to co-benefits. Therefore, in less developed regions, the extensive role of food production in cities themselves could be fostered, given that the "food footprint" of a city is typically significant. This should be combined with waste reduction, increased recycling and environmentally friendly treatment of unavoidable waste: for example, burning waste in energy efficient central incinerators, or generating electricity from harvested landfill methane (OECD, 2010).

6.2. Mitigation potential and cost effectiveness of urban and transport systems

Determining the GHG emission mitigation effect of interventions on an urban scale is a highly complicated exercise due to the difficulty in isolating the urban areas from other multi-sectoral approaches, and the interrelations of urban policies with sectors outside the urban area.

Analyses of costs versus GHG savings showed a relatively consistent match between increased emissions savings and higher investments. An analysis of costs and annual GHG savings from several case studies where technological and urban design solutions to reduce GHG emissions were deployed demonstrated that, for a wide range of policy interventions, the low cost measures like a bike campaign, producing biogas from sewage water or promoting solar air heating, were relatively easy to implement, but also resulted in low CO₂ savings (Kennedy, 2009c). In contrast, high cost measures such as introducing light rail transit, congestion charging or an incineration based CHP plant, showed the highest annual CO₂ savings.

²⁰ In developing countries, this often implies the *prevention* of a larger shift towards LDV use.

²¹ Also for motorized two-wheelers

6.3. Policy, institutional and regulatory options for urban systems

Climate change policy responses on an urban scale can be designed and implemented by local authorities, given that they hold significant governance influence in key urban sectors such as transport, buildings, water, waste, food and land use zoning (Table 6.2).

The key barriers to climate integrated urban policies are a lack of appropriate climate governance institutions or necessary authority, insufficient expertise, and the absence of funding or central government support (OECD, 2010). Governance institutions have the ability to conduct policy evaluations and measure progress. Climate priorities should be integrated in each stage of the urban policy making process, starting from agenda setting, to policy design, implementation and policy evaluation. Financial issues could partially be solved by finding ways to create additional revenue, or by introducing local fiscal instruments and incentives

or fees and charges. However, in many non-OECD urban areas, the financial capacity of the local population to bear additional charges will be limited.

In their **leadership role**, local governments can set targets for GHG emission reductions. Although usually not binding, such targets can act as a signal to create confidence within the local business community. Depending on the powers of local governments, they can have significant influence in introducing regulations to curb CO₂ emissions or to adapt to climate change impacts. In their **service provision role**, particularly in the transportation, water, electricity, public housing, and waste management domains, etc., local governments can influence the development and delivery of urban services. In their **enabling role**, local governments can facilitate voluntary action or engage in public-private partnerships that would accelerate developments or the delivery of enabling services. In their **consuming role**, local administrations can limit their own energy consumption and CO₂ emissions in, for example, public buildings and public transport.

TABLE 6.2. Governance opportunities of local authorities, institutional and regulatory options and examples (modified from IEA, 2009a).

	Potential role in promoting mitigation or GHG emission reduction in urban systems	Options	Examples
Leadership role	Target setting	Overall targets Sector specific targets	GHG emission reductions by a certain year that can then serve as the basis for an integrated policy package of measures in energy efficiency and renewable energy for the key urban sectors of transport, buildings, waste, water and food.
Authoritative role	Regulations Fiscal measures	Urban planning Building regulations Standards and mandates Tax reductions	Regulations over relevant policy areas such as building codes, urban transport, land use and waste: planning regulations prescribing building density or building orientation, building regulations prescribing energy efficiency or renewable energy, taxes on fossil fuel use, local transport fuel blending requirements.
Provision of urban services (e.g. transportation, water, electricity, public housing, waste management etc.)	Financial incentive schemes Fiscal measures	Capital grants, Operating grants Soft loans, loan guarantees Tax credits	Capital grants for low-carbon technology, operating grants for renewable technologies, exemptions from (local) eco-taxes, lower car parking charges.
Enabling role	Guidance	Education schemes, promotion campaigns Training	Providing technical assistance, labeling of appliances, financial advice, training and education programs in schools and universities.
Consuming role	Voluntary actions	Voluntary municipal operations Voluntary agreements	Limiting municipal energy consumption and CO ₂ emissions e.g. in public buildings and public transport, voluntary agreements between municipality and local building developers.



CHAPTER 7

New technologies with large mitigation potential and risks

No single sector or technology alone will be sufficient to achieve a transformational shift to a low carbon development path, or to stabilize atmospheric GHG concentrations at levels that ensure global mean temperatures remain below 2°C. It will be necessary to explore all technologies, even those that offer high mitigation potential but which bring with them risks or uncertainties. Several of the new and emerging mitigation technologies outlined in this chapter are still unproven or associated with risks. They are therefore controversial either in terms of their scientific merit, technical potential or socio-economic implications.

Costs are very difficult to assess for those technologies that do not have full-scale commercial examples in place, and for those with as yet unquantified risks. Whether or not the world will need these technologies in order to achieve a transformational shift to a low carbon development pathway will be seen in the coming years. Irrespective of perceived costs, these technologies warrant further evaluation given that they may offer high mitigation potential in achieving deep emission cuts. They may also possibly lead to immediate GHG emission reductions, if needed. The role that the GEF and other international funding organizations could play in promoting and supporting such technologies varies, and careful consideration is recommended given these technologies' early stage of development and the potential risks they encompass. A brief review of these technologies is presented in this chapter. The mitigation options considered are i) short-lived carbon forcing (including black carbon), ii) AFOLU/REDD+, iii) geoengineering, iv) carbon dioxide capture and storage (CCS), and v) nuclear.

7.1. Short-lived climate forcing

Black carbon (BC) is the product of incomplete combustion of fossil fuels, wood and other biomass. The term “black” refers to the fact that these particles absorb visible light. This absorption leads to a disturbance of the planetary radiation balance and eventually contributes to global warming. Black carbon is mixed with organic carbon (OC), which is also a product of the combustion process and reflects sunlight much more strongly than it absorbs it – thus having a net cooling effect. Calculating the overall climate forcing effect is therefore complex. A high BC to BC+OC ratio means a predominantly absorbing aerosol that will contribute to warming. A low BC to BC+OC ratio means a predominantly scattering aerosol that will contribute to cooling. The ratio depends on the emission source: close to 1:1 in the case of emissions from diesel engines; much smaller in the case of, for example, wood combustion.

During the past one hundred years, global concentration of BC aerosols has undoubtedly increased. It is, however, uncertain by how much, given that biomass burning and resulting BC emissions also occurred in pre-industrial times. Even though BC is relatively short-lived, and its global average ground level concentration is presently only 0.1 microgram/m³ (compared to 760 microgram/m³ of CO₂), its positive radiative forcing due to absorption might be equivalent of up to half that of CO₂ concentrations.

Status of the technology

Many technologies that seek to reduce BC emissions have been successfully demonstrated, while others are still in the developmental phase. Mitigation solutions include:

- creating diesel particle filters for on-road and off-road vehicles;
- banning high emitting on- and off-road diesel vehicles;
- improving engine maintenance and frequency;
- replacing coal by coal briquettes or biomass in cooking and heating stoves;
- introducing clean-cooking biomass stoves in developing countries;
- replacing traditional brick kilns with vertical shaft and Hoffman kilns; and
- banning open-field burning in the agriculture and forest sectors.

Risks and uncertainties

The warming effect of BC and the compensating cooling effect of OC create ambiguity concerning the net effect of mitigation measures on global warming. There is also uncertainty and a lack of understanding on how clouds, which have multiple effects on climate, are influenced by BC and OC. The uncertainty in global impacts are particularly large for the measures concerning biomass cook stoves and open burning of biomass.

Mitigation potential

The precise impact of black carbon on the climate system is not fully understood. Jones *et al.* (2011) suggested that BC accounted for a global warming of about 0.2 +/- 0.1° C from 1950-1999. Shindell and Faluvegi (2009), using the regional patterns in observations and the regional responses to aerosol forcing, found a global impact of ~0.35 +/- 0.25° C during the 20th century. Jacobson (2010) observed that fossil fuel BC and OC emissions contributed 0.3 to 0.5°C, while BC+OC from both fossil fuel and residential biomass combustion contributed 0.4 to 0.7°C.

Scientific evidence and new analyses demonstrate that controlling BC particles and tropospheric ozone through the rapid implementation of proven emission reduction measures, would have immediate and multiple benefits for human well-being. “Full implementation of the identified measures would reduce future global warming by 0.5°C (0.2–0.7°C range) and if the measures were to be implemented by 2030, they could halve the potential increase in global temperature projected for 2050 compared to a reference scenario based on current policies and energy and fuel projections” (UNEP 2011e). Reducing BC and tropospheric ozone will have health and food production co-benefits. The full implementation of control measures could avoid 0.7–4.6 million premature deaths and reduce the loss of 30–140Mt (1–4%) of the global production of maize, rice, soybean and wheat crops each year.

In 2005, the total global anthropogenic BC emissions were ~5460 Mt/yr, with associated OC emissions at 13,800 Mt/yr. Since residential and commercial combustion also emit high amounts of OC with BC emissions, it is a poor choice for mitigating global warming (although other benefits of mitigating health and agriculture risks remain). An exception is when these emissions take place near Arctic or glacial regions.

CONCLUSION

In the short-term, the mitigation of black carbon can deliver significant climate benefits, along with health and agriculture co-benefits. However, focusing on BC mitigation should not postpone the existing need to mitigate long-lived GHGs. Rather, it must be viewed as a complementary strategy. The GEF could support mitigation of short-lived climate forcers for their relatively low cost and their multiple environmental and social benefits.

7.2. AFOLU/REDD+

The UNFCCC considers the reduction of emissions from deforestation and forest degradation (REDD+) an important mechanism to mitigating climate change. The Bali Action Plan (UNFCCC, 2008) included REDD for developing countries. It also included the role of conservation, sustainable management of forests (SMF), and the enhancement of forest carbon stocks. Thus, REDD has since been referred to as REDD-Plus (REDD+). A work program on methodological and policy issues relating to REDD+ was also launched in Bali under UNFCCC. The Cancun Agreement on the REDD+ mechanism could pave the way for designing and implementing REDD+ activities that assist countries experiencing large-scale deforestation and forest degradation. The IPCC's initial inventory guidelines for LULUCF included land use, land-use change and forestry. These guidelines have been expanded to AFOLU (agriculture, forest and other land uses). AFOLU includes all land use sectors including methane and N₂O emissions from livestock and rice production.

Status of the technology

The key elements in implementing REDD+ are: defining the scope and scale of REDD+ activities; defining the drivers of deforestation; assessing environmental and social safeguards; financing REDD; identifying methodological issues; monitoring, reporting and verifying (MRV) emission reductions; and establishing references for emission levels.

- The Cancun decision in 2010 made reference to the drivers of deforestation and requested developing countries to address these drivers as well as forest degradation.
- Annex I of the Cancun Agreement included guidelines on how REDD+ should be implemented. It also included safeguards concerning the rights of indigenous peoples and local communities, and the conservation of natural forests and biodiversity.
- The Cancun agreement provided a phased approach to the development of MRV and capacity building. However, MRV modalities remain largely unclear.
- The Durban (2011) decision provided the opportunity for elaboration of sub-national forest reference levels (FRL) as an interim measure while transitioning to national FRL. It further suggested that FRL should be developed using the most recently adopted IPCC Guidelines.

Mitigation potential

The mitigation potential of avoiding deforestation was estimated to be 0.2 to 0.6 GtCO₂/yr at a low cost of <US\$ 20/tCO₂, reaching 0.9 to 4.5 GtCO₂/yr at a cost of <US\$ 100 /tCO₂, largely in tropical countries (IPCC, 2007b).

Costs

The financing of REDD+ projects remains uncertain due to a lack of clarity on the use of market or non-market approaches for funding REDD+ actions. The Eliasch (2008) review estimated that the finance required to halve emissions from the forest sector by 2030 could be around \$17-30 billion per year.

Risks and uncertainties

The availability of a large supply of potentially low cost carbon credits could provide an opportunity for the developed world to purchase REDD+ credits. There are complexities and uncertainties with respect to defining, and therefore estimating carbon stocks from activities under the REDD+ such as forest degradation, sustainable management of forests and forest conservation. There are also uncertainties involved in setting reference emission levels, and the methods could potentially lead to the over- or under-estimation of baseline emissions. There is a risk that the rights of indigenous peoples and local communities may not be respected, especially in regions where good governance systems are lacking.

CONCLUSION

REDD+ actions provide an immediate opportunity to mitigate climate change and should form an integral part of any strategy to stabilize CO₂ concentrations in order to achieve 2°C stabilization. If well implemented, REDD+ could provide multiple environmental and socio-economic benefits including biodiversity conservation, security of livelihoods for local communities, and carbon revenue to forest-dependent communities. The GEF could enhance support for the implementation of REDD+ projects, and consider adopting the AFOLU approach which covers all land use categories as well as livestock and rice production, given the importance of these sectors to global GHG emissions.

7.3. Geoengineering

In 2006, atmospheric scientist and Nobel Prize recipient for Chemistry, Paul Crutzen wrote:

“By far the preferred way to resolve the policy makers’ dilemma is to lower the emissions of GHGs. However, so far, attempts in that direction have been grossly unsuccessful. The essential starting point for any consideration of the ethics of geoengineering is the failure of the world community to respond to the scientific warnings about the dangers of global warming by cutting GHG emissions.”

The two major geoengineering approaches in this domain are to intercept a portion of solar radiation and reflect it back into space before it reaches the Earth’s atmosphere, or to physically remove a portion of GHGs from the atmosphere in order to lower the concentrations. Combining CCS with biomass production, planting trees in pasture or marginal lands, fertilizing oceans with iron solutions to increase their ability to absorb CO₂²², and increasing the carbon content of soil by adding biochar, can all remove CO₂ from the atmosphere, but at a slow rate and with relatively high uncertainties and risks.

Status of the technology and mitigation potential

Faster acting solar radiation management (SRM) techniques, such as deploying sunshades in space and increasing the albedo effect (by whitening of clouds and roofs of building, or spraying sulfate aerosols into the stratosphere, which are analogous to volcanic eruptions) aim to reflect a small portion of sunlight and heat back into space.

The lack of quality scientific information on the somewhat unproven and potentially high risk technologies being proposed, their unknown possible effectiveness, and the prospective unintended consequences including the cost of failure regarding ocean acidification via CO₂ absorption, led to a full evaluation of geoengineering options by the Royal Society (2009), the NAS (2010), and the Australian National Committee for Earth System Science (2010)²³. While not specifically advocating geoengineering, all three organizations called for further research to be undertaken in order to better understand how each of the proposed geoengineering approaches might impact, both positively and negatively, on the Earth’s natural systems.

The forthcoming IPCC 5th Assessment Report – Mitigation, to be released in 2014, will evaluate geoengineering technologies in detail. Only a brief overview is presented here as the technologies have not yet reached a suitable stage of understanding for the GEF to consider supporting any projects.

Costs

Cost details are limited given that most of the technologies are unproven, with many only in the modeling and testing stages for large scale application, and not yet at the pilot-scale in some cases. In most cases costs, in terms of reduced radiative forcing, are difficult to determine but are likely to be relatively high.

Risks and uncertainties

Attempts to manipulate powerful natural processes could cause unexpected consequences to related ecosystems. Undertaking geoengineering R&D could result in ethical risks as governments could consider reduction of investment in mitigation measures in expectation of a geoengineered climate change solution. They could lose sight of the social and political causes of climate change, and of our moral responsibilities with regard to mitigation and adaptation (MacCracken, 2006).

CONCLUSION

It certainly appears easier to warm the planet than to cool it. Overall, it would appear that the GEF should avoid funding SRM projects until the risks and uncertainties are more clearly defined. The GEF could consider supporting biological atmospheric CO₂ removal projects that seem to have lower risk, but only after a greater understanding of costs and barriers from on-going R&D has been established. Geoengineering may remain a potential option if the crossing of tipping points leading to abrupt climate change occurs, and if all other GHG reduction approaches fail.

²² Increased absorption rates have proven to be less than projected, more costly, and with complex side-effects, including the production of even more GHG emissions.

²³ <http://www.science.org.au/natcoms/nc-ess/documents/GESymposium.pdf>

7.4. Carbon dioxide capture and storage

CCS involves many complex steps, such as the separation and compression of CO₂, its transportation to a storage location, and its isolation from the atmosphere by pumping it into appropriate saline aquifers, oil and gas reservoirs, or coal beds equipped with effective seals that keep the CO₂ safely and securely trapped underground. CCS and biomass combustion have the potential to remove carbon from the atmosphere, as does increasing the carbon content of soils by incorporating biochar produced from biomass feedstocks by pyrolysis.

Status of the technology

The GEA (2012) reported that only CCS and co-production strategies using coal co-fired with biomass have the ability to address all the major energy-related societal challenges facing fossil fuels. CCS technologies could begin to be deployed in the 2015/2020 time frame since most components are already commercially available. However, there is no commercial reason to do so at present with low prices from carbon emissions trading schemes and little uptake beyond a few regions. In the longer-term, another option could be CCS linked with hydrogen production from fossil fuels. In the short-term, however, there are infrastructure constraints for hydrogen storage and distribution.

Global interest and public and private investment in CCS have increased in recent years, with over 280 projects at various stages of development (though some have had their funding withdrawn prior to completion). **Applying CCS with bioenergy could open up a route to achieving negative annual emissions (as could adding biochar produced from pyrolysis of biomass to some soils).**

The likely need to reduce atmospheric CO₂ concentrations during the early part of the next century in order to stabilize atmospheric GHGs below 450 ppm, should be an additional incentive for the adoption of CCS technologies. Enhanced oil recovery has shown that CO₂ can be pumped and retained underground (currently around 40 Mt CO₂/yr). Demonstration projects at Sleipner, Weyburn, In Salah, Coopers Creek and Snøhvit, have been closely monitored and show that CCS can be safe and effective. However, an individual demonstration project would have to be scaled-up five- to ten-fold for a typical single coal-fired power plant, and CCS would have to be scaled-up a thousand fold in order to reduce emissions by 4 GtCO₂/yr from industrial emitters by 2050 (IEA, 2011e). In addition, suitable storage sites need to be found near power plant stations.

Although controversial, Durban COP 17 agreed to include CCS among CDM projects and be eligible to earn carbon offset credits. It was also agreed that CO₂ could be transported across borders and stored in geological structures beneath the borders of more than one country.

Mitigation potential

CCS accounts for 18% of emissions savings by 2035 in the IEA (2011a) 450 Scenario, and similarly in the New Policies Scenario. Using full life-cycle analysis approaches, CCS can reduce CO₂ emissions from fossil fuel combustion from power stations and industrial sources by 65–85%. Assessments of future pathways (GEA, 2012) suggested that an overall requirement for cumulative CCS captured emissions is 250 GtCO₂ by 2050, which seems feasible when compared with the present estimates of total oil and gas storage reservoirs at about 1000 GtCO₂, saline aquifers from 6000 to 16,000 GtCO₂, and coal beds at around 200 GtCO₂ (IEA, 2011e). As with land for tree planting, storage sites for carbon are finite; therefore, CCS projects, like afforestation, can only buy time to enable the energy sector to eventually make the full transition away from fossil fuels. However, if the above mentioned storage estimates are correct, increasing CO₂ storage would be feasible for centuries at the current rate of emissions.

Theoretical projections aside, CCS still remains in the project demonstration stage. UNEP (2011a) estimated that upon completion, the 14 CCS projects currently operational or under construction could together capture 0.03 GtCO_{2-eq}/yr. The emission reduction technical potential for CCS in the power sector is 0.2 – 0.4 GtCO_{2-eq} in 2020. In conclusion, thermal power generation plants linked with CCS have good technical potential as a low-carbon energy technology. However, as with nuclear power, CCS remains controversial and awaits further demonstration and analysis.



< 7.4. Carbon dioxide capture and storage

Costs

In order to achieve greater confidence in the various CCS technologies and develop best-practice guidelines, governments will need to invest roughly \$45 bn by 2020 to fund approximately 60 large-scale CCS demonstration projects (IEA, 2011e), including industrial applications in developing countries (possibly through the CDM). **Government policies could be developed to: pay above market-rates for electricity linked with CCS; create regulations that make all new coal and gas plants CCS compatible; require that approved CO₂ storage sites be included in the land use plan for these plants; identify possible future conflicts, such as with geothermal energy; clarify legal rights to underground storage and long-term liabilities; and support capacity building since expertise with CCS is limited (GEA, 2012).**

Risks and uncertainties

Australian research conducted at two coal-fired power stations demonstrated that CCS techniques were able to capture 85% of CO₂, but at a 35% loss of efficiency from the power plant (Colquhoun, 2012). Economic, environmental and political factors may limit the deployment of CCS if this challenge is not adequately addressed. Critical issues include ownership of underground pore space, long-term liability and stewardship, GHG accounting approaches, and verification and regulatory oversight regimes. Government support that could lower barriers to early deployment is needed in order to encourage private-sector involvement. Developing countries will need some form of support if they are to get access to these technologies, lower the cost of CCS, develop workforce capacity, and train regulators for permitting, monitoring, and oversight.

CONCLUSION

Overall, with CCS projects now coming under the CDM, the GEF and international funding agencies could assess and consider funding these initiatives within their future strategies. **CCS combined with biomass gasification has negative emissions and offers a very high mitigation potential. CCS may become an integral component of any deep GHG emission reduction strategy, if the risks are satisfactorily addressed.**

7.5. Nuclear energy

Nuclear currently has a 13% share of total global electricity generation, down from its 16% share in 2005 (Sims *et al.*, 2007). Since 1990, about 430 reactors were operating around the world, with capacity peaking at around 375 GWe in 2010 prior to plant shutdowns and closures in Japan, Germany and elsewhere after the Fukushima tsunami tragedy (Morton, 2012).

Status of the technology

The future role of nuclear power has long been controversial and remains uncertain, especially in light of the recent Fukushima disaster (Hippel *et al.*, 2012). Many of the current reactors are aging, the average reactor in some countries is 25 years, and skilled labor to continue running these aging systems is becoming scarce. Of the 29 countries with reactors, 21 have not undertaken construction of a new plant for two decades. Several next generation nuclear power plants are planned or under construction in China, South Korea, the UK, Finland and elsewhere. Given that the costs relative to other electricity supply options can be competitive, nuclear power could have an 18% share of total electricity supply in 2030 at carbon prices up to 50 US\$/tCO_{2-eq} (IPCC, 2007b). However, constraints such as safety, weapons proliferation and waste management will remain. According to the high-end projection of the OECD Nuclear Energy Agency, nuclear plants could supply 20% of total electrical energy in 2050. There is also the possibility of a large-scale phase-out, as is currently taking place in some countries, especially if the spread of nuclear weapons cannot be decoupled from peaceful nuclear energy purpose, and if further accidents such as Fukushima occur. This is due in part to long-term fuel resource constraints, the large economic demands required to build, maintain and decommission these plants, ongoing security concerns, and growing adverse public opinion. One solution to facilitate this decoupling is abandoning fuel reprocessing and transferring uranium enrichment from the national to the multinational level. Large-scale enrichment, reactor manufacturing, and reprocessing technologies are currently concentrated in just a few countries. This may help allay concerns over nuclear weapons proliferation. Safety concerns and the price of enhanced safety will play a large part in determining the future of nuclear energy.

Mitigation potential

The construction of next generation nuclear plants by 2030 could prevent around 1.8 GtCO_{2-eq} GHG emissions if these were brought on to displace proposed and existing fossil fuel power plants in proportion to their electricity and space heating share of demand. In view of the fact that nuclear plants and their fuel system consume only small quantities of fossil fuels in the fuel cycle, net CO₂ emissions could be lowered significantly. However, assessments of future potential for nuclear power remain uncertain and controversial.

Costs

Nuclear power is likely to be a high cost mitigation option, especially in developing countries, if all the safety concerns are to be addressed and plant decommissioning costs at the end of plant life are included. In the literature generating costs cover a wide range, from \$25-75/MWh, which suggests high uncertainty regarding future costs (Sims *et al.*, 2007). The relatively low \$25/MWh costs shown by some comparative life cycle analysis assessments remain controversial. In many countries nuclear power is subsidized, and major additional costs can result when projected plant construction times are greatly exceeded, as is the current case in Finland.

Risks

Advantages of nuclear power include (a) minimal lifecycle GHG and other environmental emissions; (b) low fuel costs; and (c) fuel can be obtained from several geopolitical zones, potentially enhancing energy security. Concerns include (a) risk of accidents with large scale consequences; (b) risk of nuclear weapon proliferation; (c) challenges to waste treatment and disposal, especially the lack of viable solutions to safely store high-level waste; (d) high safety standards required (such as redundant cooling and control systems, massive radiation leak-proof containment structures, very conservative seismic-resistant designs), and extremely stringent quality controls that all drive up the investment costs; and (e) unfavorable public acceptance (Hippel *et al.*, 2012; Morton, 2012).

CONCLUSION

Nuclear energy has the potential to meet future electricity demand and could be part of a strategy to reduce GHG emissions. However, without subsidies the costs can be high as can the risks. Therefore, nuclear power is unlikely to be an option for many countries.



CHAPTER 8

Climate change mitigation, transformational shifts and the role of the GEF

"IT IS POSSIBLE FOR HUMANITY TO TRANSFORM ITS ENERGY SYSTEM INTO ONE THAT PROVIDES EVERYONE WITH ACCESS TO CLEAN, AFFORDABLE, AND SECURE ENERGY SUPPLY, WHILE CAPPING CLIMATE WARMING UNDER 2°C, AND CONTAINING THE ENVIRONMENTAL AND OTHER ANCILLARY RISKS OF ENERGY SYSTEMS. NEVERTHELESS, SUCH A CHANGE WILL REQUIRE A MAJOR TRANSFORMATION FROM TODAY'S ENERGY SYSTEMS TO TECHNOLOGICALLY AVAILABLE, ALTERNATIVE ENERGY SYSTEMS RESTING ON NEW PILLARS"

(GEA, 2012).

The United Nation's Framework Convention on Climate Change, adopted in May 1992, aims to *"achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"*. *"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"* (UNFCCC, 2011a).

Agreements made at UNFCCC's 16th and 17th Conference of Parties (COP 16 in Cancun, 2010 and COP 17 in Durban, 2011) recognized the need, and set a goal for deep cuts in global GHG emissions so as to hold the increase in global average temperature between 1.5 and 2°C above pre-industrial levels.

The challenges developing countries face in participating in the global effort to limit temperature rise below 2°C and de-carbonize their economies is enormous. Reducing the carbon footprint of key economic sectors (power, industry, transport, buildings, waste, forestry and agriculture) to sustainable levels is possible, but will require substantial resources²⁴ and innovative ways of mitigating the carbon footprint of key sectors. In the long-term, however, reducing GHG emissions will help improve economic performance and global wealth overall while enhancing natural capital – bringing society into a more sustainable resource-use trajectory, while concomitantly making a significant impact on poverty alleviation.

8.1. Dangerous climate change

IPCC (2007a) suggested that “defining what is dangerous interference with the climate system is a complex task that can only be partially supported by science, as it inherently involves normative judgments.” “Different approaches to defining danger, and an interpretation of Article 2 are likely to rely on scientific, ethical, cultural, political and/or legal judgments.”

Based on the available knowledge at the time, a 2°C increase was determined to be ‘an upper limit’ beyond which the risks of grave damage to ecosystems, and of non-linear responses, were expected to increase rapidly. Some scientists consider 2°C to be too high, arguing the world should aim at stabilization of warming at <1.5°C (Hansen, 2009).

The planet has already warmed by about 0.8°C above pre-industrial levels (Huber and Knutti, 2011), and the warming could cross the 2°C threshold as



early as the 2030s (Smith et al., 2011) and reach 6°C before the turn of the century (IEA, 2011a) (see section 2.3). The IPCC recently reported on the risks of extreme weather events (IPCC, 2012) and showed that many countries, particularly developing countries, face severe challenges in coping with climate-related disasters.

The UNEP report *Bridging the Emission Gap* (2011a) suggested that “in order to have a likely chance of keeping within the 2°C limit this century, emissions in 2020 should be no higher than 44 Gt CO_{2-eq}” (Fig. 8.1). In 2010, emissions were approximately

48 Gt CO_{2-eq}. Depending on conditional and unconditional pledges by various

countries under the climate change COP agreements and compliance rules, the gap between business-as-usual emissions (assuming no pledges will be implemented) and reduced emissions levels consistent with a 66% chance to stay below the 2°C target, is in the range of 9 to 18 GtCO_{2-eq} (median 12 GtCO_{2-eq}).

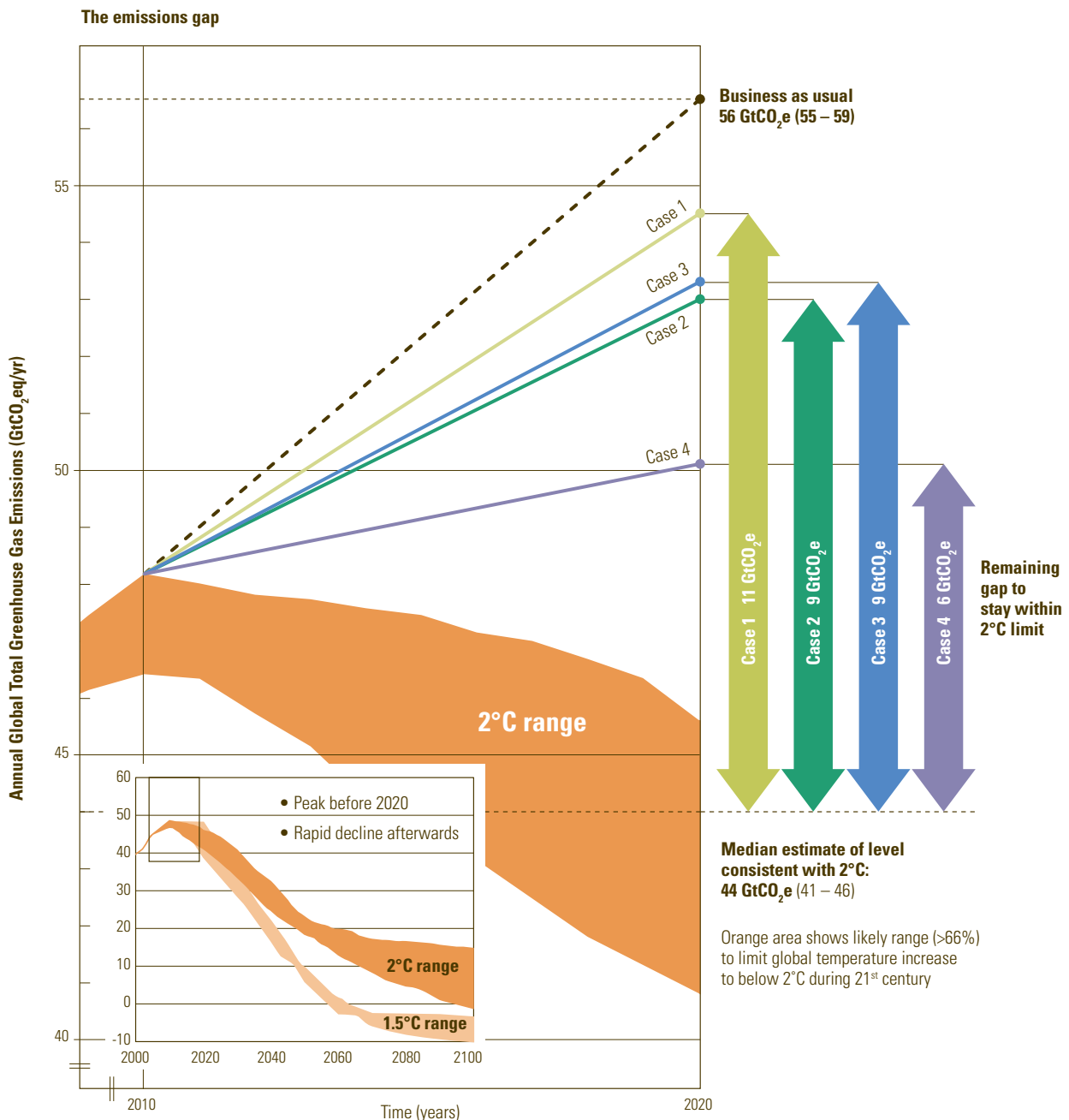
Even if all the current commitments and pledges are met in full, a gap of 6 GtCO_{2-eq} still remains to be bridged by 2020 (Fig. 8.1, Case 4). Each

year that passes without action further increases this gap and reduces the likelihood of staying within the 2°C threshold.

There remains a chance to limit global warming below 2°C without relying on future bioenergy + CCS efforts to physically remove CO₂ from the atmosphere. Emission reductions of between 14 to 20 GtCO_{2-eq} are theoretically possible by 2020, even without any significant technical or financial breakthroughs (UNEP, 2011a).

²⁴ The Green Economy Report (UNEP, 2011c) estimated that the annual financing needs to green the global economy was in the range of US\$1.05-2.59 trillion, or about 2% of the global GDP or 10% of the global total annual investments. A significant part of these investments would go into the reduced carbon footprint of major sectors.

FIGURE 8.1: Gaps in GHG emissions reductions below business as usual (56 GtCO₂-eq) needed by 2020 in order to reach 44 GtCO₂-eq, and eventually stabilize warming at below 2°C (UNEP, 2011a).



CASE 1 – UNCONDITIONAL PLEDGES, LENIENT RULES:

If countries implement their lower-ambition pledges and are subject to “lenient” accounting rules, then the median estimate of annual GHG emissions in 2020 is 55 GtCO₂e, within a range of 53 – 57 GtCO₂e.

CASE 2 – UNCONDITIONAL PLEDGES, STRICT RULES:

This case occurs if countries keep to their lower-ambition pledges, but are subject to “strict” accounting rules. In this case, the median estimate of emissions in 2020 is 53 GtCO₂e, within a range of 52 – 55 GtCO₂e.

CASE 3 – CONDITIONAL PLEDGES, LENIENT RULES:

Some countries will be more ambitious with their pledges. Where this is the case, but accounting rules are “lenient”, median estimates of emissions in 2020 are 53 GtCO₂e within a range of 52 – 55 GtCO₂e. Note that this is higher than in Case 2.

CASE 4 – CONDITIONAL PLEDGES, STRICT RULES:

If countries adopt higher-ambition pledges and are also subject to “strict” accounting rules, the median estimate of emissions in 2020 is 51 GtCO₂e, within a range of 49 – 52 GtCO₂e.

Please note: All emission values shown in the text are rounded to the nearest gigatonne.

8.2. Assessment of existing efforts

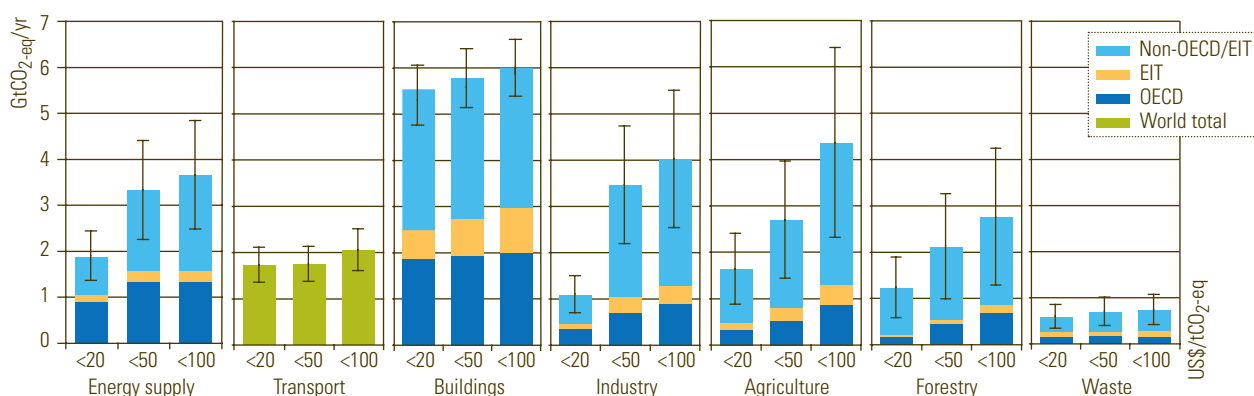
The signatories to the Kyoto Protocol are 37 industrialized countries and the European Community that are committed to reducing their emissions by an average of 5% against 1990 levels over the period 2008-2012 (UNFCCC, 2011b). A reduction of 11% was estimated to be possible for these countries during the first Kyoto commitment period from 2008 to 2012, provided policies and measures planned by these countries are put in place. Although the Kyoto goal will be more than achieved, it is ironic that global CO₂ emissions rose by 45% over the period 1990-2010 (Olivier *et al.*, 2011) and 2010 witnessed a record increase in CO₂ emissions of about 6% (Peters *et al.*, 2011). With Canada withdrawing from the Kyoto Protocol less than one fifth of total global GHG emissions will be regulated in the second commitment period. The growth in global emissions exceeds the marginal reduction in GHG emission of the Kyoto signatories.

The voluntary GHG reduction pledges made at COP 15, Copenhagen, 2009, are considered insufficient to arrest global warming below 2°C and the world is on a path to higher warming (Rogeji *et al.*, 2010;

UNEP, 2011a). Additional pledges at later COPs are also insufficient with Cancun (COP 16 in 2010) leading to a warming of 3.2°C (Chen *et al.*, 2011). The Durban agreement (COP 17 in 2011) did not propose additional action before 2020 (Hohne *et al.*, 2011). The IEA (2011a) concluded that the window of opportunity to keeping global temperatures below 2°C is fast closing, unless urgent mitigation actions are implemented before 2017. Even with all these agreements, the risk of warming exceeding 2°C remains very high.

It is difficult to envisage a scenario that can address the emissions gap by 2020 with sectoral mitigation efforts. Even at a price of \$100/tCO_{2-eq}, no sector has the potential to mitigate in excess of 6 GtCO_{2-eq} per year (Fig. 8.2). Thus the challenge of the current emission gap requires a fundamental shift involving multiple sectors and regions. An integrated approach to energy for sustainable development is needed; wherein energy policies are coordinated with policies involving industry, buildings, urbanization, transport, food, health, environment, climate, security, and others to make them mutually supportive (GEA 2012).

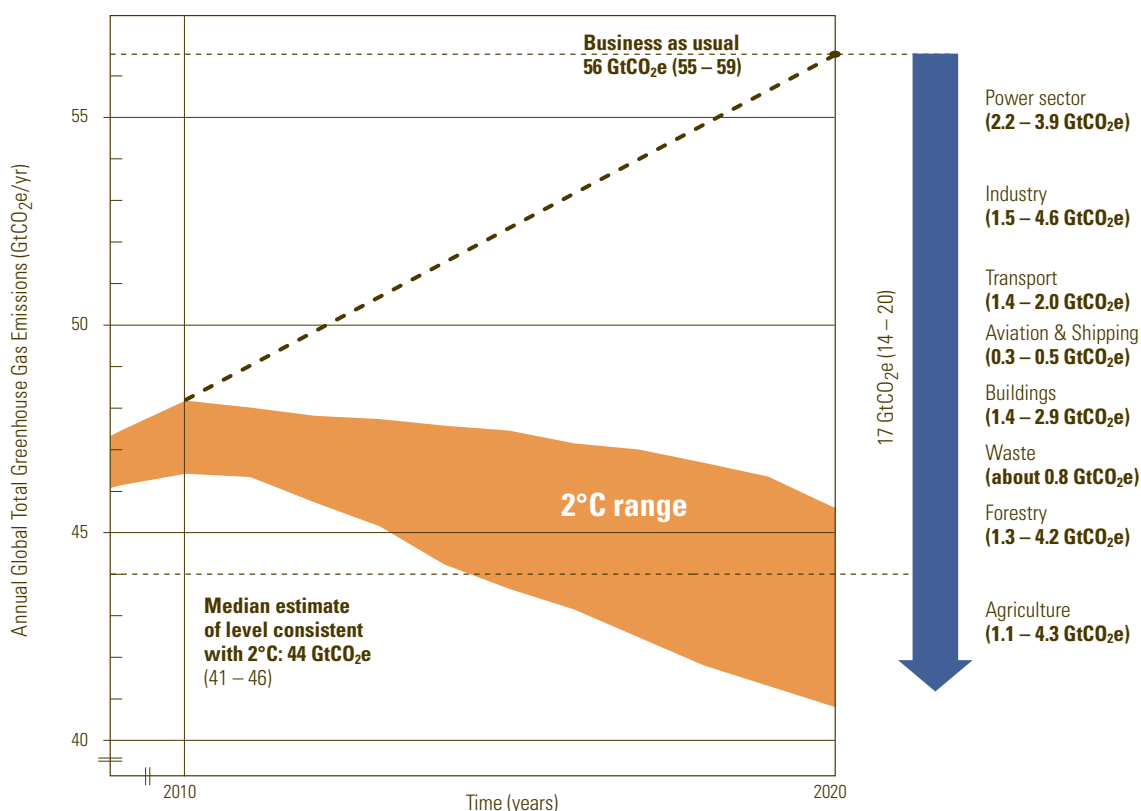
FIGURE 8.2: Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments (IPCC, 2007b).



Notes:

1. The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
2. The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
3. Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the WEO 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste specific baseline, agriculture and forestry used baselines that mostly used B2 driving forces.
4. Only global totals for transport are shown because international aviation is included.
5. Categories excluded are: non-CO₂ emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10-15%.

FIGURE 8.3: How to bridge the emissions gap to give a 1.5-2°C global warming scenario (UNEP, 2011a).



8.3. Bridging the emission gap

UNEP (2011a) estimated an emission gap of 9 to 18 GtCO_{2-eq} (median 12 GtCO_{2-eq}) by 2020 between the business-as-usual emissions (with no pledges implemented) and emissions consistent with a 66% chance to stay below the 2°C (Fig. 8.1). It further argued that 14 to 20 GtCO_{2-eq} of GHG emissions could be avoided without major technological breakthroughs by reducing emissions in the major sectors (Fig. 8.3).

While UNEP (2011a) took a holistic view of the entire spectrum of emissions and reduction opportunities in all sectors, IEA (2011a) looked more closely at the energy sector and estimated an emission gap of 4.18 GtCO_{2-eq} per year by 2020, increasing to 22 GtCO_{2-eq} per year by 2035. Energy efficiency and renewables can provide up to 90% of the required reduction (Fig. 8.4) with biofuels, nuclear and CCS covering the other 10%. Energy efficiency provides the least cost mitigation opportunities.

Beyond the energy sector, a range of mitigation options are available for abatement of agricultural emissions, short-lived black carbon and organic aerosols, and emissions arising from deforestation and forest degradation (REDD+), particularly in

developing countries (Chapter 7). Key mitigation opportunities include improved energy efficiency, renewable heat and power generation, transport options, urban systems, agriculture and forestry management (IEA, 2011a; UNEP, 2011a) (Table 8.1).

FIGURE 8.4: World energy-related CO₂ emissions abatement in the 450 Scenario relative to the New Policies Scenario (IEA, 2011a).

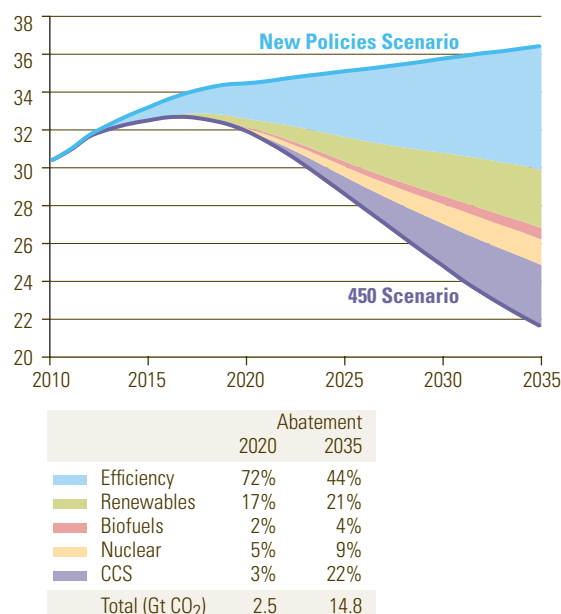


TABLE 8.1. Summary of key mitigation options for helping achieve the 450ppm goal for limiting warming to <2°C.

Energy efficiency	• Around 72% of the required GHG reduction in the energy sector could come from energy efficiency (IEA, 2011a) with an emission reduction potential between 4.3 to 9.5 GtCO₂-eq per year by 2020 excluding energy efficiency in the energy supply sector (UNEP, 2011a). Key energy efficiency emission reduction potentials in the industry, transport and building sectors could provide over one third of total GHG emission reduction potential.
	• Policies and measures that encourage improved energy efficiency uptake (both technological and behavioral) tend to be the cheapest abatement options available (in terms of \$/t CO₂-eq avoided).
	• Global investments in combined energy efficiency and supplies will need to increase from about 1.7 to 2.2 trillion dollars per year as compared to the present levels of about 1.3 trillion dollars per year (about 2% of current world GDP) (GEA, 2012).
	• Encourage policies that set ambitious appliance standards, building codes and fuel economy norms. Promote minimum efficiency performance standards due to their cost-effectiveness and high policy acceptability in most jurisdictions. Promote deployment of energy management systems that can overcome non-technical barriers to organizational and continual energy efficiency improvements. Support “feebates” and proactive utility regulations that provide real mitigation opportunities as well as significant social and economic co-benefits.
	• National and international experiences widely agree that while improving the efficiency of individual components might yield minor gains, only system optimization can result in significant gains with payback periods of less than two years.
Renewable energy	• Currently renewables contribute approximately 19% of global electricity supply which could increase significantly by 2020 (Deng <i>et al.</i>, 2011; Krewitt <i>et al.</i>, 2009) including the contribution to global electricity production increasing from 21 to 38% (IPCC, 2011).
	• The share of non-hydro renewable power generation could increase from 3% in 2009 to 15% in 2035 on the back of rising subsidies to renewables of around \$180 billion (IEA, 2011a).
	• RE technology investment costs per unit of capacity are continuing to decline as a result of mass production and greater project experience from increased deployment (IPCC, 2011a), but RE system costs vary widely with local resource availability.
	• The levelized costs of RE from many technologies (calculated over their lifetime) are typically higher than present average wholesale prices for electricity, heat and transport fuels, although in specific situations (and especially where they compete with retail prices), they can be economically competitive.
	• RE systems can provide multiple co-benefits, including employment, energy security, human health, environment, and mitigation of climate change.
	• In remote rural regions with no electricity grid access, autonomous RE systems can avoid expensive grid connection costs and are therefore already competitive. Recent reductions in solar PV prices have also made them more competitive with small diesel-generating systems.
	• Renewables can provide an emission reduction potential of 1.5 – 2.5 GtCO₂-eq per year by 2020, with 11 to 13% of the total reduction potential of all sectors (UNEP, 2011a).
	• Renewable energy offers some key co-benefits for society such as energy security, employment, local pollution abatement and sustainable development.
	• Bioenergy + CCS appears to be a possible opportunity to obtain negative emissions in the long-term but more RD&D is required.



Food supply chain	- The global agri-food supply chain is responsible for approximately 22% of total GHG emissions. This share can be reduced by numerous methods including the uptake of improved energy efficiency measures along the entire food supply chain, increasing the deployment of RE systems on farms and in food processing plants, and reducing the various sources of food losses, which currently account for around one third of all the food produced (Gustavsson <i>et al.</i> , 2011).
	- There is high potential to decrease the current fossil fuel dependence of the agri-food supply chain in both high- and low-GDP countries, and hence to reduce related GHG emissions.
	- Key agricultural emission reduction measures include changing soil and livestock practices such as reduced tillage, improved fertilizer management, irrigation management, manure and ruminant methane through changes in livestock feed and handling.
	- The potential range of emission reductions from the agriculture sector at carbon prices of up to US\$20, 50 and 100 /tCO ₂ -eq were estimated to be 1.5-1.6, 2.5-2.7, and 4.0-4.3 GtCO ₂ -eq respectively (Smith <i>et al.</i> , 2007).
	- Increasing soil carbon content is gaining international interest, particularly the concept of biochar production and integration ²⁵ . Increasing carbon stocks of agricultural soils is likely to be one of the most <i>win-win</i> mitigation opportunities, with a large mitigation potential as well as co-benefits consisting of increasing soil fertility and agricultural productivity and reducing climate risks due to moisture stress.
Biofuels	- Liquid and gaseous biofuels have good potential to supply a greater share of transport fuels than the 2-3% at present, so long as the biomass is produced in a sustainable manner and without direct and indirect land use change impacts increasing GHG emissions.
	- Although 1 st generation biofuel technologies are mature, life-cycle GHG emissions are uncertain, and in extreme cases can exceed those of petroleum fuels when indirect land-use change is included. Advanced biofuels are expected to have lower life-cycle emissions when biomass wastes or crop residues are used rather than purpose-grown feedstocks.
	- By 2030, a modest 10% of global residues could yield about 155 billion liters of gasoline equivalent of lignocellulosic ethanol, or roughly 4.1% of the projected transport fuel demand (IEA, 2010).
Urban energy and infrastructure	-The challenge in responding to climate change in urban systems is to develop an integrated, continuous and long-term strategy that includes a combination of solutions in transport, buildings, water, waste, food and land use zoning. Such an integrated approach should address other challenges that have interfaces at the urban level such as chemicals managements, coastal management (as many cities are concentrated in coastal zones) and overall human well-being development goals.
	- Intervention in the sustainability of urban systems should ensure that initiatives are beneficial to local governments, businesses and consumers (Khare <i>et al.</i> , 2011), enhancing human well-being and local natural resources, while reducing future costs, ecological scarcities and environmental risks (ICLEI, 2011).
	- Integrated smart management of urban energy systems can contribute to employment benefits at a local level by stimulating a move from a capital intensive sector to more labor-intensive sectors. Cities could be important for the emerging green economy because of their proximity and density, delivery of productivity benefits and stimulating innovation, and the fact that green industries are dominated by service activities concentrated in urban areas where consumer markets are largest (UNEP, 2011c).
	- The main challenge in realizing sustainable low-carbon cities is to combine technology solutions in a number of sectors such as buildings, transport, manufacturing and others with broader development issues such as water, food and waste. Supporting a “green urban economy” can only be achieved through an integrated and long-term strategy combined with land-use zoning.
	- Integrated smart management of urban energy systems can help to address several challenges at the urban level while at the same time contributing to employment benefits and greening the economy. Barriers to this transition are related to climate governance institutions and insufficient expertise and lack of funding, especially in non-OECD countries.
	- The GEF should consider supporting integrated, smart management of urban energy systems, and focus on encouraging development of long-term strategies at an urban level that combine interventions in energy efficiency and renewable energy throughout different energy end-use sectors. The existing GEF strategic objective on transport and urban systems should be strengthened and more integrated urban approaches for energy, water, food and waste receive larger support. Specific attention could be dedicated to addressing key barriers by encouraging capacity building and climate governance institutional support.

²⁵ <http://www.biochar-international.org/>

TABLE 8.1.

Municipal wastes	- Methane constitutes around 90% of total GHG emissions arising from municipal wastes, over half from landfill gas and the rest from wastewater. The remaining 10% arises from nitrous oxide (N ₂ O) emissions from wastewater.
	- The contribution of the waste sector to global GHG emissions in 2005 was 1.3 GtCO ₂ -eq (Bogner et al., 2007). Under the BAU scenario, these emissions could rise to about 1.7 GtCO ₂ -eq by 2020.
	- The total emission reduction potential for the waste sector is around 0.8 GtCO ₂ -eq assuming an 80% reduction below the baseline of landfill emissions is feasible (UNEP, 2011a).
Short-lived climate forcers	- "Scientific evidence and new analyses demonstrate that control of black carbon particles and tropospheric ozone through rapid implementation of proven emission reduction measures would have immediate and multiple benefits for human well-being." (UNEP, 2011e).
	- Full implementation of the identified measures could reduce future global warming by 0.5°C (0.2–0.7°C range). If the measures were to be implemented by 2030, they could halve the potential increase in global temperature projected for 2050 based on current policies and baseline energy and fuel use projections.
	- Reducing black carbon and tropospheric ozone will have health and production co-benefits. The full implementation of control measures could avoid 2.4 million premature deaths (within a range of 0.7–4.6 million) and the loss of 52 Mt (within a range of 30–140 Mt; 1–4%), of the global production of maize, rice, soybean and wheat each year.
AFOLU, LULUCF and REDD+	- Mitigation options in the forestry sector include reducing emissions from deforestation and forest degradation (REDD) and enhancing carbon sequestration from afforestation and sustainable management of new and existing forests.
	- The emission reduction potential from forestry was estimated to be in the range of 1.3 to 4.2 GtCO ₂ -eq in 2030 at carbon prices of up to 100 US\$/ tCO ₂ -eq (Nabuurs et al., 2007).
	- With appropriate policies and safeguards, reducing emissions from deforestation and forest degradation in developing countries can be a win-win mitigation option due to a large and immediate mitigation potential and several co-benefits such as conservation of biodiversity, improvement of livelihoods of forest-dependent communities and watershed protection.
Peat-lands	- The GEF could use the AFOLU approach adopted by IPCC inventory guidelines as well as the fifth assessment report of the IPCC, which covers all the land use sectors as well as non-CO ₂ emissions from livestock and rice production, given the importance of these land and livestock categories.
	- Peat-land contains approximately 550 Gt of organic carbon being twice the amount of carbon stored in the world's forests (Fenner and Freeman, 2011).
	- Peat-land currently emits about 2 GtCO ₂ -eq/yr due to forest clearing and drainage for agricultural cropping. Avoidance could provide one of the most immediate and large-scale mitigation options.
Nuclear power	- Peat-lands are likely to be impacted by the changing climate due to more frequent droughts and wild fires. They could become a source of higher levels of GHG emissions in the future.
	- Nuclear power generation has remained stable over the past decade, providing 13% of global electricity production in 2011.
	- The contribution could rise to reach between 12.5% - 14.5% by 2020 (IEA, 2010a), representing an increase of between 35-40% since 2008. However in the wake of the Fukushima tsunami disaster, uncertainty remains on the future for nuclear power.
Carbon dioxide capture and storage	- The overall life-cycle power generation costs for nuclear electricity can be competitive but remain debatable if the full life cycle and externality costs are not included.
	- CCS is a key emission reduction option that could account for 18% of emissions savings in the IEA 450 Scenario, relative to the New Policies Scenario by 2035 (IEA, 2011a).
	- CCS technologies are still at the demonstration phase with no commercial plant in operation other than through enhanced oil recovery or linked with natural gas extraction.
	- An emission reduction technical potential of 0.2 – 0.4 GtCO ₂ -eq in 2020 was projected from CCS in the power sector (UNEP, 2011a).
	- Thermal power generation plants linked with CCS have good technical potentials as low-carbon energy technologies but await further demonstrations and analysis.
	- Assessments of CCS system costs have been undertaken but with few, if any, commercial CCS power plants operational, they are difficult to validate.
	- Bioenergy power combined with CCS could provide the best case for negative GHG emissions.

8.4. Investment costs to achieve <2°C stabilization

There are a few estimates available of how much it will cost to restrict global warming to less than 2°C. However, these estimates differ considerably in their scope and methods and thus vary widely. IEA (2011a) stated a total investment of approximately \$38 trillion would be required over the next 25 years (2011-2035) in the energy sector to meet its New Policy Scenario. The 450 ppm Scenario would require an additional cumulative investment of \$15.2 trillion. The transport sector would require \$6.3 trillion (~40%) of the additional investment for the purchase of more efficient and alternative vehicles and the building sector would require \$4.1 trillion (~27%).

The World Economic Forum (2010) estimated that clean energy investment needs to rise to US\$ 500 billion per year by 2020 to restrict global warming to less than 2°C. The HSBC bank estimated the transition to a low carbon economy will see a total growth in cumulative capital investments of US\$ 10 trillion between 2010 to 2020 (Robins *et al.*, 2010).

UNEP (2011c) provided an economy wide investment projection and suggested that to achieve both the IEA's *Blue Map scenario* as well as the Millennium Development Goals, the investment costs would range from US\$ 1.05 to US\$ 2.59 trillion annually at the outset. These additional investments amounted to 2% of global GDP per year over 2010-2050 and were needed across a range of sectors to build capacity, adopt new technologies and management techniques, and scale up green infrastructure. These cost projections look feasible when compared to the fossil fuel price and production subsidies exceeding \$650bn in 2008 (UNEP, 2011c).

The GEF is not an agency that provides large investment capital and can, at best, provide incremental costs for selected technologies. However, it could play a critical role in improving assessments of mitigation opportunities, developing low carbon strategies, building institutional and technical capacity, and assisting with development and implementation of policies, regulations, standards, etc. in order to help developing countries and EITs shift to a low carbon society.

8.5. Potential role for the GEF in limiting global warming to <2°C

To stabilize atmospheric GHG concentrations at levels low enough to avoid the mean global temperature rising above 2°C (as was internationally agreed at the UNFCCC 15th Conference of Parties, Copenhagen in 2009), small interventions and incremental changes will not be enough. A transformational shift will be required, closely linked with the sustainable development aims and objectives of many developing countries and EITs.

Future investments in technologies that provide essential energy services but are not low-carbon emitting, will not be possible if the stabilization goals are to be met. Therefore the GEF should identify the major investment opportunities combining technologies, systems, policies and practices that can give the greatest climate change mitigation impacts in the shortest time and at the lowest costs. Such ambitions could include systems approach, urban programs, energy-food systems, REDD+ projects, peatland management, and energy access for all in least developed and land-locked countries. This would be a significantly different approach for the GEF which to date has largely focused on technologies.

For example, in Chapter 6 urban mitigation solutions bring together energy efficient transport, land-use planning, water and waste management and calls on the GEF to take a more comprehensive approach to cities and take advantage of potential synergies.

Energy-smart food systems (Chapter 5) is another example of a holistic approach by which developing countries can identify low-carbon food supply solutions that would also encourage investments in sustainable land use management, renewable energy and energy efficiency. Efficiencies in producing, processing, transporting, and storing food would help create employment and improve energy security, through having a mix of technologies and policies focused on decentralized power supply with a large share of renewable energy.

For buildings, Chapter 4 calls for a mix of policies and technologies to transform this sector by focusing on whole-building solutions for both new

constructions and retrofits, rather than supporting individual energy-efficient technologies such as insulation, replacing inefficient boilers, or installing energy-efficient air-conditioners. Setting ambitious performance standards and allowing these to be met by different, individually tailored packages of architectural and equipment efficiency measures recognizes that whole systems approaches can achieve higher savings at lower costs.

How these systemic interventions should be applied to particular country/regional circumstances needs consideration on a case-by-case basis, and is not covered here. This chapter has simply outlined examples where big “synergetic” opportunities and programs could be applied given limited GEF resources. For the GEF to move towards such systemic approaches will require true integration, both within and between focal areas, where actual opportunities are abundant. The GEF is a unique global funding mechanism that supports projects across different domains. Most of the submitted programs represented to date are loosely connected bundles of separate projects with limited cross-fertilization between them.

In an effort to hold warming at 2°C, it is essential to assist the higher GHG emitters (such as Brazil, Russia, India, China and South Africa) to evaluate and pursue transformational shifts – i.e. energy efficiency improvements and renewable energy deployment – in the building, industry and transport sectors, as well as mitigation options in forest and agricultural sectors. Along with OECD countries, these countries can contribute significantly to both early peaking of annual GHG emissions and deep GHG emission reductions through comprehensive, cost-effective interventions that can derive economies of scale.

Undertaking an optimization approach to provide systemic solutions should become the focus for GEF-6 project support. Rather than supporting single, low-carbon technologies or improving the performance of individual system components, the GEF should consider supporting more comprehensive approaches that could encompass a combination of energy demand reductions, low-carbon option deployment, innovative IT systems, capacity building, energy security and policy development, whilst contributing towards sustainable development. Monitoring of such integrated

projects and assessing their successful completion will present challenges, and careful consideration will need to be given as to how this may best be achieved.

An example of an optimization approach is that of the GEF’s urban strategic objective that supported projects that were not just typical transport-oriented projects, but also considered optimizing energy supply and distribution systems, supporting low-carbon buildings etc. Such integrated programs may carry higher risks of failure, and the GEF’s commitment may have to be longer-term. However, such ambitious programs could be replicated at the individual country level and should also commit countries to continue with these strategies after GEF support ceases.

Market transformation for Climate mitigation: the GEF’s approach to mitigation through market transformation and investment in climate-friendly systems is technically and environmentally sound.

Market transformation relies on several key principles.

- Interventions should be direct responses to identified market barriers.
- The co-benefits of market transformation should be sustainable.
- New products, services and practices should be established within existing market frameworks.
- Private capital, investment know-how and competitive market forces should drive transformation.
- The transformation should be based on a partnership between all market stakeholders including government, private sector, consumers, and civil society (Birner and Martinot, 2005).

The market transformation approach embedded in the GEF-5 strategy is providing a “supply push” and “demand pull” for particular technologies and practices, thereby addressing both supply and demand sides of the market. Rather than focusing on individual technologies, however, energy efficient systems can often be best promoted by setting

ambitious and carefully designed approaches pertaining to systems (e.g. appliance standards). This approach has proven to be a very effective means of transforming approaches to climate mitigation and achieving targets (Woerlen, 2011).

Principles for supporting GHG mitigation. In the context of GEF-6 and growing support for green economy approaches, a number of key principles pertaining to support for transformational approaches have been identified. Significant additional contributions to global efforts in reducing global warming can be achieved if the strategies are designed based on a number of the following overarching principles.

These five principles could be used to guide future strategies of the GEF so that it can continue to play a catalytic role in addressing climate change in an era of competing international institutions and limited financial resources.

Role for the GEF in enabling transformation to a low carbon society: Due to its vast experience, the GEF can continue to be a critical institutional mechanism in promoting global environmental benefits and supporting comprehensive, transformational shifts to achieve global warming stabilization below 2°C. The key conclusions and recommendations aimed at enhancing the role of the GEF in its journey towards promoting a green economy and responding to UNFCCC are presented in the Executive Summary. **Overall, the GEF should assist recipient countries to assess, select and evaluate technologies, policies, measures, regulations, financial incentives and disincentives, financial needs, technology transfer mechanisms and institutional capacity that will enable them to rapidly make transformational shifts to a low-carbon pathway, consistent with national sustainable development goals.**

Principle 1: Define common goals with differential delivery approaches. Focus on rapidly urbanizing economies to enable deep emissions reductions while concomitantly supporting energy access. A common goal of reducing GHG emissions and supporting low-carbon development paths should be implemented, taking into account different geographies and stages of national development.

Principle 2: Enhance leverage of available global climate financing. Existing barriers to leveraging a range of public and in particular private sector resources for GEF projects should be eased. In order to promote innovation and make the necessary transformational impacts we need, private sector financing for GEF projects should be increased significantly.

Principle 3: Utilize economies of scale and the opportunity for synergies between sectors and GEF focal areas. Provided similar or higher levels of funding are available as for GEF-5, GEF-6 should strongly focus on systemic approaches to energy production and consumption that would utilize economies of scale and produce multiple benefits from multiple sectors/focal areas.

Principle 4: Account for climate risks and increase the resilience of GEF climate mitigation projects. Recognize climate change risks and ensure GEF projects and programs address these to become climate resilient wherever possible. There is a need to explore and promote mitigation and adaptation synergies when addressing climate change.

Principle 5: Assure transparency, accountability and global learning. High levels of transparency, GHG monitoring and accountability, and support for global learning should continue to be key ingredients of GEF funding for climate change mitigation initiatives.

REFERENCES

- Akbari, H., Menon, S., and Rosenfeld, A.** (2009). Global cooling: increasing world-wide urban albedos to offset CO₂. *Climatic Change*, 94 (3-4), 275-286.
- Amjad, S., Rudramoorthy, R., and Neelakrishnan, S.** (2011). Assessment of petroleum saving and greenhouse gas emission reduction from two-wheeler segment: 2011–2021. *Transportation Research Part D: Transport and Environment*, 16 (3), 265-269.
- Arora, V. K., J. F. Scinocca, G. J. Boer, J. R. Christian, K. L. Denman, G. M. Flato, V. V. Kharin, W. G. Lee, and W. J. Merryfield.** (2011). Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. *Geophys. Res. Lett.* 38, L05805, doi:10.1029/2010GL046270.
- Bacovsky, D., Dallos, M., and Worgetter, M.** (2010). Status of 2nd generation biofuel demonstration facilities in June 2010. Rome: IEA Bioenergy Task 39.
- Bálint, M., Domisch, S., Engelhardt, C.H.M., Haase, P., Lehrian, S., Sauer, J., Theissinger, K., Pauls, S.U., and Nowak, C.** (2011). Cryptic biodiversity loss linked to global climate change. *Nature Climate Change* 1, 313–318.
- Banerjee, R., Cong, Y., DolfGielen, G., Januzzi, F., Marechal, A., McKane, M., van Denies, B., and Worrel, E.** (2012). Chapter 8: Energy End-Use: Industry. In N. Nakicenovic & T. Johansson (Eds.), *Global Energy Assessment*. Cambridge: Cambridge University Press.
- Beaumonta, L. J., Pitman A., Perkins S., Zimmermann N., Yoccoze E., Nigel G., and Thuiller W.** (2011). Impacts of climate change on the world's most exceptional ecoregions. *PNAS*, 108 (6), 2306–2311.
- Beddington, J., Asaduzzaman, M., Clark, M., Fernandez, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo N., Nobre C., Scholes, R., Sharma, R., Wakhungu, J.** (2012a). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. *CGIAR Research Program on Climate change Agriculture and Food security*. Copenhagen: CCAFS.
- Beddington, J., Asaduzzaman, M., Clark, M., Fernandez, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo N., Nobre C., Scholes, R., Sharma, R., and Wakhungu, J.** (2012b). What next for agriculture after Durban? *Science*, 335 (6066), 289-290.
- Bergengren, J., Waliser, D., and Yung, Y.L.** (2011). Ecological sensitivity: a biospheric view of climate change. *Climatic Change*, 107 (3-4), 433–457.
- Betts, R., Collins, M., Hemming, D., Jones, L., Chris, D., Jason, L., and Sanderson, M.** (2011). When could global warming reach 4°C? *The Royal Society*, 369 (1934), 67-84.
- Birner, S. and Martinot, E.** (2005). Promoting energy-efficient products: GEF experience and lessons for market transformation in developing countries. *Energy Policy*, 33 (14), 1765–1779.
- Bloomberg New Energy Finance** (2011). Global renewable energy market outlook. Retrieved from <http://bnef.com/>
- Bogner J, Ahmed M. A., Diaz, C., Faaij, A., Gao, Q., Hashimoto, S., Mareckova, K., Pipatti, R., and Zhang, T.** (2007). Chapter 10: Waste Management. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (Eds.), *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.
- Bouwman, A. F., Van der Hoek, K. W., Eickhout, B., and Soenar, I.** (2005). Exploring changes in world ruminant production systems. *Agricultural Systems*, 84 (2), 121-153.
- Burrows, M.T., Schoeman, D.S., Buckley, L.B., Moore, P., Poloczanska, E.S., Brander, K.M., Brown, C., Bruno, J.F., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C.V., Kiessling, W., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F.B., Sydeman, W.J., and Richardson A.J.** (2011). The pace of shifting climate in marine and terrestrial ecosystems. *Science*, 334 (6056), 652-655.
- California Energy Commission.** (2011). Energy losses in a vehicle, Consumer Energy Center. http://www.consumerenergycenter.org/transportation/consumer_tips/vehicle_energy_losses.html
- Carnicer, J., Coll, M., Ninyerola, M., Pons, X., Sánchez, G., and Peñuelas, J.** (2011). Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. *PNAS*, 108 (4), 1474–1478.
- Chen, C., Hare, B., Hagemann, M., Höhne, N., Moltmann, S. and Schaeffer, M.** (2011). Cancun Climate Talks: Keeping options open to close the gap. Climate Action Tracker Briefing Paper. Climate Analytics, EcoFys and Potsdam Institute for Climate Impact Research. Available at: http://www.climateactiontracker.org/briefing_paper_cancun.pdf (assessed on 10/23/2012).

- Chum, H., Faaij, A., Moreira, J., Berndes, G., Dhamija, P., Dong, H., Gabrielle, B., Goss Eng, A., Lucht, W., Mapako, M., Masera Cerutti, O., McIntyre, T., Minowa, T., and Pingoud, K. (2011).** Bioenergy. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlomer, C. von Stechow (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, Cambridge: Cambridge University Press.
- Colquhoun, L. (2012).** CSIRO likes carbon capture, Energy Business. Available at: <http://www.energybusinessnews.com.au/2012/04/05/csiro-likes-carbon-capture/> (assessed on 10/23/2012).
- Convention on Biological Diversity (2010).** *Global Biodiversity Outlook 3 - Executive Summary*, CBD, Montreal, Canada. Available at: <http://www.cbd.int/gbo/gbo3/doc/GBO3-Summary-final-en.pdf> (assessed on 10/23/2012).
- Coumou, D., and Rahmstorf, S. (2012).** A decade of weather extremes. *Nature Climate Change*, 2 (4), 491-496.
- Deng, Y., Klaus, S., Cornelissen, S., van der Leun, K., and Blok, K. (2011).** *Pathway to a fully sustainable global energy system by 2050*. Linköping Electronic Conference Proceedings, Vol. 57: 3492-3496. Linköping, Sweden.
- Ebinger, J., and Vergara, W. (2011).** *Climate impacts on energy systems: Key issues for energy sector adaptation*. World Bank Publication. Washington, DC.
- Edenhofer, O., Carraro, C., Hourcade, J.-C., Neuhoﬀ, K., Luderer, G., Flachslund, C., Jakob, M., Popp, A., Steckel, J., Strohsehein, J., Bauer, N., Brunner, S., Leimbach, M., Lotze-Campen, H., Bosetti, V., de Cian, E., Tavoni, M., Sassi, O., Waisman, H., Crassous-Doerfler, R., Monjon, S., Dröge, S., van Essen, H., del Rio, R., and Türk, A. (2009).** *The Economics of Decarbonization*. Report of the RECIPE project. Potsdam-Institute for Climate Impact Research: Potsdam, Germany.
- El Sioufi, M. (2010).** *Climate change and sustainable cities: major challenges facing cities and urban settlements in the coming decades*. International Federation of Surveyors. Article of the Month – June 2010. Available at: http://www.fig.net/pub/monthly_articles/june_2010/june_2010_el-sioufi.pdf (assessed on 10/23/2012).
- Eliasch, J. (2008).** *Climate Change: Financing Global Forests - The Eliasch Review*. UK. Available at <http://www.official-documents.gov.uk/document/other/9780108507632/9780108507632.pdf> (assessed on 10/23/2012).
- FAO (2011a).** *The State of the World's land and water resources for food and agriculture: Managing systems at risk*. Rome: Food and Agriculture Organization of the United Nations. Available at: <http://www.fao.org/docrep/015/i1688e/i1688e00.pdf> (assessed on 10/23/2012).
- FAO (2011b).** *"Energy-Smart" Food for People and Climate*. Issue Paper. Rome: Food and Agriculture Organization of the United Nations. Available at: <http://www.fao.org/docrep/014/i2454e/i2454e00.pdf> (assessed on 10/23/2012).
- Fenner, N. and Freeman, C. (2011).** Drought-induced carbon loss in peatlands. *Nature Geoscience*, 4. 895-900.
- Fischedick, M., Schaeffer, R., Adedoyin, A., Akai, M., Bruckner, T., Clarke, L., Krey, V. et al (2011).** Mitigation potential and costs. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge: Cambridge University Press.
- Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D. P. M. (2011).** Solutions for a cultivated planet. *Nature*, 478, 337-342.
- GCP (Global Carbon Project) (2011).** Available at: <http://www.globalcarbonproject.org/> (assessed on 10/23/2012).
- GEA (2012).** *Global Energy Assessment: Towards a Sustainable Future*. Cambridge: Cambridge University Press.
- GEF-STAP (2010)** *Advancing Sustainable Low-Carbon Transport Through the GEF*. A STAP advisory document by Holger Dalkmann and Cornie Huizenga. Global Environment Facility, Washington, DC. Available at: <http://stapgef.org/sustainable-low-carbon-transport> (assessed on 10/23/2012).
- Goldstein, B., Hiriart, G., Bertani, R., Bromley, C., Gutierrez-Negrin, L., Huenges, E., Muraoka, H., Ragnarsson, A., Tester, J., Zui, V. (2011).** Geothermal energy. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge: Cambridge University Press.
- Greene, D. L. (2010).** *Assessment of Fuel Economy Technologies for Light-duty Vehicles*. National Academies Press. Washington, DC.
- Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A. (2011).** *Global food losses and food wastes – Extent, causes and prevention*. Rome: Food and Agricultural Organization of the United Nations. Available at: <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf> (assessed on 10/23/2012).
- Hansen, J. (2009).** *Storms of My Grandchildren: The truth about the coming climate catastrophe and our last chance to save humanity*. Bloomsbury Press.
- Harvey, L. D. (2010).** *Energy and the new reality: Energy efficiency and the demand for energy services*. Earthscan. London & Washington, DC.

- Hibbard, K. A., Van Vuuren, D. P., Edmonds, J. (2011).** A primer on the Representative Concentration Pathways RCPs and the coordination between the climate and integrated assessment modeling communities. *CLIVAR*, No 56 Vol 16 No 2s.
- Hippel V F., Bunn, B., Diakov, A., Ding, M., Goldston, R., Katsuta, T., Ramana, M. V., Suzuki, T., and Yu, S. (2012).** Chapter 14: Nuclear Energy. In N. Nakicenovic, T. Johansson (Eds.), *Global Energy Assessment*, Cambridge: Cambridge University Press.
- Haiyan, L., Yu, J., Xu, J., Fan, Y., and Bao, X. (2007).** Identification of key oil refining technologies for China National Petroleum Co (CNPC). *Energy Policy*, 35, 2635-2647.
- Heyder, U., Schaphoff, S., Gerten D., and Lucht, W. (2011).** Risk of severe climate change impact on the terrestrial biosphere. *Environmental Research Letters*, 6 (3), 034036. doi:10.1088/1748-9326/6/3/034036.
- Höhne, N., Hare, B., Schaeffer, M., Chen, C., Vieweg, M., & Moltmann, S. (2011).** No move to close the gap at Bangkok climate talks. Berlin: Climate Analytics. Available at: http://www.climateactiontracker.org/briefing_paper_bangkok_2011.pdf (assessed on 10/23/2012).
- Huber, M. and Knutti, R. (2011).** Anthropogenic and natural warming inferred from changes in Earth's energy balance. *Nature Geosciences*, 5, 31-36.
- ICAO (2011).** *Sustainable alternative fuels for aviation*. Montreal: International Civil Aviation Organization. Available at: www.icao.int/SUSTAF (assessed on 10/23/2012).
- ICLEI (2011).** *Green Urban Economy*. Bonn: ICLEI Briefing Sheet. Available at: http://www.iclei.org/fileadmin/user_upload/documents/Global/Publications/Briefing_Sheet_Green_Urban_Economy_20110906_for_web.pdf (assessed on 10/23/2012).
- IEA (2004).** *Coming in from the cold: improving district heating policy in transition economies*. Paris: International Energy Agency.
- IEA (2006a).** *Energy Technology Perspectives 2006: Scenarios and strategies to 2050, Fact Sheet, Buildings and Appliances*. Paris, France: International Energy Agency.
- IEA (2006b).** *Light's Labour's Lost: Policies for energy-efficient lighting*. Paris: International Energy Agency.
- IEA (2008).** *World Energy Outlook 2008*. Paris: International Energy Agency.
- IEA (2009a).** *Cities, towns and renewable energy: Yes In My Front Yard*. Paris: International Energy Agency.
- IEA (2009b).** *Gadgets and Gigawatts: Policies for energy-efficient electronics*. Paris: International Energy Agency.
- IEA (2010a).** *Energy technology perspectives 2010*. Paris: International Energy Agency.
- IEA (2010b).** *Energy performance certification of buildings: a policy tool to improve energy efficiency*. Paris: International Energy Agency.
- IEA (2010c).** *Technology roadmap: concentrating solar power*. Paris: International Energy Agency.
- IEA (2011a).** *World Energy Outlook 2011*. Paris: International Energy Agency.
- IEA (2011b).** *Deploying renewables 2011: Best and future policy practice*. Paris: International Energy Agency.
- IEA (2011c).** *Technology roadmap: Biofuels for transport*. Paris: International Energy Agency.
- IEA (2011d).** *Technology roadmap: Geothermal heat and power*. Paris: International Energy Agency.
- IEA (2011e).** *Technology roadmap: Carbon capture and storage in industrial applications*. Paris: International Energy Agency.
- IEA (2011f).** *Technology Roadmap: Energy efficient buildings – heating and cooling equipment*. Paris: International Energy Agency.
- IEA (2011g).** *Energy transition for industry: India and the global context*. Paris: International Energy Agency.
- IPCC (2007a).** *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland
- IPCC (2007b).** *Summary for policy makers*. In *IPCC, Contribution of Working Group III to the 4th Assessment Report of Intergovernmental Panel on Climate Change, 2007*. Cambridge: Cambridge University Press. Available at http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html (assessed on 10/23/2012).
- IPCC (2011).** *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC (2012).** *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
- Jacobson, M.Z. (2010).** Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health. *J. Geophys. Res.*, 115, D14209. doi:10.1029/2009JD013795
- Jones, G. S., Christidis, N., & Stott, P. A. (2011).** Detecting the influence of fossil fuel and bio-fuel black carbon aerosols on near surface temperature changes. *Atmos. Chem. Phys.*, 11, 799-816.
- Kennedy, C. A., Ramaswami, A., Carney, S., and Dhakal, S. (2009a).** *Greenhouse gas emission baselines for global cities and metropolitan regions*. World Bank's Fifth Urban Research Symposium. Marseille, France. Available at: <http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1256566800920/6505269-1268260567624/KennedyComm.pdf> (assessed on 10/23/2012).

- Kennedy, C.**, Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havranek, M., Pataki, D., Phdungsilp, A., Ramaswami, A., and Villalba Mendez, G. (2009b). Greenhouse gas emission from global cities. *Environmental Science & Technology*, 43 (19), 7297-7302
- Kennedy, C.**, Bristow, D., Derrible, S., Mohareb, E., Saneinejad, S., Tupka, R., Sugar, L., Zizzo, R., and McIntyre, B. (2009c) *Getting to Carbon Neutral: A Review of Best Practices in Infrastructure Strategy*. World Bank's Fifth Urban Research Symposium. Marseille, France. Available at <http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1256566800920/6505269-1268260567624/Kennedy.pdf> (assessed on 10/23/2012).
- Khare, A.**, Beckman, T., & Crouse, N. (2011). Cities addressing climate change: introducing a tripartite model for sustainable partnership. *Sustainable Cities and Society*, 1, 227-235.
- Kirkels, A.** & Verbong, G. (2011). Biomass gasification: still promising? A 30-year global overview. *Renewable and Sustainable Energy Reviews*, 15 (1), 471-481.
- Krewitt, W.**, Nienhaus, K., Klebmann, C., Capone, C., Stricker, E., Grauss, W., Hoggwijk, M., Supersberger, M., Von Winterfeld, U., and Samadi, S. (2009). Role and potential of renewable energy and energy efficiency for global energy supply. Available at: http://www.umweltbundesamt.de/uba-info-medien/mysql_medien.php?anfrage=Kennummer&Suchwort=3768 (assessed on 10/23/2012).
- Lenton, T. M.**, Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *PNAS*, 105 (6), 1786-1793.
- Lenton, T. M.** (2011). Early warning of climate tipping points. *Nature Climate Change*, 1, 201-209.
- Lewis, A.**, Estefen, S., Huckerby, J., Musial, W., Pontes, T., and Torres-Martinez, J. (2011). Ocean energy. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Le Quéré, C.**, Raupach, M.R., Canadell, J.G., Marland G., et al. (2009). Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, 2, 831 – 836.
- Liu, H.**, Yu, J., Xu, J., Fan Y., and Bao, X. (2007). Identification of key oil refining technologies for China National Petroleum Co. (CNPC). *Energy Policy*, 35(4), 2635-2647.
- Lobell, D.**, Schlenker, W., and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, 333 (6042), 616-620.
- MacCracken, M. C.** (2006). *Geoengineering: Worthy of cautious evaluation*. *Climatic Change*, 77(3-4), 235-243.
- Makarow, M.**, Ceulemans, R., and Horn, L. (2009). Science Policy Briefing 37: impacts of ocean acidification. Strasbourg: European Science Foundation. Available at: <http://www.esf.org/publications/science-policy-briefings.html> (assessed on 10/23/2012).
- Martin, W. J.**, Glass, R. I., Balbus, J. M., and Collins, F. (2011). A major environmental cause of death. *Science*, 334 (6053), 180-181.
- Matthews, D. H.** and Weaver, J. A. (2010). Committed climate warming. *Nature Geosciences*, 3, 142-143
- McDonald, R. I.**, Green P., Balk, D., Fekete, B. M., Revenga, C., Todd M., and Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. *PNAS*, 108 (15), 6312-6317.
- Min, S.**, Zhang, X., Zwiers, F. W., and Hegerl, G. C. (2011). Human contribution to more-intense precipitation extremes. *Nature*, 470, 378-381
- MIT** (2012). *Energy and Climate Outlook 2012*. Cambridge: MIT joint program on the Science and Policy of Global Changes. Available at: <http://globalchange.mit.edu/research/publications/other/special/2012Outlook> (assessed on 10/23/2012).
- Mitchell, C.**, Sawin, J., Pokharel, G., Kammen, D., & Wang, Z. (2011). Chapter 11: Policy, financing and implementation. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Montzka, S. A.**, Dlugokencky, E. J., and Butler, J. H. (2011). Non-CO₂ greenhouse gases and climate change. *Nature*, 476, 43-50.
- Morton, O.** (2012). *The dream that failed. Special report on nuclear energy*, London: The Economist. Available at <http://www.economist.com/node/21549098/print> (assessed on 10/23/2012).
- Moss, R.**, Edmonds, J., Hibbard, K., Manning, M., Rose, S., van Vuuren, D. P., Carter, T., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). A new approach to scenario development for the IPCC Fifth Assessment Report. *Nature*, 463, 747-756.
- Nabuurs, G. J.**, Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., et al. (2007). Forestry in climate change mitigation. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.), *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press.
- NAS** (2010). *Advancing the Science of Climate Change, America's Climate Choices: Panel on Advancing the Science of Climate Change*; Washington, DC: National Research Council, National Academy of Sciences.

- Naswa, P.** and Garg, A. (2011). Managing climate-induced risks on Indian infrastructure assets. *Current Science*, 101(3), 395-404.
- Nelson, G. C.,** Rosegrant, M. W., Palazzo, A. Gray, I., Ingersoll, C., Robertson R., Tokgoz, S., Zhu T., Sulser, T. B., Ringler, C., Msangi, S., and You, L. (2010). *Food security farming and climate change to 2050: Scenarios results policy options*. Washington, DC: International Food Policy Research Institute. Available at: <http://www.ifpri.org/sites/default/files/publications/rr172.pdf> (assessed on 10/23/2012).
- Nevoa, E.,** Fib Y.-B., Pavlicecka, T., Khalifaa, S., Tavasias, M., and Beileasa, A. (2012). Evolution of wild cereals during 28 years of global warming in Israel. *PNAS*, 109 (9), 3412-3415.
- OECD.** (2010). *Cities and Climate Change*, Paris: OECD.
- Olivier, J. G. J.,** Janssens-Maenhout, G. Peters, J. A. H. W., and Wilson, J. (2011). Long term trend in global CO₂ emissions. The Hague: PBL/JRL. Available at: http://edgar.jrc.ec.europa.eu/news_docs/C02%20Mondiaal_%20webdef_19sept.pdf (assessed on 10/23/2012).
- Pall, P.,** Aina, T., Stone D. A., Stott P. A., Nozawa, T., Hilberts A. G. J., Lohmann, D., & Allen, M. R. (2011). Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature*, 470 (7334), 382-386.
- Parry, M.L.,** Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
- Peters, G. P.,** Marland, G., Le Quéré C., Boden, T., Canadell, J. G., and Raupach M. R. (2012). Rapid growth in CO₂ emissions after the 2008–2009 global financial crisis. *Nature Climate Change*, 2, 2-4.
- Potter, C.,** Klooster, S., Hiatt, C., Genovese, V., & Castilla-Rubio J. C. (2011). Changes in the carbon cycle of Amazon ecosystems during the 2010 drought. *Environmental Research Letters*, 6, 034024. doi:10.1088/1748-9326/6/3/034024.
- Rahmstorf, S.** (2010). A new view on sea level rise. *Nature Reports Climate Change*, 4, 44-45. doi:10.1038/climate.2010.29.
- Reid, G.,** Lilliestam, J., Patt, A., Schellekens, G., Mitchell, C., Battaglini, A., and Jariz, H. (2010). *A Global Renewables Investment Plan: Scaling up investments in renewable energy technologies*. GIZ, 2010. Available at: http://www.direc2010.gov.in/pdf/2209-10_GTZ_GRIP-Studie_RZ_SCREEN.pdf (assessed on 10/23/2012).
- REN21.** (2011). *Renewables 2011 Global Status Report*. Paris: REN21 Secretariat. Available at: www.ren21.net (assessed on 10/23/2012).
- REN21.** (2012). *Renewables 2012 Global Status Report*. Paris: REN21 Secretariat. Available at www.ren21.net (assessed on 10/23/2012).
- Riahi, K.,** Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V. et al. (2012). Energy Pathways for Sustainable Development Chapter 17. In N. Nakicenovic & T. Johansson (Eds.), *Global Energy Assessment*, Cambridge: Cambridge University Press.
- Ribeiro, S. K.,** Dubeux, C., Figueroa, M. J., Hupe, J., Kobayashi, S., Melobretas, L. A., Thrasher, T., and Webb, S. (2012). Chapter 9: Energy End-Use: Transport. In N. Nakicenovic, T. Johansson (Eds.), *Global Energy Assessment*, Cambridge: Cambridge University Press.
- Rignot, E.,** Velicogna, I., van den Broeke, M. R., Monaghan, A., and Lenaerts, J. (2011). Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters*, 38, L05503. doi:10.1029/2011GL046583.
- Robins, N.,** Singh, C., Clover, R., Knight, Z., and Magness, J., (2010). *Sizing the climate economy*. HSBC Global Research. Available at: <http://www.research.hsbc.com/midas/Res/RDV?ao=20&key=wU4BbdyRmz&n=276049.PDF> (assessed on 10/23/2012).
- Robinson, A.,** Calov, R., & Ganopolski, A. (2012). Multistability and critical thresholds of the Greenland ice sheet. *Nature Climate Change*, 2 (4), 429-432.
- Rogelj, J.,** Meinshausen, M. et al. (2010). Copenhagen Accord pledges are paltry. *Nature*, 464, 1126-1128.
- Rowlands, D. J.,** Frame, D. J., Ackerley, D., Aina, T., Booth, B. B., Christensen, C., Collins, M., Faull, N., Forest, C. E., Grandey, B. S., Gryspeerdt, E., Highwood, E. J., Ingram, W. J., Knight, S., Lopez, A., Massey, N., McNamara, F., Meinshausen, N., Piani, C., Rosier, S. M., Smith, L. A., Stone, D. A., Thurston, M., Yamazaki, K., Yamazaki, Y. H., Allen, M. R. (2012). Broad range of 2050 warming from an observationally constrained large climate model ensemble. *Nature Geoscience*, 5, 256-260.
- Royal Society.** (2009). *Geoengineering the climate: science governance and uncertainty*. London: The Royal Society. Available at http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf (assessed 10/23/2012).
- Sachs, H.,** Talbot, J., & Kaufman, N. (2011). *Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011*. American Council for an Energy-Efficient Economy. Washington, DC.
- Sathaye J.,** Dale, L., Larsen, P., Fitts, G., Koy, K., Lewis, S., and Lucena, A. (2012). Estimating risk to California energy infrastructure from projected climate change. Berkeley: Lawrence Berkeley National Laboratory. Available at: <http://www.energy.ca.gov/2012publications/CEC-500-2012-057/CEC-500-2012-057.pdf> (assessed 10/23/2012).
- Schipper, L.** (2007). *Automobile Fuel Economy and CO₂ Emissions in Industrialized Countries: Troubling Trends through 2005/6*, Washington, DC: EMBARQ World Resources Institute Center for Sustainable Transport. Available at <http://pdf.wri.org/automobile-fuel-economy-co2-industrialized-countries.pdf> (assessed on 10/23/2012).

- Schipper, L., Anh, T. L., Orn, H., Cordeiro, M., and Liska, T.** (2008). *Measuring the Invisible Quantifying Emissions Reductions from Transport Solutions*, Washington, DC: World Resources Institute. Available at: <http://www.wri.org/publication/measuring-the-invisible-hanoi> (assessed on 10/23/2012).
- Schnieders, J. and Hermelink, A.** (2006). CEPHEUS Results: Measurements and Occupants' Satisfaction Provide Evidence for Passive Houses Being an Option for Sustainable Building, *Energy Policy*, 34, 151-171.
- Schock, R., Sims, R., Bull, S., Larsen, H., Likhachev, V., Nagano, K., Vuori, S., Yeager, K., & Zhou, L.** (2012). Energy supply systems. In *Global Energy Assessment: Toward a Sustainable Future*. Cambridge: Cambridge University Press. Luxembourg: IIASA.
- Shindell, D. and Faluvegi, G.** (2009). Climate response to regional radiative forcing during the 20th century. *Nature Geoscience*, 2, 294-300.
- Sims, R.E.H., Schock, R.N., Adegbulugbe, A., Fenhann, J., Konstantinaviute, I., Moomaw, W., Nimir, H.B., Schlamadinger, B., Torres-Martínez, J., Turner, C., Uchiyama, Y., Vuori, S.J.V., Wamukonya, N., and Zhang X.** (2007). Energy supply. In *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Sims, R., Mercado, P. Krewitt, W., Bhuyan, G., Flynn, D., Holttinen, H., Jannuzzi, G., Khennas, S., Liu, Y., O'Malley, M., Nilsson, L. J., Ogden, J., Ogimoto, K., Outhred, H., Ulleberg, O., and van Hulle, F.** (2011). Integration of Renewable Energy into Present and Future Energy Systems. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., & Smith, J.** (2008). Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society London. *Biological Sciences*, 363(1492), 789-813.
- Smith, S. M., Horrocks, L., Harvey, A., & Hamilton, C.**, (2011). Rethinking adaptation for a 4°C world. *Phil. Trans. R. Soc. A*, 369(1934), 196-216.
- Sokolov, A. P., Stone, P. H., Forest, C. E., Prinn, R., Sarofim, M. C., Webster, M., Paltsev, S., Schlosser, C. A., Kicklighter, D., Dutkiewicz, S., Reilly, J., and Wang, C. et al.** (2009). Probabilistic forecast for twenty-first-century climate based on uncertainties in emissions without policy and climate parameters. *J. Climate*, 22, 5175-5204.
- Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L.** (Eds.) (2007). *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Solomon, S., Plattner G. K., Knutti, R., and Friedlingstein, P.** (2009). Irreversible climate change due to carbon dioxide emissions. *PNAS*, 106 (6), 1704-1709.
- Stern, N.** (2007). *The Economics of Climate Change: The Stern Review*. Cambridge: Cambridge University Press.
- Tedesco, M., Fettweis, X., van den Broeke, M. R., van de Wal, R. S. W., Smeets, C. J. P. P., van de Berg, W. J., Serreze, M. C., & Box, J. E.** (2011). The role of albedo and accumulation in the 2010 melting record in Greenland. *Environmental Research Letters*, 6. doi:101088/1748-9326/6/1/014005.
- UN** (2012). UN Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2011 Revision*, New York: United Nations. CD-ROM Edition.
- UNEP** (2011a). *Bridging the emissions gap – a UNEP synthesis report*, United Nations Environment Programme. Available at: http://www.unep.org/pdf/UNEP_bridging_gap.pdf (assessed on 10/23/2012).
- UNEP** (2011b). *Global trends in renewable energy investment 2011*, United Nations Environment Programme. Available at: http://www.unep.org/pdf/BNEF_global_trends_in_renewable_energy_investment_2011_report.pdf (assessed on 10/23/2012).
- UNEP** (2011c). *Towards a Green Economy: pathways to sustainable development and poverty eradication*, Paris: United Nations Environment Programme. Available at: <http://www.unep.org/greeneconomy/> (assessed on 10/23/2012).
- UNEP** (2011d). *Towards a green economy – transport, investing in energy and resource efficiency*, Paris: United Nations Environment Programme. Available at: <http://www.unep.org/greeneconomy/> (assessed on 10/23/2012).
- UNEP** (2011e). *Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers*. United Nations Environment Programme and World Meteorological Organization. Available at: http://www.unep.org/dewa/Portals/67/pdf/Black_Carbon.pdf (assessed on 10/23/2012).
- UNEP** (2012). *GEO 5 – Global Environment Outlook: Summary for Policy Makers*, United Nations Environment Programme. Available at: http://www.unep.org/geo/pdfs/GEO5_SPM_English.pdf (assessed on 10/23/2012).
- UNFCCC** (2008). *Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007*, Bonn: United Nations Framework Convention on Climate Change. Available at <http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf> (assessed on 10/23/2012).

- UNFCCC** (2011a). *Report of the conference of the parties on its sixteenth session*, Bonn, UNFCCC. Available at: <http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf> (assessed on 10/23/2012).
- UNFCCC**. (2011b). *Fact sheet: The Kyoto Protocol*, Bonn: United Nations Framework Convention on Climate Change. Available at: http://unfccc.int/files/press/backgrounders/application/pdf/fact_sheet_the_kyoto_protocol.pdf (assessed on 10/23/2012).
- UNIDO** (2008). *Policies for promoting industrial energy efficiency in developing countries and transition economies*, Vienna: UN Industrial Development Organisation. Available at: <http://www.unido.org/index.php?id=1000596> (assessed on 10/23/2012).
- UNIDO** (2011). *Industrial Development Report 2011: Industrial energy efficiency for sustainable wealth creation. Capturing environmental, economic and social dividends*, Vienna: UN Industrial Development Organization. Available at: http://www.unido.org/fileadmin/user_media/Publications/IDR/2011/UNIDO_FULL_REPORT_EBOOK.pdf (assessed on 10/23/2012).
- Ürge-Vorsatz, D.**, Eyre, N., Graham, P., Harvey, D., Hertwich, E., Jiang, Y., Kornevall, C., et al., (2012a). Towards Sustainable Energy End-Use: Buildings Chapter 10. In N. Nakicenovic & T. Johansson (Eds.), *Global Energy Assessment*, Cambridge: Cambridge University Press.
- Ürge-Vorsatz, D.**, Petrichenko, K., Antal, M., Staniec, M., Labelle, M., Ozden, E., & Labzina, E. (2012b). *Best practice policies for low energy and carbon buildings- a scenario analysis*, Budapest: Center for Climate Change and Sustainable Policy (3CSEP) for the Global Buildings Performance Network. Available at: http://www.globalbuildings.org/resources/uploads/WEBSITE_CEU_FULL_low.pdf (assessed on 10/23/2012).
- Vermeer, M.** and Rahmstorf, S. (2009). Global sea level linked to global temperature. *PNAS*, 106, 21527-21532
- Vörösmarty, C. J.**, McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., and Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555-561.
- Wang, M.** and Overland, J. E. (2009). A sea ice free summer Arctic within 30 years? *Geophysical Research Letters*, 36, 5. doi: 10.1029/2009GL037820.
- Weinert, J. X.**, Ogden, J. M., Sperling, D., and Burke, A. (2008). The future of electric two-wheelers and electric vehicles in China. *Energy Policy*, 36, 2544-2555.
- Williams, J. W.**, Jackson, S. T., and Kutzbach, J. E. (2007) Projected distributions of novel and disappearing climates by 2100 AD. *PNAS*, 104, 5738-5742.
- William, F. L.** et al. (2012). Averting biodiversity collapse in tropical forest protected areas. *Nature*, 489, 290-294.
- Wiser, R.**, Yang, Z., Hand, M., Hohmeyer, O., Infield, D., Jensen, P. H., Nikolaev, V., O'Malley, M., Sinden, G., and Zervos, A. (2011). Wind energy. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Woerlen, C.** (2011). *Meta-evaluation of climate mitigation evaluations, Climate Change Evaluation Community of Practice Study*, Washington, DC: Arepo Consults, GEF Evaluation Office. Available at: http://www.climate-eval.org/sites/default/files/file/MetaEvaluation_Woerlen.pdf (assessed on 10/23/2012).
- Woodall, C. W.**, Oswalt, C. M., Westfall, J. A., Perry, C. H., Nelson, M. D., and Finley, A. O. (2009). An indicator of tree migration in forests of the eastern United States. *Forest Ecology and Management*, 257, 1434-1444.
- World Economic Forum** (2010). *Green investing 2010: Policy mechanisms to bridge the financing gap*. Geneva, Switzerland: World Economic Forum. Available at: <http://www.weforum.org/reports/green-investing-2010-policy-mechanisms-bridge-financing-gap> (assessed on 10/23/2012).
- Xu, T.**, Sathaye, J., Akbari, H., Gard, V., and Tetali, S. (2012). Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions. *Building and Environment*, 48, 1-6.
- Yude, P.**, Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.P., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, D.A., Piao, S., Rautiainen, A., Sitch, S., and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*. 333 (6045), 988-993.
- Zhu, K.**, Woodall, C. W., and Clark, J. S. (2012). Failure to migrate: lack of tree range expansion in response to climate change. *Global Change Biology*, 18 (3), 1042-1052.

www.theGEF.org



GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET