The Century Ahead: Four Global Scenarios

Technical Documentation

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Forward

The research documented in this report carries forward a two-decade program to examine alternative scenarios and the requirements for redirecting global development toward a sustainable future. The roots of this program lie with the 1987 publication of *Our Common Future* by the World Commission on Environment and Development ("Brundtland Commission"). This seminal report placed the concept of sustainable development at the center of international research and policy agendas, inspiring the Earth Summit of 1992 where world leaders endorsed the commitment to a form of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."

This call to pass on an undiminished world to future generations raises deep and daunting questions for analysis, social and environmental policy, and values and ethics: what approaches and methods are appropriate for examining long-range socio-ecological prospects in a coherent and scientifically-grounded way? What policy adjustments in the near term are necessary to assure a vibrant and verdant civilization for the future? What are the implications for our values, behaviors, and lifestyles of taking seriously the concern for the well-being of people who are distant in space and time, and of the wider community of life with whom we share the biosphere?

To address such critical, large-scale questions, the Tellus Institute and the Stockholm Environment Institute launched The PoleStar Project in 1991 (www.polestarproject.org). The early years of that effort were devoted to collecting and systematically organizing a vast global data set covering a vast range of economic, social, resource, and environmental parameters; building a flexible computer-based tool for constructing integrated, long-range scenarios (The PoleStar System); and building an international network of partners to formulate and quantify real-world scenarios at national, regional, and global scales. PoleStar projects were distinguished by a commitment to both narrative richness in scenario description and detail in scenario quantification. The work was unique in its consideration of the possibility of fundamental change in global development including discontinuities and restructuring of socio-ecological systems. This included both unwelcome descents into barbarized futures and "great transitions" to sustainable, peaceful, and livable civilizations.

To further advance this effort, the Global Scenario Group (www.gsg.org) was assembled by the Tellus Institute and Stockholm Environment Institute as an interdisciplinary and international group. Coordinated by physicist Paul Raskin and ecologist Gilberto Gallopín, each with broad experience conducting integrated scenario assessments, and with the aid of a research and support unit at Tellus Institute, the GSG produced a series of path-breaking reports between 1995-2002. Its culminating report summarized its perspective in a widely read non-technical monograph *Great Transition: The Promise and Lure of the Times Ahead* (http://www.tellus.org/documents/Great_Transition.pdf). In 2003, the Great Transition Initiative (www.GTInitiative.org), a broader network of several hundred scholars and

activists, was convened by the Tellus Institute under the directorship of Paul Raskin to help carry this global scenario work forward.

This report summarizes the technical assumptions and key findings of the 2009 scenario updates and enhancements using the PoleStar System. As such, it builds upon earlier reports, especially Kemp-Benedict et al. (2002), Raskin et al. (1998) and Gallopín and Raskin (2002). While broadly compatible with earlier findings, the current simulations benefit from a decade of additional data (the base year has been advanced from 1995 to 2005), and an expanding literature on unfolding environmental, resource, and social developments. Among other features, the report introduces a new index (*Quality of Development*) that combines indicators of human, community, and environment well-being to provide a consolidated measure of the state-of-the-world under the very different conditions envisioned across the various scenarios.

Acknowledgements

As the latest chapter in an ongoing saga of exploration, the authors are indebted to the contributions, insights, and critiques of individuals too numerous to list here: the score of researchers at the Tellus Institute, many of whom have gone on to their own careers in integrated assessment; the thirty distinguished members of the Global Scenario Group; the hundreds of participants in the Great Transition Inititiative network who continue to guide and apply this research; and the funders who made it possible, especially the United Nations Environment Programme, Rockefeller Foundation, Stockholm Environment Institute, and Nippon Foundation. Several colleagues warrant special mention for their leading roles in early phases of this work: Dr. Gilberto Gallopín for theoretical leadership, Dr. Eric Kemp-Benedict for technical contributions, and Dr. Gordon Goodman for his visionary inspiration at the inception of the PoleStar Project.

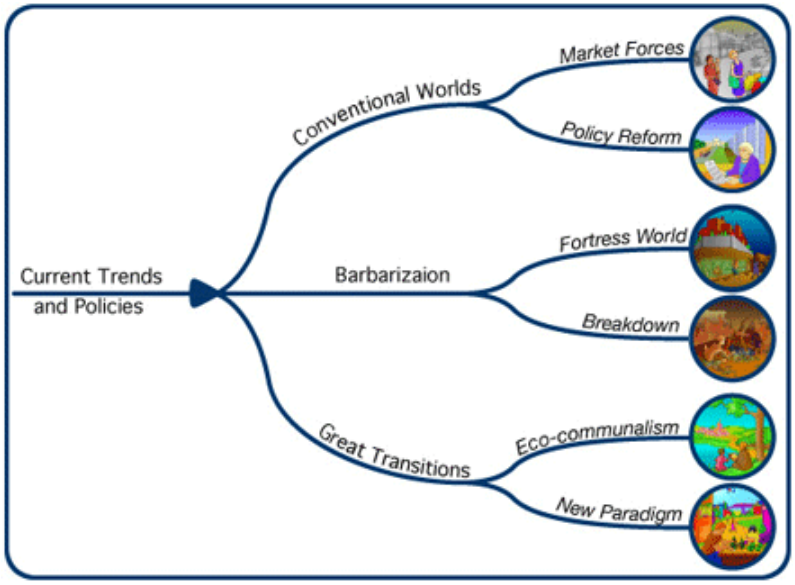
1 Introduction

This report updates and enhances four scenarios originally developed by the *Global Scenario Group* (www.gsg.org), an international and interdisciplinary group active from 1995-2002. The GSG scenarios were applied widely at global, regional and national levels in projects to evaluate strategies for sustainable development. The scenarios are based on a two-tier hierarchy (Gallopín et al., 1997; Raskin et al., 2002). The two tiers were *classes*, distinguished by fundamentally different social visions, and *variants*, reflecting a range of possible outcomes within each class.

Three broad classes were developed – *Conventional Worlds*, *Barbarization*, and *Great Transitions* – characterized by essential continuity with current patterns, fundamental but undesirable social change and fundamental and favorable social transformation. *Conventional Worlds* envisioned the global system of the 21st Century evolving without major surprises, sharp discontinuities, or fundamental transformations in the basis for human civilization. The future is shaped by the evolution, expansion and globalization of the dominant values and socioeconomic relationships of industrial society. By contrast, the *Barbarization* and *Great Transition* scenario classes relax the assumption of the long term continuity of dominant values and institutional arrangements. In *Barbarization*, crises are not ameliorated by *Conventional World* policies and market mechanisms, and civilization deteriorates. In *Great Transition*, the world responds to contemporary challenges by establishing adequate global institutions, prioritizing environmental sustainability, and adjusting values and behaviors.

Two variants are introduced for each class as depicted in the figure below.

Figure 1-1. Scenario Taxonomy



This report analyzes four of these. The two *Conventional Worlds* (occasionally referred to as CW) scenarios – *Market Forces* and *Policy Reform* – are discussed in considerable detail, followed by chapters on the *Fortress World* scenario and *Great Transitions* scenario (New Sustainability Paradigm variation).

The *Current Accounts* (base year) data and scenarios have been developed using the PoleStar system, a software tool for mounting economic, resource and environmental information, and for examining alternative development scenarios (www.PolestarProject.org). The report focuses on assumptions and computational methodologies. Detailed quantitative outputs can be found at http://tellus.org/programs/integratedscenarios.html.

The Market Forces Scenario

Within *Conventional Worlds*, the *Market Forces* scenario is a story of a market-driven world in the 2lst Century in which demographic, economic, environmental and technological trends unfold without major surprise relative to currently unfolding trends. Continuity, globalization and convergence are key characteristics of world development – institutions gradually adjust without major ruptures, international economic integration proceeds apace and the socioeconomic patterns of poor regions converge slowly toward the development model of the rich regions. Despite economic growth, extreme income disparity between rich and poor countries, and between the rich and poor within countries, remains a critical social trend. Environmental transformation and degradation are a progressively more significant factor in global affairs.

The Policy Reform Scenario

The *Policy Reform* scenario envisions the emergence of strong political will for taking harmonized and rapid action to ensure a successful transition to a more equitable and environmentally resilient future. Rather than a projection into the future, the *Policy Reform* scenario is a normative scenario constructed as a backcast *from* the future (Robinson, 1990). It is designed to achieve a set of future sustainability goals. The analytical task is to identify plausible development pathways for reaching that end-point. Thus, the *Policy Reform* scenario explores the requirements for simultaneously achieving social and environmental sustainability goals under the high economic growth conditions of *Conventional Worlds*. The goals are summarized below in Table 1-1 and Table 1-2.

Table 1-1. Social indicators and targets for the *Policy Reform* scenario

Indicator		1995	2005	2025	2050	2100
Hunger	millions of people	820	893	446	223	56
	% of 2005 value	-	-	50%	25%	6%
	% of population	14%	13.8%	5.7%	2.6%	0.66%
Unsafe Water	millions of people	1,360	-	680	340	150
		-	-	50%	25%	11%
	% of population	24%	-	9%	4%	
Illiteracy	millions of people	1,380	-	690	345	170
	% of 1995 value	-	-	50%	25%	12%
	% of population	24%	-	9%	4%	2%
Life Expectancy	Years	66	-	> 70 in all countries		

Source: Adapted from (Gallopín and Raskin, 2002).

Table 1-2. Environmental indicators and targets for the *Policy Reform* scenario

CLIMATE						
Region[1]	Indicator	1995	2005	2025	2050	2100
World	CO_2 concentration	360 ppmv	350 ppmv	stabilize at < 350 ppmv CO_2 by 2100		
	Warming			< 2.0° rise between 1990 and 2100		
	CO_2 emissions	19.7 GtC	60.4 GtC	< 325 GtC cumulative, 1990-2100		
OECD	CO_2 emissions rate	various and rising		< 80% of 1990	< 20% of 1990	10% below 1990 OECD rates. Per capita emissions of -0.25 GtC
non-OECD	CO_2 emissions rate	various and rising		increases slowing, energy efficiency rising	reach OECD per capita rates by 2075	
RESOURCE USE						
Region	Indicator	1995	2005	2025	2050	2100
OECD	Eco-efficiency	$100 GDP/ 300 kg		4-fold increase ($100 GDP/75 kg)	10-fold increase ($100 GDP/30 kg)	
	Materials use/capita	80 tonnes		< 60 tonnes	< 30 tonnes	
non-OECD	Eco-efficiency	various but low		converge toward OECD practices		
	Materials use/capita	various but low		converge toward OECD per capita values		
TOXICS						
Region	Indicator	1995	2005	2025	2050	2100
World	Releases of persistent organic pollutants & heavy metals	various but high		< 40% of 2005	< 7% of 2005	< 4% of 2005
FRESHWATER						
Region	Indicator	1995	2005	2025	2050	2100
World	Use-to-Resource ratio	various and rising		reaches peak values	decrease if feasible; below 2005 value in high-stress areas	
	Population in water stress	1.8 billion (32%)	1.73 billion (27%)	< 1.65 billion (<21%)	< 1.2 billion, (<14%)	< 0.6 billion, (<7%)
ECOSYSTEM PRESSURE						
Region	Indicator	1995	2005	2025	2050	2100
World	Deforestation	various but high		no further deforestation	net reforestation	
	Land degradation	various but high		no further degradation	net restoration	
	Marine over-fishing	fish stocks declining		over-fishing stops	healthy fish stocks	

Source: Adapted from (Gallopín and Raskin, 2002).

[1] OECD stands for Organisation for Economic Co-operation and Development. The OECD and non-OECD regions used in this analysis are defined on page 5.

The Fortress World Scenario

The *Fortress World* scenario is a variant of a broader class of *Barbarization* scenarios, in the hierarchy of the Global Scenario Group (Gallopín et al., 1997). *Barbarization* scenarios envision the grim possibility that the social, economic and moral underpinnings of civilization deteriorate, as emerging problems overwhelm the coping capacity of both markets and policy reforms. The *Fortress World* variant of the Barbarization story features an authoritarian response to the threat of breakdown. Ensconced in protected enclaves, elites safeguard their privilege by controlling an impoverished majority and managing critical natural resources, while outside the fortress there is repression, environmental destruction and misery.

The Great Transition Scenario

The *Great Transition* scenario explores visionary solutions to the sustainability challenge, including new socioeconomic arrangements and fundamental changes in values. This scenario depicts a transition to a society that preserves natural systems, provides high levels of welfare through material sufficiency and equitable distribution, and enjoys a strong sense of local solidarity.

Global Regions

- As with other global assessments, we have adopted multi-country regions as the basic structure of analysis. Specifically, we have grouped countries into eleven global regions, based on the comparability of socioeconomic development and on geographical considerations. The regional groupings used in this analysis, and the countries included in each region, are displayed in Table 1-3.

In some cases, we further combine the eleven regions into two *macro-regions*:

- *OECD* (North America, Western Europe, and OECD Pacific)[2], and
- *Non-OECD, or Developing* (Africa, FSU, Eastern Europe, Latin America, Middle East, China+, South Asia and Southeast Asia).

[2] Polestar's three "OECD regions" do not include certain **Organisation for Economic Co-operation and Development** (**OECD**) countries, such as Czech Republic, Hungary, Mexico, Poland, Slovak Republic and Turkey, and include some non-OECD regions.

Table 1-3. Regional structure[3]

North America			
The Bahamas	Canada	Puerto Rico	United States
Western Europe			
Andorra	Greece	Malta	Switzerland
Austria	Greenland	Netherlands	United Kingdom
Belgium	Iceland	Norway	Yugoslavia, FR (Serbia/Montenegro)
Denmark	Ireland	Portugal	
Finland	Italy	Slovenia, Rep	
France	Luxembourg	Spain	
Germany	Macedonia, FYR	Sweden	
Pacific OECD			
American Samoa	Japan	New Caledonia	Samoa
Australia	Kiribati	New Zealand	Solomon Islands
Cook Islands	*Korea, Rep.*	Niue	Tokelau
Fiji	Marshall Islands	Northern Mariana Is.	Tonga
French Polynesia	Micronesia, Fed. Sts.	Palau	Vanuatu
Guam	Nauru	Pitcairn Is.	Wallis and Futuna Is.
Former Soviet Union			
Armenia	Georgia	Lithuania	Turkmenistan
Azerbaijan	Kazakhstan	Moldova	Ukraine
Belarus	Kyrgyz Republic	Russian Federation	Uzbekistan
Estonia	Latvia	Tajikistan	
Eastern Europe			
Albania	*Croatia*	Poland	*Turkey*
Bosnia & Herzegovina	Czech Republic	Romania	
Bulgaria	Hungary	Slovak Republic	

[3] Countries shown in *italics* were included in a different PoleStar Region in the previous analysis (see Forward for more details).

Table 1-3 Continued. Regional structure

Africa			
Algeria	Djibouti	Madagascar	Seychelles
Angola	Egypt, Arab Rep.	Malawi	Sierra Leone
Benin	Equatorial Guinea	Mali	Somalia
Botswana	Eritrea	Mauritania	South Africa
Burkina Faso	Ethiopia	Mauritius	Sudan
Burundi	Gabon	Morocco	Swaziland
Cameroon	Gambia, The	Mozambique	Tanzania
Cape Verde	Ghana	Namibia	Togo
Central African Rep.	Guinea	Niger	Tunisia
Chad	Guinea-Bissau	Nigeria	Uganda
Comoros	Kenya	Rwanda	Western Sahara
Congo	Lesotho	St. Helena	Zambia
Congo, Dem. Rep.	Liberia	Saõ Tome & Principe	Zimbabwe
Côte d'Ivoire	Libya	Senegal	
Latin America			
Anguilla	Chile	Guatemala	Paraguay
Antigua and Barbuda	Colombia	Guyana	Peru
Argentina	Costa Rica	Haiti	St. Kitts and Nevis
Aruba	Cuba	Honduras	St. Lucia
Barbados	Dominica	Jamaica	St. Vincent and the Grenadines
Belize	Dominican Republic	Martinique	Suriname
Bermuda	Ecuador	Mexico	Trinidad & Tobago
Bolivia	El Salvador	Montserrat	Turks & Caicos Is.
Brazil	French Guiana	Neth. Antilles	U.S. Virgin Islands
Brit. Virgin Islands	Grenada	Nicaragua	Uruguay
Cayman Islands	Guadeloupe	Panama	Venezuela
China+			
China (including Hong Kong)	Lao PDR	Mongolia	
Korea, Dem. Rep.	Macao	Vietnam	

Table 1-3 Continued. Regional structure

South Asia			
Bangladesh	Nepal	Sri Lanka	
India	Pakistan		
Southeast Asia			
Bhutan	Indonesia	Papua New Guinea	Thailand
Brunei	Malaysia	Philippines	
Cambodia	Maldives	Singapore	
East Timor	Myanmar	Taiwan	
Middle East			
Afghanistan	Iraq	Lebanon	Syrian Arab Republic
Bahrain	Israel	Oman	United Arab Emirates
Cyprus	Jordan	Qatar	West Bank & Gaza
Iran, Islamic Rep.	Kuwait	Saudi Arabia	Yemen, Rep.

The Structure of this Report

Chapters 2 through 7 address major topics or sectors, specifically in relation to the *Conventional Worlds* scenarios of *Market Forces* and *Policy Reform*. We first introduce the data and assumptions used to construct the *Current Accounts* (base year) data for the topic. The base year is 2005, the most recent year for which data are generally available across a wide range of topics. Next, we introduce the data, methodologies and assumptions used to construct the *Market Forces* and *Policy Reform* scenarios for each topic, and review the detailed results of the scenario projections. In the final two chapters we discuss the methodologies for the *Fortress World* and *Great Transition* scenarios.

Chapter 2 summarizes the methodology used for developing demographics, economics and poverty patterns in the *Market Forces* and *Policy Reform* scenarios.

Chapter 3 examines the energy sector and climate change issues, and describes the results of the *Market Forces* and *Policy Reform* scenarios. Climate goals are translated into carbon emissions budgets, which constrain energy sector production and consumption patterns in the *Policy Reform* scenario. Energy requirements are analyzed for five sectors: industry, transport, households, services and agriculture.

Chapter 4 discusses agriculture and food. It considers the demands for food and other agricultural products that result from the

population and income assumptions of the *Market Forces* and *Policy Reform* scenarios, and considers the agricultural production systems that satisfy those demands.

Chapter 5 treats land use and forestry. It examines the implications of human settlement patterns, agricultural production and forestry for land use of the *Market Forces* and *Policy Reform* scenarios.

Chapter 6 considers water requirements and the sufficiency of water resources. It examines trends in water use and water scarcity in the *Market Forces* and *Policy Reform* scenarios, and describes how, in the *Policy Reform* scenario, measures are introduced to mitigate water scarcity.

Chapter 7 reviews local and regional environmental issues, focusing specifically on acidification, water pollution, solid waste, toxic wastes and indoor air pollution associated with the use of traditional biomass fuels. It describes the impacts of the *Market Forces* and *Policy Reform* scenarios.

Chapter 8 discusses the assumptions and methodology for developing the *Great Transition* scenario.

Chapter 9 discusses the assumptions and methodology for developing the *Fortress World* scenario.

Chapter 10 discusses the Quality of Development Index, and compares the results for all four scenarios.

2 Population, Economy, Poverty

Demographic and economic assumptions play a fundamental role in driving patterns of resource consumption and pollutant emission in the scenarios. They are also important in the poverty analysis. There, in combination with assumptions about income distribution, they determine the extent of poverty.

This section deals with the *Current Accounts* data for 2005, and the two *Conventional Worlds* scenarios, *Market Forces* and *Policy Reform*. The assumptions for the other two scenarios (*Great Transition* and *Fortress World*) are addressed in separate sections that build on the foundation established in the discussion of the *Conventional Worlds*. How the extent of poverty is determined differs substantially between the two *Conventional Worlds* scenarios:

- In the *Market Forces* scenario, the extent of poverty is a consequence of the assumed trends in population, average income and the income distribution, each of which is developed to reflect the overall business-as-usual perspective of the scenario.

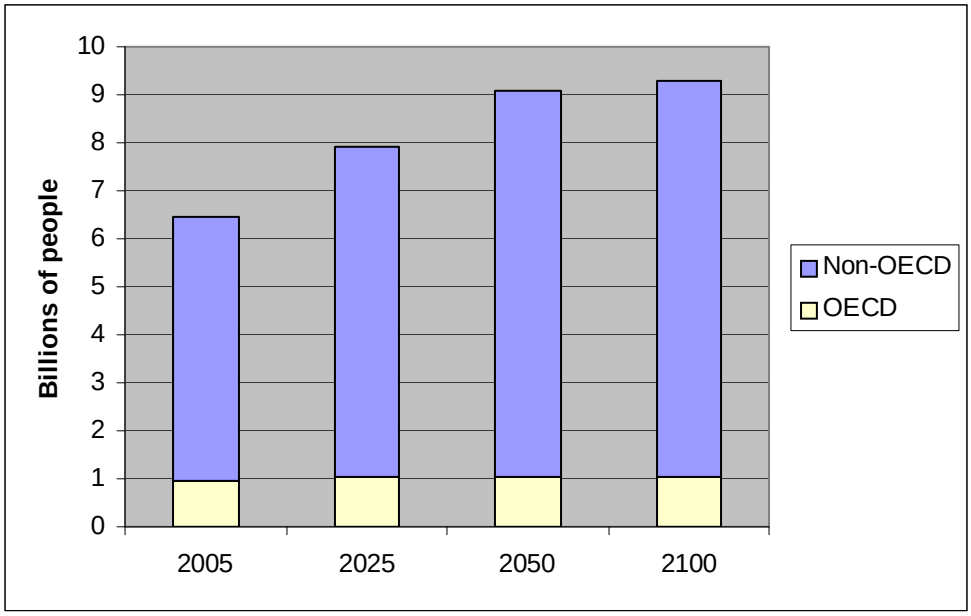
- In the *Policy Reform* scenario, achieving specific targets for poverty reduction constrains the assumptions. The economic growth rates and national income distributions are chosen with the objective of meeting these targets.

Demographics and Economics

Population

In the *Market Forces* scenario, population growth follows the 2005 revision of the UN mid-range (i.e., medium-variant) population projection, in which global population increases from 6.5 to 9.1 billion people between 2005 and 2050 (UN, 2006a). The UN medium variant growth rate projections in the UN report on long-range projections “World Population to 2300” are used for the 2100 value in Market Forces, reaching a global population just slightly higher than the 2050 value due to the demographic transition assumed (UN, 2004). The projections are shown in Figure 2-1.

Figure 2-1. UN mid-range population projections to 2100



Source: 2005 data and 2025 and 2050 projections (UN, 2006a), 2100 projections (UN, 2004)

In the *Policy Reform* scenario, the population growth assumptions for the OECD regions are the same as those of the *Market Forces* scenario. Those for the non-OECD regions are slightly lower: by 2% in 2025 and by 5% in 2050. In 2100 non-OECD regions have populations that are 10% lower than the *Market Forces* scenario. These lower population figures in non-OECD regions are assumed to result from reduced fertility rates associated with higher incomes and educational levels in the scenario. The population assumptions used in the scenarios are shown in Table 2-1 below.

A massive shift of population to urban areas has been occurring, and is projected to continue. For the non-OECD regions this shift is one factor behind the increasing consumption trends (not explicitly modeled, but reflected in the economic growth trends in our analysis), since, in these regions, urban populations consume more resources than rural populations. The fraction of the populations that are urban are projected to be the same in both scenarios. Urbanization figures for 2005 and 2025 are computed using data from the United Nations data and projections (UN, 2006b). For 2050, the urban fraction of the population is extrapolated, assuming a slowing urbanization trend relative to 2005-2025. Table 1-1 below shows the actual urban fraction for 2005, as well as projections through 2050, for each of the 11 regions. In 2100, the fraction of total population living in urban centers is increased by 2% from the 2050 value.

Table 2-1. Population by region in *Market Forces* and *Policy Reform*

	Population (Millions of People)						
	2005	2025-MF	2050-MF	2100-MF	2025-PR	2050-PR	2100-PR
North America	335	393	443	468	393	443	468
Western Europe	412	422	414	367	422	414	367
Pac OECD	203	207	194	195	207	194	195
FSU	285	272	245	235	267	233	212
Eastern Europe	178	190	187	147	186	178	132
Africa	906	1,344	1,937	2,425	1,317	1,840	2,182
Latin America	557	692	778	744	678	739	669
Middle East	225	337	466	549	330	443	495
China+	1,439	1,591	1,558	1,314	1,559	1,480	1,183
South Asia	1,451	1,881	2,215	2,219	1,843	2,104	1,997
Southeast Asia	474	577	640	612	565	608	551
Global	6465	7906	9077	9275	7767	8676	8451

Table 2-2. Urban fraction of population in *Market Forces* and *Policy Reform*

	Urban Fraction of Population			
	2005	2025	2050	2100
North America	80.9%	85.7%	92.9%	94.8%
Western Europe	75.6%	80.3%	84.8%	86.5%
Pac OECD	71.7%	77.5%	79.4%	81.0%
FSU	64.1%	66.9%	70.4%	71.8%
Eastern Europe	63.4%	71.5%	81.6%	83.2%
Africa	38.3%	48.2%	60.6%	61.8%
Latin America	77.2%	82.8%	89.8%	91.6%
Middle East	59.9%	65.0%	71.5%	72.9%
China+	40.2%	55.5%	74.7%	76.2%
South Asia	28.6%	38.8%	51.5%	52.5%
Southeast Asia	46.7%	60.8%	78.3%	79.9%

Gross Domestic Product

In the two *Conventional Worlds* scenarios, data on income, that is Gross Domestic Product (GDP) per capita, are developed and used in Purchasing Power Parity (PPP) terms. GDP data are simply the GDP per capita values multiplied by population.

Data on GDP per capita for 2005 at the country level are taken from the World Bank's updated PPP analysis in the International Comparison Program's report "Global Purchasing Power Parities and Real Expenditures" (World Bank, 2008a). Country-level income data for 2005 were aggregated to provide income data for the 11 Polestar regions.

Income growth rate projections were developed through 2100 using a two-step procedure, beginning with OECD and Global GDP per-capita growth rates, obtained from a variety of sources. The corresponding GDP per capita growth rate for the non-OECD regions were then calculated. This was done by computing GDP at the OECD and global level and then dividing by the non-OECD population. These rates were used for the *Market Forces* scenario. For *Policy Reform*, the OECD growth rates selected for *Market Forces* were reduced by 0.5% to create greater global equity. Non-OECD growth was increased to produce essentially the same global growth in GDP. The resulting projections are shown in Table 2-3 below.

Table 2-3. OECD and Non-OECD GDP per capita growth rates for scenarios

Market Forces	GDP/cap					GDP/cap Growth Rate		
	2005	**2025**	**2050**	**2100**		**'05-'25**	**'25-'50**	**'50-2100**
OECD	33493	49768	75854	159690		2.00%	1.70%	1.50%
Non-OECD	4560	7649	13772	37583		2.62%	2.38%	2.03%
World	**8811**	**13093**	**20961**	**51144**		**2.00%**	**1.90%**	**1.80%**

Policy Reform	GDP/cap					GDP/cap Growth Rate		
	2005	**2025**	**2050**	**2100**		**'05-'25**	**'25-'50**	**'50-2100**
OECD	33493	45110	60783	99966		1.50%	1.20%	1.00%
Non-OECD	4560	8332	15789	45495		3.06%	2.59%	2.14%
World	**8811**	**13171**	**21240**	**51826**		**2.03%**	**1.93%**	**1.80%**

Note: Yellow boxes denote that these values were selected. Green boxes were calculated given the data and assumptions.

In the second step, initial regional growth rates were developed for each time period. For the *Market Forces* scenario, the rates in *OECD Environmental Outlook to 2030* (OECD, 2008) for 2005-2025 were used. These growth rates were extended to 2100, based on a review of other long-range studies such as the forecasts of the World Bank Global Economic Prospects (World Bank, 2008b). For the *Policy Reform* scenario, preliminary regional growth rates were chosen to roughly correspond to the shift of growth from the OECD to the non-OECD regions shown in Table 2-3. To complete the process the regional incomes and income growth rates were renormalized to be consistent with the aggregate growth rates specified in Table 2-3. The resulting regional growth rates for both scenarios are shown in Table 2-4.

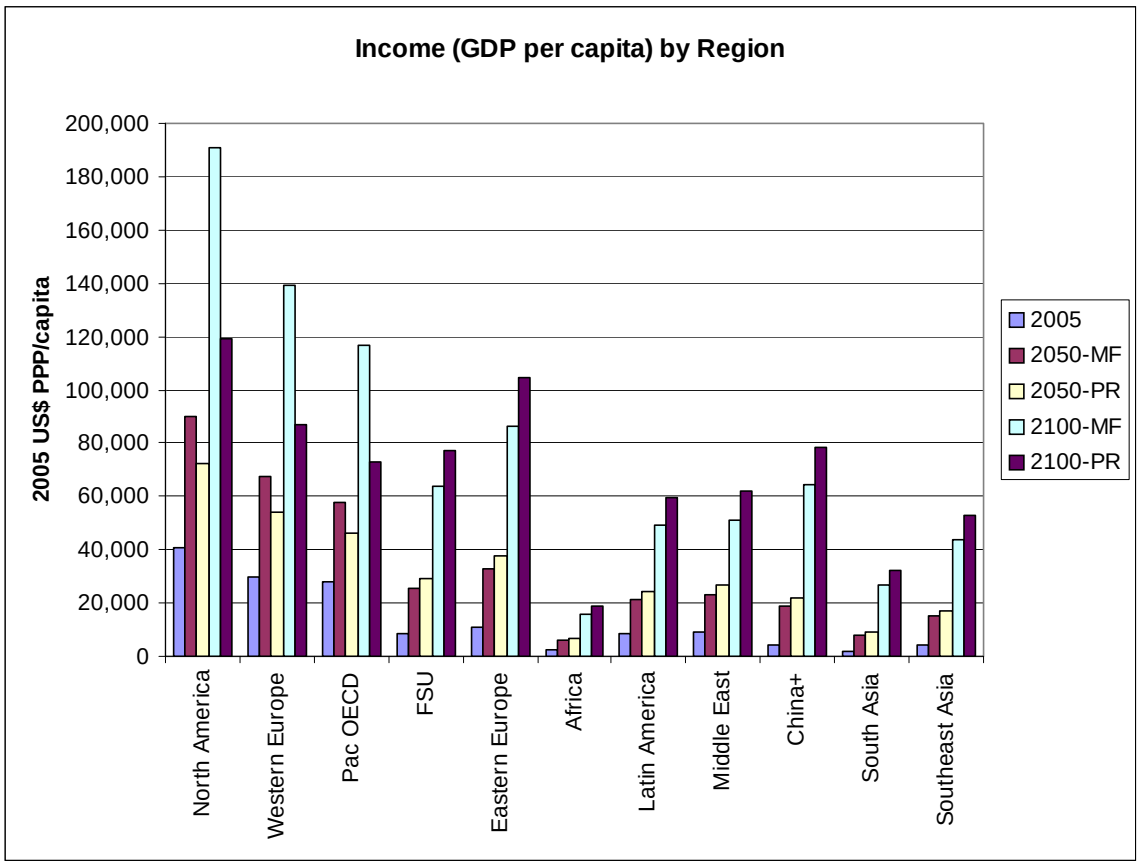
Regional scenario values for GDP per capita are shown in Figure 2-2. Average GDP per capita for the world in 2050 is roughly the same in both scenarios, but the regional distribution is quite different. This reflects the design of the scenarios. In the *Policy Reform* scenario, regional patterns of average income growth and income distribution are shifted from those in *Market Forces*, to meet equity and poverty targets as discussed in Gallopín and Raskin (2002). As shown in Figure 2-2, in the *Policy Reform* scenario, incomes are higher in the non-OECD regions and lower in the OECD regions than in the *Market Forces* scenario.

Table 2-4. Regional growth rates for *Market Forces* and *Policy Reform*

Market Forces	Growth Rates		
Regions	**2005-2025**	**2025-2050**	**2050-2100**
North America	1.93%	1.67%	1.51%
Western Europe	2.10%	1.63%	1.46%
Pac OECD	1.62%	1.59%	1.42%
FSU	2.71%	2.24%	1.85%
Eastern Europe	2.66%	2.35%	1.97%
Africa	1.92%	2.19%	2.00%
Latin America	2.08%	2.08%	1.69%
Middle East	2.07%	1.98%	1.60%
China+	3.83%	3.18%	2.50%
South Asia	3.05%	2.98%	2.50%
Southeast Asia	2.81%	2.57%	2.18%

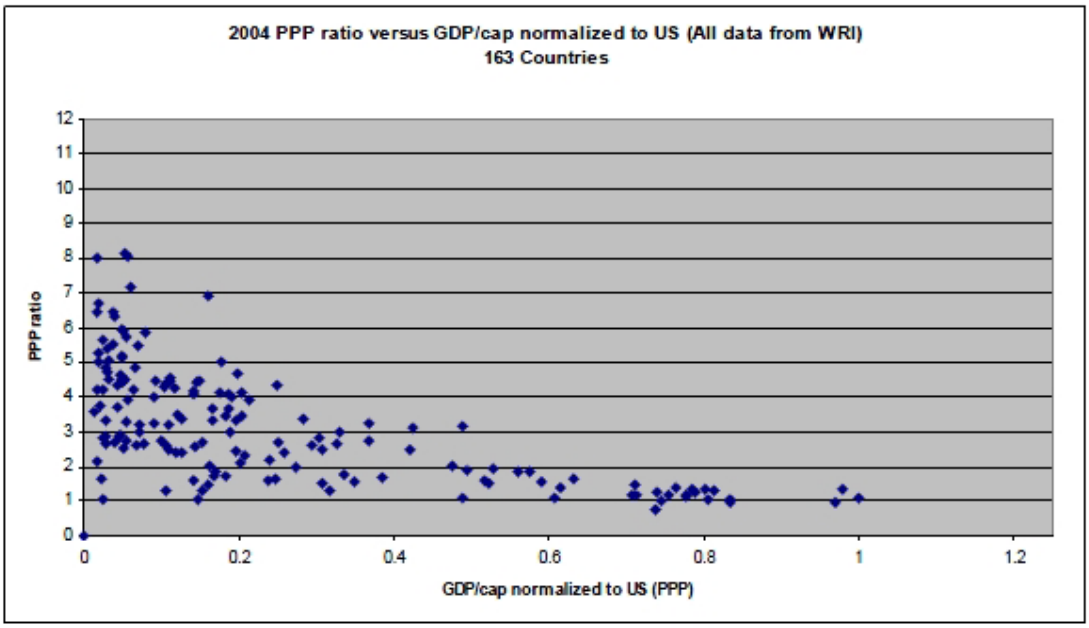
Policy Reform	Growth Rates		
Regions	**2005-2025**	**2025-2050**	**2050-2100**
North America	1.43%	1.17%	1.01%
Western Europe	1.60%	1.13%	0.96%
Pac OECD	1.13%	1.09%	0.93%
FSU	3.16%	2.45%	1.96%
Eastern Europe	3.11%	2.57%	2.08%
Africa	2.38%	2.40%	2.11%
Latin America	2.54%	2.29%	1.80%
Middle East	2.53%	2.19%	1.71%
China+	4.29%	3.40%	2.61%
South Asia	3.51%	3.20%	2.61%
Southeast Asia	3.27%	2.78%	2.29%

Figure 2-2. GDP per capita in the *Market Forces* (MF) and *Policy Reform* (PR) scenarios



In the development of the *Conventional Worlds* scenarios, all the GDP and income data and forecasts are presented in PPP terms. However, they can be expressed in Market Exchange Ratio (MER) terms as well. This is done by using a PPP-to-MER ratio. Historical data show that the ratio – given by GDP_{PPP}/GDP_{MER} – tends to be higher than 1 for developing countries, and close to 1 for most OECD countries. Cross-sectional data for different years was assembled, to look for quantitative patterns. These data, some of which appear in Figure 2-3 below, suggest that PPP-to-MER ratios show much greater variance for countries having very low incomes than for those whose income is at least half as high as the United States income. The ratio is close to 1 for countries whose GDP_{PPP} per capita is higher than about one-half the U.S. value. In the scenarios it is assumed that regional PPP-to-MER ratios vary with income consistent with this pattern.

Figure 2-3. Estimated PPP-to-MER ratio vs. income



Source: World Resources Institute (WRI)

Based on the patterns in the cross-sectional data, a procedure for developing the ratio was devised. The PPP-to-MER ratio is set to 1 when GDP_{PPP} per capita is above one-half the North American value. Otherwise the PPP-to-MER ratio varies along a curve that includes the base-year value and the point defined by (income = one-half the U.S. value, PPP-to-MER ratio= 1). Specifically,

$$PPP\ Ratio = \max\left[1, \left(\frac{GDP\ per\ capita}{0.5 \times GDP\ per\ capita_{North\ America}}\right)^{-PPP\ Expontent}\right], \qquad (2\text{-}1)$$

where the *PPP Exponent* variable depends on the value of *PPP Ratio* in the base year, *PPP Ratio*$_0$. For OECD countries, it is set to zero and for Non-OECD countries, it is given by the following formula:

$$PPP\ Exponent_{NonOECD} = -\frac{\ln(PPPRatio_0)}{\ln(\frac{GDP_{MER}}{0.5GDP_{MERNorthAmerica}})} \qquad (2\text{-}2).$$

Value Added by Sector

One way to express GDP is as the sum of the value added from different sectors of the economy. Value added is used in the Polestar modeling as a measure of sectoral activity. Figure 2-5 and Figure 2-6 below show how the structure of value added is expected to evolve over time for the OECD and non-OECD regions as a whole in the two *Conventional Worlds* scenarios. The changes in value added shown in the figure continue the historical trend toward greater value added from services, and less from agriculture and industry.

In Figure 2-5 the value added from energy conversion and production sectors ("energy"), which is normally included with industry, is kept separate, because energy conversion and production is explicitly treated separately from other industry in our analysis. The use of the aggregate OECD and non-OECD data in the figure is solely for simplicity of presentation. The value added shares are developed for each of the eleven global regions and then aggregated to produce the results shown in Figure 2-6.

For 2005 the sectoral shares of value added are based on data provided by the World Bank (World Bank, 2008c). The shares are adjusted over time based on the following approach.

- Agricultural Sector Value Added: In the OECD regions, agricultural GDP per capita is assumed to remain constant at 2005 values throughout the scenarios. This assumption is broadly supported by trends in agricultural GDP per capita since 1970 in a number of OECD countries. Since total GDP is growing faster than population in these regions, the effect is that the agricultural share of value added continues to decrease over time. In non-OECD regions future agricultural GDP per capita values approach the base year OECD average values as their GDP per capita approaches the base year OECD GDP per capita.

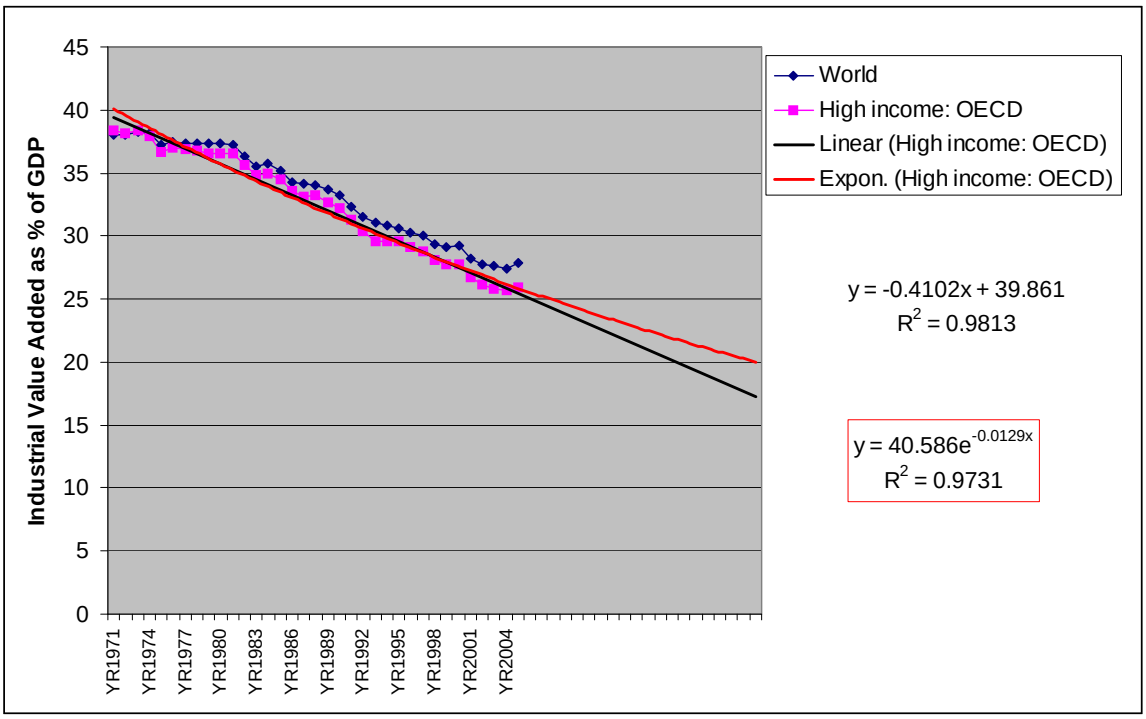
- Industrial Sector Value Added: As indicated by the historic evidence from the World Bank, there has been a declining trend in the industrial share of value added since data begin in 1971 (See Figure 2-4). Guided by these trends, the industrial share of value added is assumed to continue to decrease, but at a slower rate in the scenarios. In *Market Forces*, the OECD regions' Industrial share of GDP is decreased to 80% of the 2005 value by 2025, and 60% of the 2005 value by 2050. Extending to 2100, we decrease the *Market Forces* industrial share to 35% of the 2005 value of Industrial share of GDP. In Policy Reform, we decrease the value of Industrial share of GDP in 2050 to 35% of the 2005 value. For the *Policy Reform* scenario, the industrial share of GDP is set to decline more slowly in order to have balanced growth between the Services value added and the light industries portion of Industrial value added. In *Policy Reform*, the OECD regions' Industrial share of GDP is decreased to 85% of the 2005 value in 2025, and 70% of the 2005 value by

2050, and 50% of the 2005 value in 2100. In the non-OECD regions the convergence algorithm (see Annex 1) is used to determine the share of GDP in industry.

- Energy Value Added: Base year value added for "energy" is small, ranging from fractions of a percent to a few percent. In the absence of information upon which to base a projection, the share of "energy" remains at its base-year value.

- Service Sector Value Added: The share of value added from services is computed as a remainder, using the previously determined levels of GDP.

Figure 2-4. Industrial value added as a percent of GDP



Source: Data points from 1971 through 2005 are taken from World Bank Data (2008c). Trend line projections (linear in black and exponential in red) are calculated through 2025.

Figure 2-5. Value added shares by macro-region

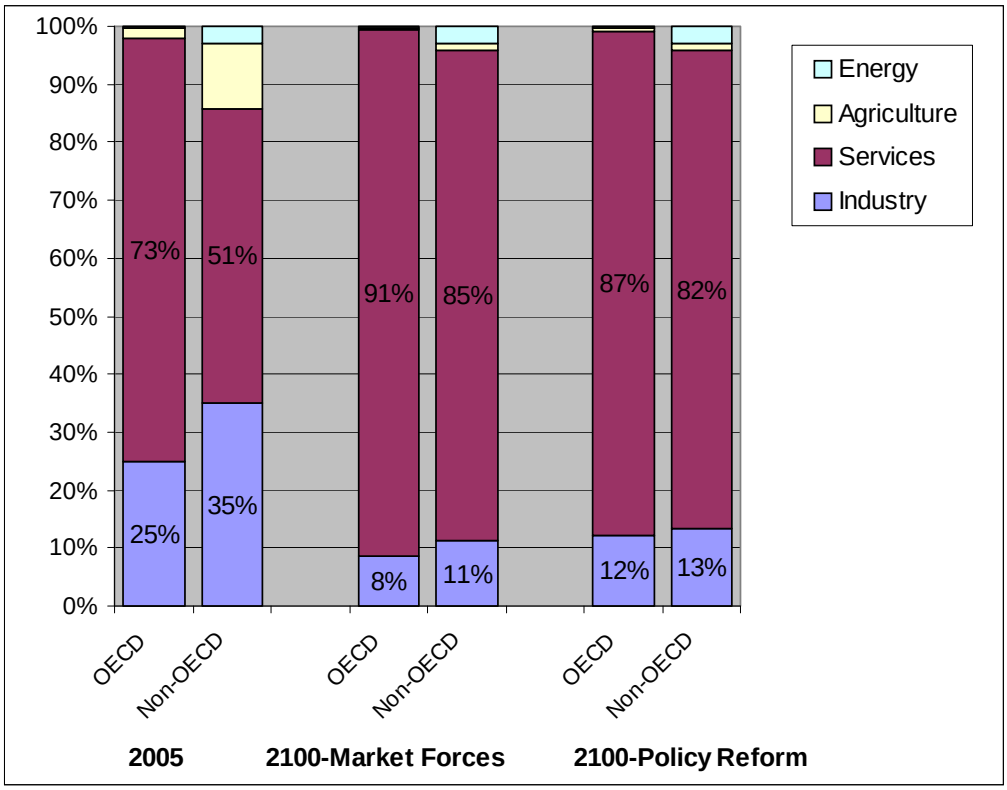
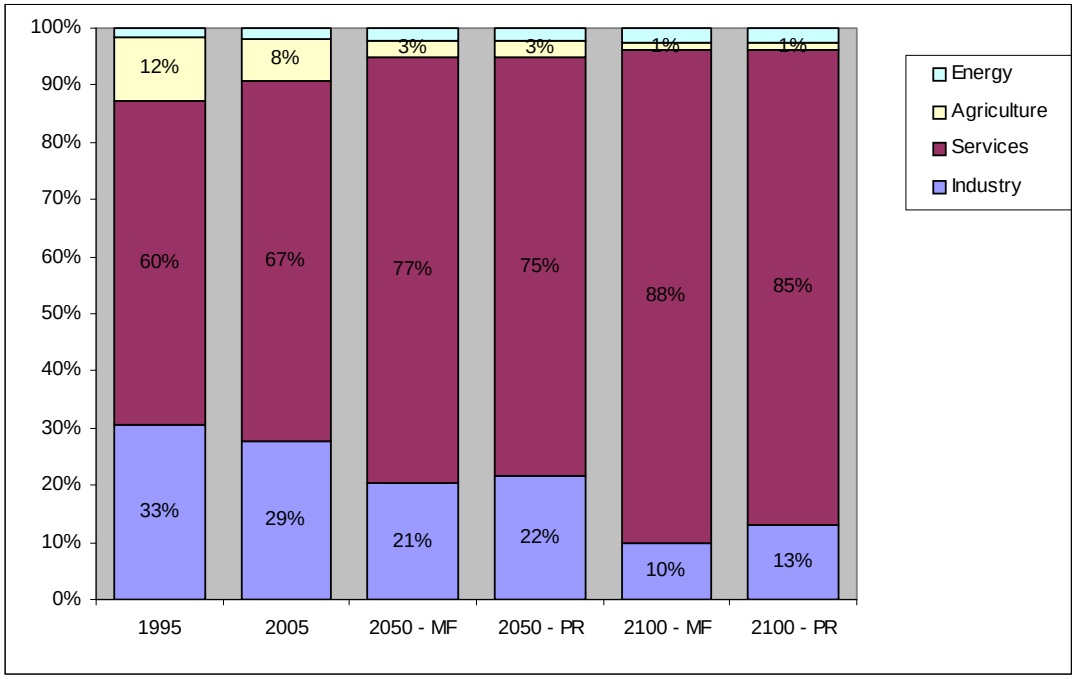


Figure 2-6. Global Sector Shares of Value Added



Value Added by Industrial Subsector

For each of the 11 global regions, within industry, the value added is divided among six subsectors. The first five are energy- and water-intensive subsectors: iron and steel, non-ferrous metals, non-metallic minerals (i.e., stone, glass, and clay), paper and pulp, and chemicals. Together these five constitute what we refer to as "heavy industry." A sixth subsector, which we refer to as "light industry," covers the wide-ranging list of remaining industries. Base-year shares of value added for each of the six sectors are calculated from 3-digit ISIC subsector value added statistics, using the categories shown in Table 2-5 below (UNIDO, 2007). This value added data is consistent with the aggregate historical data for industry discussed above.

There are indications that, in OECD countries, historical growth rates of material consumption have leveled off over recent decades. In both scenarios, we capture this saturation effect in the assumptions concerning the level of industrial activity in our scenarios. We assume that value added per capita for iron and steel, and non-metallic minerals, decrease by ten percent over the 2005-2050 period, and that value added per capita for non-ferrous metals, paper and pulp, and chemicals remain constant. Since industrial activity increases sector-wide more rapidly than population, these assumptions imply that expansion of industrial sector activity in OECD regions is predominantly in the less material and energy-intensive light industry category.

Table 2-5. Industrial subsectors and 3-digit ISIC codes

Industrial Subsector	ISIC Code(s)	ISIC Subsector(s)
Iron and Steel	371	Iron and Steel
Non-ferrous metals	372	Non-ferrous metals
Stone, glass & clay	361, 362, 369	Pottery; glass and products; other non-metallic mineral products
Paper and pulp	341, 342	Paper and products; Printing and publishing
Chemical	351, 352	Industrial chemicals; other chemicals
Light Industry	311, 313, 314, 321, 322, 323, 324, 331, 332, 355, 356, 381, 382, 383, 384,	Food products; Beverages; Tobacco; Textiles; Wearing apparel, except footwear; Leather products; Footwear, except rubber or plastic; Wood products, except furniture; Furniture, except metal; Rubber products; Plastic Products; Fabricated metal products,; Machinery, except electrical; Machinery electrical; Transport equipment, Professional & scientific equipment;
	385, 390	Other manufactured products.
Energy and Related Excluded	*353, 354*	Petroleum refineries; Misc. petroleum and coal products

Note: Energy and related industries are included in the Energy Conversion subsector.

For the non-OECD regions, we apply the convergence algorithm (see Annex 1) to develop industrial activity assumptions for each of the five heavy industry subsectors. Specifically, the value added per capita in a given subsector approaches the projected OECD average value added per capita as a region's total GDP per capita approaches the 2005 OECD average GDP per capita. The value added per capita in the light industrial subsector is calculated as a remainder in the Market Forces scenario. In Policy Reform, the light industrial subsector is scaled back from the Market Forces values by the same ratio as all other subsectors to meet the reduced total Industrial Sector Value Added. The results are displayed in Table 2-6 and Table 2-7 which show value added per capita, and in Table 2-8 and Table 2-9 which show total value added.

A basic concept behind the development of the scenarios for the *Conventional Worlds* is that, as GDP per capita rises in the developing regions, the structure of the economies of these regions "converges" to the structure in the OECD regions. In order to implement this convergence in the Polestar model which provides a limited treatment of trade, the structure in each region converges to the OECD average. In some cases this produces results, such as the emergence of a significant Pulp and Paper industry in the Middle East, which are not very likely in reality. When considering these anomalies, two points need to be kept in mind. First, the anomalies are not numerous nor do they affect a large portion of the value added. Second, the results of interest from the Polestar analysis are often global aggregates, such as the Greenhouse Gas (GHG) emissions and resource use due to industrial production. These are not sensitive to industrial location. Compared to the uncertainty that would be introduced by the development of trade and region-specific forecasts of industrialization, the problems created by our simple convergence approach are modest.

Table 2-6. Industrial value added per capita – *Market Forces* scenario

US$ PPP/capita	Chemical		Iron + steel		Non-ferr. metals		Paper + pulp		Stone,glass,clay		Other	
	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050
North America	1,557	1,557	346	311	86	86	692	692	259	234	5,708	8,635
Western Europe	1,245	1,245	410	369	79	79	740	740	378	340	5,034	7,956
Pac OECD	1,253	1,253	704	634	69	69	687	687	300	270	5,571	7,635
FSU	358	1,059	483	424	307	151	125	528	155	245	1,549	3,062
Eastern Europe	338	1,350	218	389	27	79	176	696	158	279	2,072	2,125
Africa	137	279	43	84	7	15	20	99	20	51	556	1,328
Latin America	468	939	204	306	73	77	175	453	139	215	1,559	2,921
Middle East	679	1,080	455	423	4	48	34	423	71	195	2,485	3,809
China+	188	791	140	271	45	63	50	385	86	188	1,151	3,595
South Asia	119	351	61	124	11	24	15	144	28	76	301	1,168
Southeast Asia	274	673	49	176	0	29	77	306	86	159	1,259	3,174
World	396	681	181	220	46	46	154	315	107	146	1632	2929

Table 2-7. Industrial value added per capita – *Policy Reform* scenario

US$ PPP/capita	Chemical		Iron + steel		Non-ferr. metals		Paper + pulp		Stone,glass,clay		Other	
	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050
North America	1,557	1,557	346	311	86	86	692	692	259	234	5,708	7,884
Western Europe	1,245	1,245	410	369	79	79	740	740	378	340	5,034	7,257
Pac OECD	1,253	1,253	704	634	69	69	687	687	300	270	5,571	6,949
FSU	358	1,218	483	409	307	115	125	619	155	264	1,549	3,281
Eastern Europe	338	1,378	218	393	27	80	176	710	158	282	2,072	3,569
Africa	137	314	43	95	7	17	20	119	20	59	556	1,517
Latin America	468	1,056	204	330	73	78	175	522	139	234	1,559	3,267
Middle East	679	1,182	455	414	4	59	34	521	71	225	2,485	3,927
China+	188	906	140	296	45	66	50	449	86	207	1,151	3,904
South Asia	119	398	61	137	11	27	15	170	28	86	301	1,359
Southeast Asia	274	758	49	203	0	35	77	355	86	174	1,259	3,519
World	396	716	181	224	46	46	154	341	107	152	1632	2971

Table 2-8. Total Industrial value added – *Market Forces* scenario

Billion U.S, $PPP	Chemical		Iron + steel		Non-ferr. metals		Paper + pulp		Stone,glass,clay		Other		TOTAL IND	
	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050
North America	522	690	116	138	29	38	232	307	87	103	1912	3825	2898	5101
Western Europe	513	515	169	153	32	33	305	307	156	141	2074	3294	3249	4443
Pac OECD	254	243	143	123	14	13	139	133	61	52	1131	1481	1742	2045
FSU	102	260	138	104	87	37	36	129	44	60	442	750	849	1340
Eastern Europe	60	252	39	73	5	15	31	130	28	52	369	397	532	919
Africa	124	541	39	163	6	30	18	193	18	99	504	2572	709	3598
Latin America	261	731	114	238	41	60	98	352	77	168	868	2272	1459	3821
Middle East	153	503	102	197	1	22	8	197	16	91	559	1775	839	2785
China+	270	1233	201	423	65	98	72	600	124	293	1657	5601	2389	8248
South Asia	172	778	88	275	16	53	22	319	40	168	436	2587	774	4180
Southeast Asia	130	431	23	113	0	19	36	196	41	101	597	2031	827	2891
OECD	1289	1448	428	414	75	84	676	747	304	296	5117	8600	7889	11589
Non-OECD	1272	4729	744	1586	221	334	321	2116	388	1032	5432	17985	8378	27782
World	2561	6177	1172	2000	296	418	997	2863	692	1328	10549	26585	16267	39371

Table 2-9. Total Industrial value added – *Policy Reform* scenario

Billion U.S. $PPP	Chemical		Iron + steel		Non-ferr. metals		Paper + pulp		Stone,glass,clay		Other		TOTAL IND	
	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050	2005	2050
North America	522	690	116	138	29	38	232	307	87	103	1912	3493	2898	4769
Western Europe	513	515	169	153	32	33	305	307	156	141	2074	3004	3249	4153
Pac OECD	254	243	143	123	14	13	139	133	61	52	1131	1348	1742	1912
FSU	102	283	138	95	87	27	36	144	44	61	442	764	849	1374
Eastern Europe	60	245	39	70	5	14	31	126	28	50	369	634	532	1139
Africa	124	578	39	174	6	32	18	219	18	108	504	2792	709	3903
Latin America	261	780	114	244	41	57	98	385	77	173	868	2415	1459	4054
Middle East	153	523	102	183	1	26	8	231	16	100	559	1738	839	2801
China+	270	1341	201	438	65	98	72	665	124	306	1657	5778	2389	8626
South Asia	172	838	88	288	16	56	22	358	40	180	436	2861	774	4581
Southeast Asia	130	461	23	124	0	21	36	216	41	106	597	2140	827	3068
OECD	1289	1448	428	414	75	84	676	747	304	296	5117	7845	7889	10834
Non-OECD	1272	5049	744	1616	221	331	321	2344	388	1084	5432	19122	8378	29546
World	2561	6497	1172	2030	296	415	997	3091	692	1380	10549	26967	16267	40380

Income Distribution and Poverty

The Tellus scenarios, including in particular the *Conventional Worlds* scenarios, address a wide range of social and environmental issues. A key feature is their treatment of poverty. There the focus is on hunger, which is taken as a representative for many possible measures of poverty. In the *Market Forces* scenario the extent of hunger reflects the pattern of development around the globe. In the *Policy Reform* scenario the situation is reversed: hunger reduction targets constrain the path of development. The remainder of this section provides a brief, high-level discussion of the treatment of hunger, with particular attention to the development of the data on hunger provided in the output of the Polestar modeling for the *Conventional Worlds* scenarios. Readers interested in a more thorough discussion of hunger and Tellus' treatment of it should consult the analysis provided in Annex 2.

Methodology

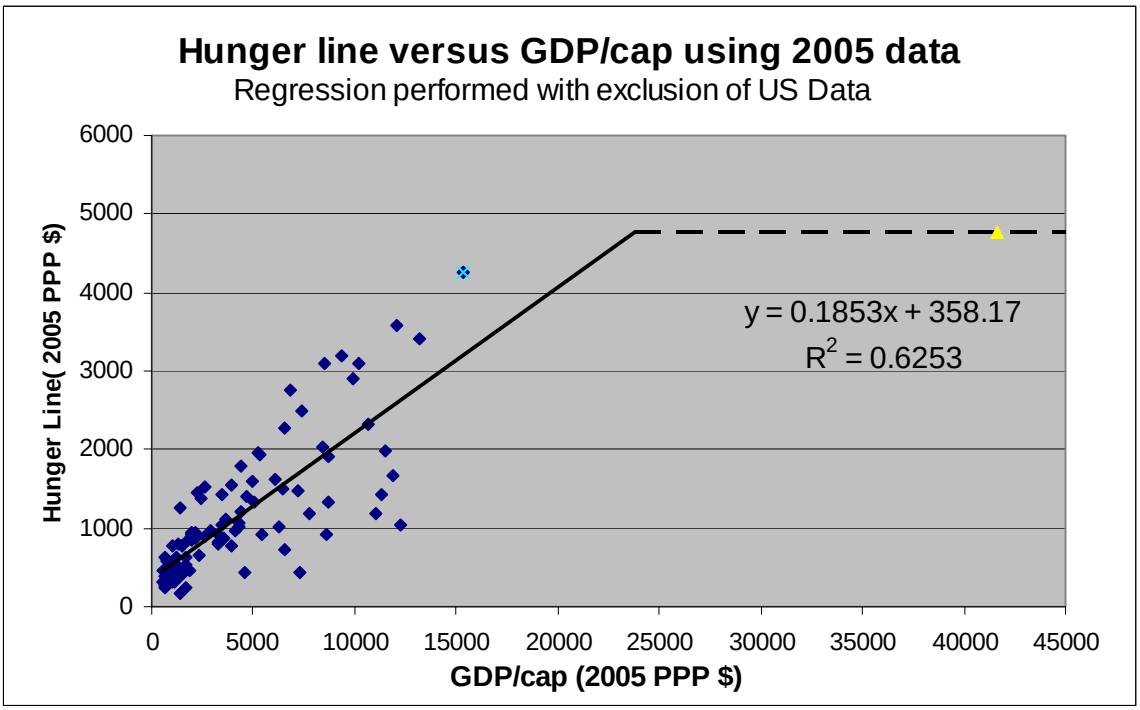
The *hunger line* is the basic concept used in Tellus' treatment of poverty. The hunger line is defined simply as the minimum income below which an individual will be chronically hungry. For the hunger line to be useful, one must be able to do two things:

- Determine how the level of the hunger line changes over time.
- Compute the size of the population at or below the hunger line.

To do these things, two mathematical relationships are relied upon. The first is shown in Figure 2-7 below.

For many countries historical data on both the hunger line and the average GDP per capita are available. The values for many developing countries and for the U.S. are plotted in Figure 2-7. A simple linear regression shows a fairly robust relationship until saturation near the level of U.S. income. In the *Conventional Worlds* scenarios, national hunger lines are assumed to increase from their base-year values toward $4,767, the current hunger line for the United States, as GDP per capita approaches $23,797 along the regression line shown in Figure 2-7. Above an income of $23,797, hunger lines are assumed to remain constant at the U.S. level. The broken linear relationship between GDP per capita and the hunger line shown in Figure 2-7 is the first mathematical relationship used in the analysis of hunger.

Figure 2-7. Hunger line versus GDP/cap



The second mathematical relationship involves the distribution of national income. In order to compute the size of the population at or below the hunger line for a given year and scenario, the distribution of income needs to be described in a computationally tractable fashion. In Tellus' analyses, income distributions are described using the lognormal distribution, a standard mathematical formula closely related to the normal distribution used extensively in elementary statistics. For a value of income, y, the lognormal distribution provides a formula for the number of people at that income level, f(y). The computation of f(y) depends on three parameters: the total population, the mean income (i.e., the average value of GDP per capita), and a measure of income inequality which can be expressed in a number of different ways. If one knows these parameters one can use the formula to make various computations. In particular, one can use it to compute the population at or below the hunger line.

The measure of income inequality used in Tellus' hunger analysis is the *Gini coefficient*. The value of the Gini indicates the extent to which a particular distribution of income differs from absolute equality, that is everyone having exactly the same income. The coefficient varies from 0 to 1. At a Gini of 0 there is absolute equality. As the value of the Gini rises toward 1 the share (i.e., percentage) of national income received by those at the top of income distribution increases, and the share received by those at the bottom declines. Current Gini coefficients for most nations are available in the 2008 World Development Report (World Bank, 2007). These provide reasonable estimates for 2005 data at the national level. Taking population weighted averages over the nations in each region for which Ginis are

available provides regional values for 2005. Future values, as with population and income, must be projected. The projections used in the *Market Forces* and *Policy Reform* scenarios are shown in Figure 2-8 and Figure 2-9 below. In both figures the Ginis begin with a wide range of values, from a low of 0.3 in Western Europe to a high of 0.53 in Latin America in 2005. In both scenarios the ranges narrow over time, but the pattern of narrowing is quite different. The basis for these patterns and their relationship to the levels of hunger is discussed in the next section.

The Gini values indicated in Figure 2-8 and Figure 2-9 together with the regional data on population and GDP per capita discussed earlier are sufficient to specify log normal income distribution consistent with the two *Conventional Worlds* scenarios for the years 2005, 2025, 2050, and 2100. These distributions are the second mathematical relationship needed for the hunger analysis.

Figure 2-8. Gini Coefficients – Market Forces

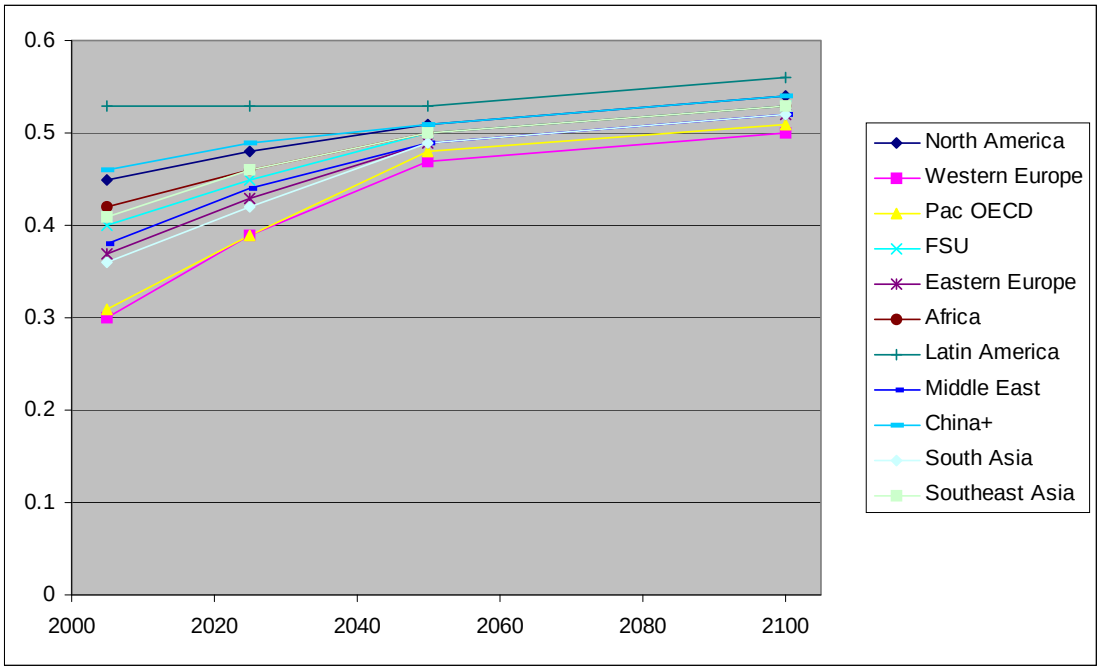
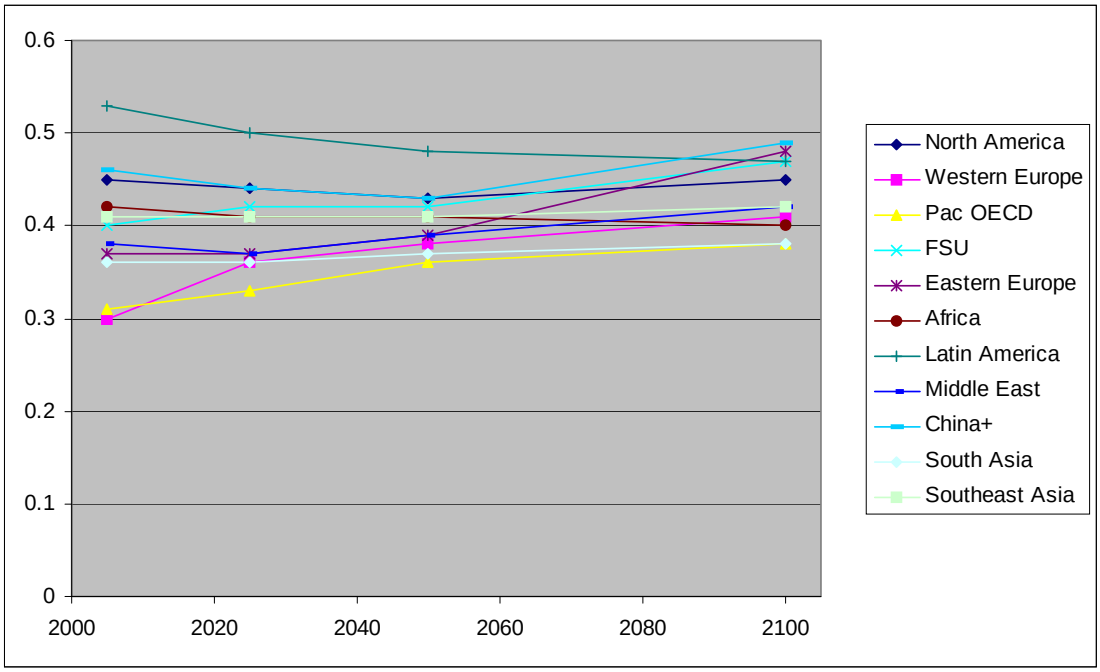


Figure 2-9. Gini Coefficients – Policy Reform



Inequality and Hunger

The two *Conventional Worlds* scenarios reflect the continuation of prominent features of our world today. However, they differ in the features they emphasize and in the mechanisms that govern the way those features change over time. This difference is apparent in the way the two scenarios address the patterns of growth in population and average GDP per capita:

- In *Policy Reform* population grows more slowly in the non-OECD regions than in *Market Forces*, due to the assumed effects of better education, particularly for women, leading to smaller families.

- Compared to the *Market Forces* scenario, *Policy Reform* GDP per capita grows more rapidly in the non-OECD regions and less rapidly in the OECD regions, reflecting policies designed to allow the nations in the non-OECD regions to catch up economically.

The treatment of hunger in the two scenarios reflects the difference between market-driven outcomes and government policy targets in a sharp and simple fashion. Table 2-10 and Table 2-11 present the hunger results for the two scenarios. In both scenarios there is progress in hunger reduction, particularly in the percentage of the population which experience hunger. However, the progress is far greater in the *Policy Reform* scenario.

Table 2-10. Hungry population

Millions of People	Hungry Population						
	2005	2025-MF	2050-MF	2100-MF	2025-PR	2050-PR	2100-PR
North America	7	5	3	1	3	1	0
Western Europe	2	3	3	0	1	1	0
Pac OECD	1	1	3	1	0	0	0
FSU	19	15	15	6	8	4	1
Eastern Europe	5	6	8	1	2	1	0
Africa	242	283	304	230	177	106	27
Latin America	55	58	55	46	41	26	6
Middle East	20	27	33	19	9	5	1
China+	179	130	100	36	67	28	7
South Asia	310	250	235	144	115	41	10
Southeast Asia	54	52	48	33	24	11	3
Global	893	829	806	517	446	223	56

Table 2-11. Percent of population hungry

Percent	Percent of Population Hungry						
	2005	2025-MF	2050-MF	2100-MF	2025-PR	2050-PR	2100-PR
North America	2.0%	1.2%	0.7%	0.2%	0.7%	0.2%	0.0%
Western Europe	0.5%	0.6%	0.7%	0.1%	0.2%	0.1%	0.0%
Pac OECD	0.4%	0.7%	1.3%	0.3%	0.2%	0.1%	0.0%
FSU	6.6%	5.6%	6.0%	2.4%	3.1%	1.6%	0.4%
Eastern Europe	2.8%	3.3%	4.4%	1.0%	1.0%	0.7%	0.2%
Africa	26.8%	21.1%	15.7%	9.5%	13.4%	5.8%	1.2%
Latin America	9.9%	8.3%	7.1%	6.2%	6.0%	3.5%	1.0%
Middle East	8.7%	8.0%	7.0%	3.5%	2.8%	1.2%	0.3%
China+	12.4%	8.2%	6.4%	2.8%	4.3%	1.9%	0.6%
South Asia	21.4%	13.3%	10.6%	6.5%	6.3%	1.9%	0.5%
Southeast Asia	11.3%	8.9%	7.6%	5.4%	4.2%	1.8%	0.5%
Global	13.8%	10.5%	8.9%	5.6%	5.7%	2.6%	0.7%

The data for 2005 in the two tables reflect available historical data on hunger from the Food and Agriculture Organization (FAO) of the United Nations (FAO, 2007b). However, even for 2005, estimates need to be made. These are developed using the two mathematical relationships discussed in the preceding section. Where data on the hunger line is not available, figures can be estimated using the relationship between

the hunger line and GDP per capita shown in Figure 2-7. Where a hunger line is available, but the number hungry is not, the log normal distribution can be used to estimate the number hungry if population, average GDP per capita, and a Gini coefficient are known. The data for 2005 were assembled using these techniques. (Additional details on the specific sequence of steps followed is available in Annex 2.)

For 2025 and 2050, hunger lines and the corresponding population experiencing burden needs to be developed. In the *Market Forces* scenario the procedure closely follows the process used in the base year. Hunger lines are determined on the basis of a regression analysis similar to that presented in Figure 2-7. Next the projected Gini coefficients shown for the Tellus regions in Figure 2-8 are introduced. These are based on the assumption that in a world shaped by the market, income inequality will rise. In particular, the Ginis for all regions are assumed to converge through 2050 toward the 2005 value in Latin America, the region known historically to have the highest levels of income inequality. The 2100 values in the *Market Forces* scenario are set by simply adding 0.03 to the 2050 Gini coefficient value for a uniform, but not converging increase in inequality. Using the projected Gini coefficients along with the assumptions on future population and average GDP per capita introduced earlier, the log normal distribution is used to make the computations required to determine the size of the populations at or below the hunger lines for each region. (Again, for more details, see the Annex 2.)

For the *Policy Reform* scenario, the process used for *Market Forces* is essentially reversed. In *Policy Reform*, it is assumed that in each region policies have been put in place which, taken together, cause the number below the hunger line to be reduced to 50% of the 2005 level in 2025, to 25% of the 2025 level in 2050, and to 25% of the 2050 level by 2100. The policy choices that contribute to this reduction are reflected in the Tellus analysis through the higher incomes in non-OECD regions shown in Table 2-3 and the convergence toward a lower level of Gini coefficient shown in Figure 2-9. Assuming the regional growth in population and average income specified earlier, the convergence of the Gini coefficients is set so that the desired reductions in hunger compared to the 2005 levels result from the computation of those numbers using the log normal distribution.

The analysis performed using the two *Conventional Worlds* scenarios shows the extent to which policies that address equity among and within the regions of the world could reduce the extent of extreme poverty in the future. Hunger, rather than poverty (as indicated by the World Bank's $1 or $1.25 per day standards (World Bank, 2008a)), is the focus of our analysis because, as shown in Figure 2-7, the income required to avoid hunger rises with average income. This adds an important element of realism to the analysis.

It is the effects of policies designed to address equity, not the policies themselves, that appear directly in our analysis. In our analysis the policies that affect equity between regions are reflected in the differences in the growth in population and average income between the two scenarios, and in the differences in the assumptions

for the Gini coefficients. Table 2-12 below provides an indication of the inter and intra regional policy effects. The table shows global hunger in 2005, 2025, and 2050 in the two scenarios with and without the effects of changes in the Gini coefficients. "Turning off" the change in Gini coefficients provides a simple mechanism for isolating the effects of the interregional policy differences in the two scenarios.

Table 2-12. Hunger sensitivity analysis with *MF* with and without convergence

Sensitivity Analysis - Hungry Population with and without Gini Convergence (Millions of People)					
		With convergence		Without convergence	
	2005	2025-MF	2050-MF	2025-MF	2050-MF
North America	6.8	4.7	3.0	2.7	0.9
Western Europe	2.1	1.6	2.8	0.5	0.1
Pac OECD	0.7	1.4	2.6	0.1	0.0
FSU	18.8	15.3	14.6	10.2	5.0
Eastern Europe	5.0	6.2	8.2	2.3	1.6
Africa	242.3	283.2	303.8	216.2	158.4
Latin America	55.2	57.5	55.2	56.8	54.2
Middle East	19.6	27.0	32.8	11.2	6.7
China+	178.8	130.3	99.6	89.0	47.4
South Asia	309.7	249.6	234.5	132.6	36.6
Southeast Asia	53.6	51.5	48.5	30.1	14.7
Global	893	828	806	552	326

3 Energy

In this chapter, we describe the data, methods and assumptions for projecting energy consumption in the *Market Forces* and *Policy Reform* scenarios. The *Market Forces* scenario analysis is, to a large extent, an update of the earlier reports (Raskin and Margolis, 1995 and Gallopín and Raskin, 2002), incorporating a later year base year (2005 instead of 1990 or 1995), additional sources of data, and updated methodologies. Some of the text in this chapter is adapted from the earlier reports.

In the *Market Forces* scenario, energy use is driven by the demographic, economic and technical trends of the scenario for each region. In the normative *Policy Reform* scenario, fuel supply trends are highly constrained by the climate change mitigation targets imposed on the scenario. Greenhouse gas emissions and climate change are discussed in Chapter 7 (page 261). In this section we review regional patterns of energy consumption, energy conversion, and primary energy supply in each of the two scenarios.

Energy Consumption

Energy consumption refers to fuel and electricity requirements at the point of use. Consumption is analyzed in each region independently of the others for each of the five major final demand sectors: industry, transport, households, services and agriculture. In each sector, the analysis is based on further disaggregation of end-uses, subject to the availability of data. For example, the industrial sector is divided into five major energy-consuming sub-sectors plus a sixth sub-sector dealing with miscellaneous industrial energy consumption. Similarly, in the transport sector, freight and passenger transport are considered separately, and each is further sub-divided by mode (road, rail, air, water).

Total Final Consumption

Current Accounts - 2005

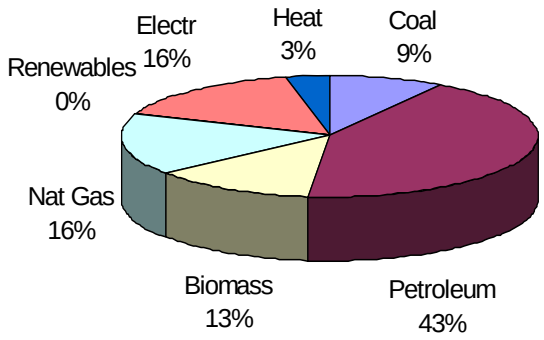
Global total final energy consumption in 2005 was about 326 EJ (exojoules). As shown in Figure 3-1, final end-use fuel demand composition is currently dominated by fossil fuels, which account for 68% of the global total. Other significant final energy forms are electricity, biomass and district heat. The direct use of non-biomass renewable energy forms (e.g., direct use of solar for water heating) currently accounts for less than one tenth of one percent of final energy consumption.

Figure 3-1 shows the breakdown of total end-use final demand by sector. Global consumption is led by the industrial sector (37%), followed by households (27%), transport (26%), services (8%), and agriculture (2%). Turning to regional patterns, global energy consumption is dominated by the OECD regions, which account for 48% of

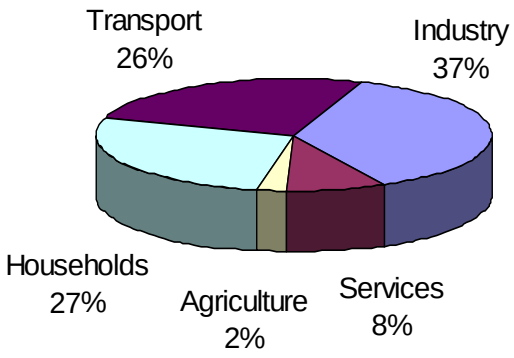
global energy consumption. The developing regions account for 41% of global energy consumption and the transitional regions account for the remaining 11%.

Figure 3-1. Global final energy consumption shares - 2005

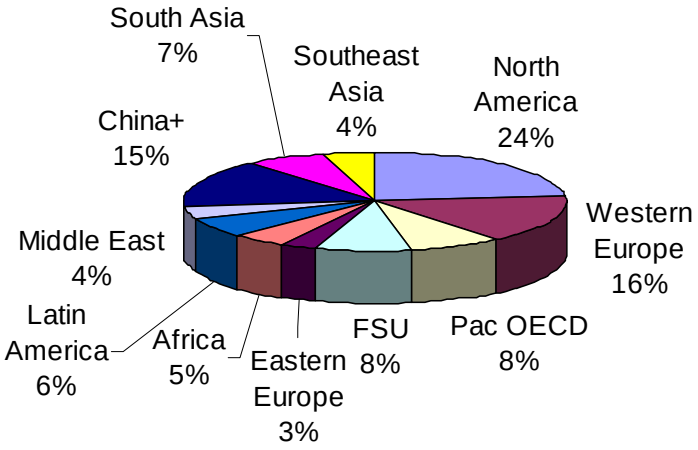
By fuel



By sector



By region



The breakdown by fuel is presented for each region in Table 3-1. Petroleum products account for more than 50% of final demand in five regions (North America, Western Europe, Pacific OECD, Middle East, and Latin America), while coal accounts for nearly a third of final energy demand in China+. Energy from biomass accounts for about half the energy use in Africa and South Asia, and is significant in Latin America, China+ and Southeast Asia.

Table 3-1. Global energy consumption by fuel – 2005 (PJ)

	Coal	Oil	Natural Gas	Elec.	Heat	Biomass	Renew-ables	Total
North America	1,708	40,755	16,596	14,885	170	2,106	78	76,298
Western Europe	1,339	26,194	11,005	9,352	1,613	1,762	68	51,333
Pac OECD	1,772	14,666	2,252	5,525	218	368	47	24,848
FSU	1,732	6,087	8,651	3,159	6,456	276	-	26,361
Eastern Europe	1,413	3,514	2,160	1,479	665	683	55	9,969
Africa	1,079	4,338	1,079	1,490	-	8,079	-	16,065
Latin America	529	10,375	3,288	3,098	-	3,285	2	20,577
Middle East	33	7,788	4,123	1,717	-	39	37	13,737
China+	16,250	13,588	1,754	7,107	1,518	10,200	-	50,417
South Asia	1,827	5,635	1,406	1,897	-	10,998	-	21,763
Southeast Asia	1,382	7,086	1,325	1,409	-	3,265	-	14,467
World	29,064	140,026	53,639	51,118	10,640	41,061	287	325,835
OECD	4,819	81,615	29,853	29,762	2,001	4,236	193	152,479
Non-OECD	24,245	58,411	23,786	21,356	8,639	36,825	94	173,356

Note: PJ stands for petajoules, where 1 PJ = 10^6 joules (J)

The sectoral composition of final energy demand across regions is presented in Table 3-2. The variation of relative sectoral shares is related to a number of factors specific to each region. First, the structure of economic activity evolves with the level of industrial development and the particular economic growth strategy that has been adopted. For example, service sector output is a rising share of total national output in OECD regions, and hence the share of energy demanded by the service sector is also steadily increasing in the OECD and many other regions. Also, heavy industry is especially important in China+, where 50% of the energy consumption in the region occurs, but also in FSU, Latin America, the Middle East and Pacific OECD, where over 40% of energy consumption goes to the industrial sector. The household sector is dominant in Africa and South Asia, where subsistence lifestyles retain their dominance and modern forms of economic activity for many remain relatively undeveloped.

Table 3-2. Global energy consumption by sector – 2005 (share as %)

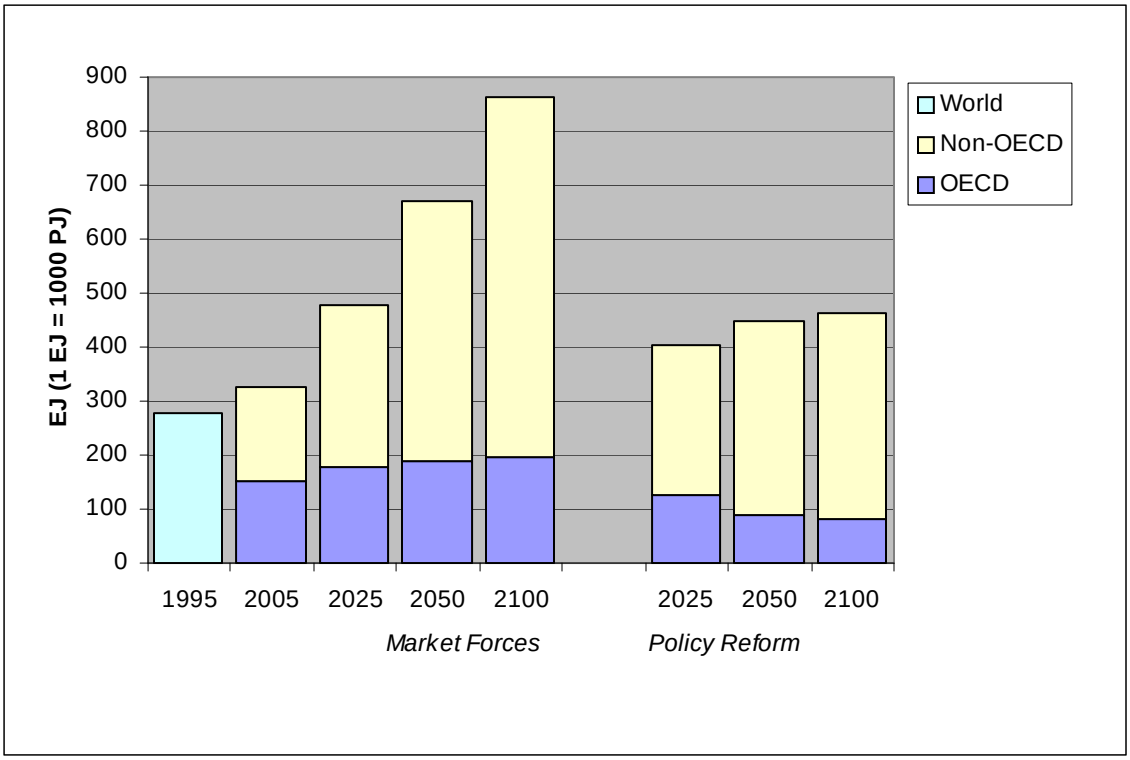
	Industry	Households	Transport	Services	Agriculture
North America	31%	17%	38%	13%	1%
Western Europe	31%	25%	32%	10%	2%
Pac OECD	41%	13%	29%	14%	2%
FSU	42%	35%	13%	5%	4%
Eastern Europe	39%	28%	20%	9%	4%
Africa	25%	54%	16%	3%	2%
Latin America	43%	17%	31%	5%	4%
Middle East	43%	21%	29%	5%	2%
China+	50%	31%	11%	4%	4%
South Asia	30%	55%	11%	2%	2%
Southeast Asia	35%	27%	31%	5%	2%
World	37%	27%	26%	8%	2%
OECD	33%	19%	35%	12%	2%
Non-OECD	41%	34%	18%	4%	3%

Second, the energy efficiency of end-use equipment influences the sectoral energy-use pattern. For example, electric devices, which tend to grow in importance with rising incomes, are relatively efficient at the end-use level while traditional wood stoves are quite inefficient, thereby contributing to the anomalously high share of end-use energy demand for household energy consumption in Africa and South Asia. Third, infrastructure and life-style variations influence the sectoral composition. For example, in North America, where there is heavy reliance on the private automobile and a highly mobile population, the share of energy use in transportation is large (See Table 3-2 above).

Scenarios

Figure 3-2 summarizes total final energy demand in the *Market Forces* scenario and the *Policy Reform* scenario. In the *Market Forces* scenario, total final demand more than doubles from 326 EJ in 2005 to 670 EJ in 2050, and 864 EJ in 2100. The Non-OECD regions (Developing) account for about 90% of the growth in demand between 2005 and 2100, although demand increases in the OECD regions as well. In the *Policy Reform* scenario, this growth in energy demand is substantially reduced, reaching 464 EJ in 2100.

Figure 3-2. Global final energy demand by macro-region



In the *Policy Reform* scenario, the effects of slower economic growth and intensive policy efforts to improve energy efficiency lead to declines in energy demand in the OECD regions, where total final demand in 2100 drops to 53% of its 2005 value. All of the net increase in total final demand is therefore accounted for by the developing non-OECD regions where, with all the energy efficiency improvements beyond those in the *Market Forces* scenario, energy demand increases at a rate of approximately 0.8% per year. This is significantly less than the 1.4% per year growth seen in the *Market Forces* scenario. The increased economic growth in the *Policy Reform* scenario somewhat counterbalances the increased improvement in the efficiency of energy use.

Also, the results in the *Policy Reform* scenario reflect the severe CO_2 emission constraints placed on all sectors of society in order to limit climate change to less than 2°C by meeting a CO_2 atmospheric concentration of 350 ppm. This carbon-constraint and the methodology for implementing it are discussed in great detail in Chapter 7 on Pollution starting on page 261.

Households

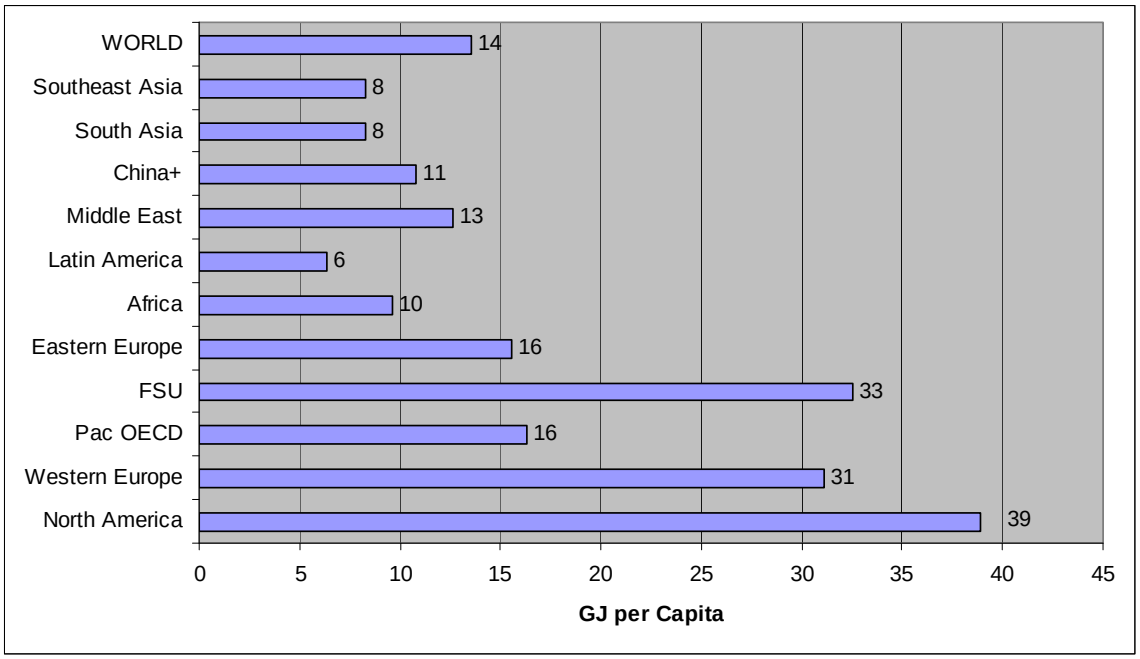
Current Accounts

Energy is used in households for a wide variety of end-uses: cooking, lighting, space heating and cooling, water heating, refrigeration, etc. The character of household consumption varies between and within regions as a function of income, culture, life-style, climate and access to energy forms, such as electricity.

Ideally, achieving a satisfactory understanding of household energy use requires information broken down by end-use, and when examining developing countries, broken down by urban and rural households. Unfortunately, such data are available in only a few countries, and thus when analyzing global and regional patterns we have to rely upon aggregate fuel consumption data (IEA, 2006a-b). Yet, this more aggregate data presents serious analytical problems. For example, estimates of traditional biomass consumption in developing country households (firewood, charcoal, crop and animal residues) remain poorly known.

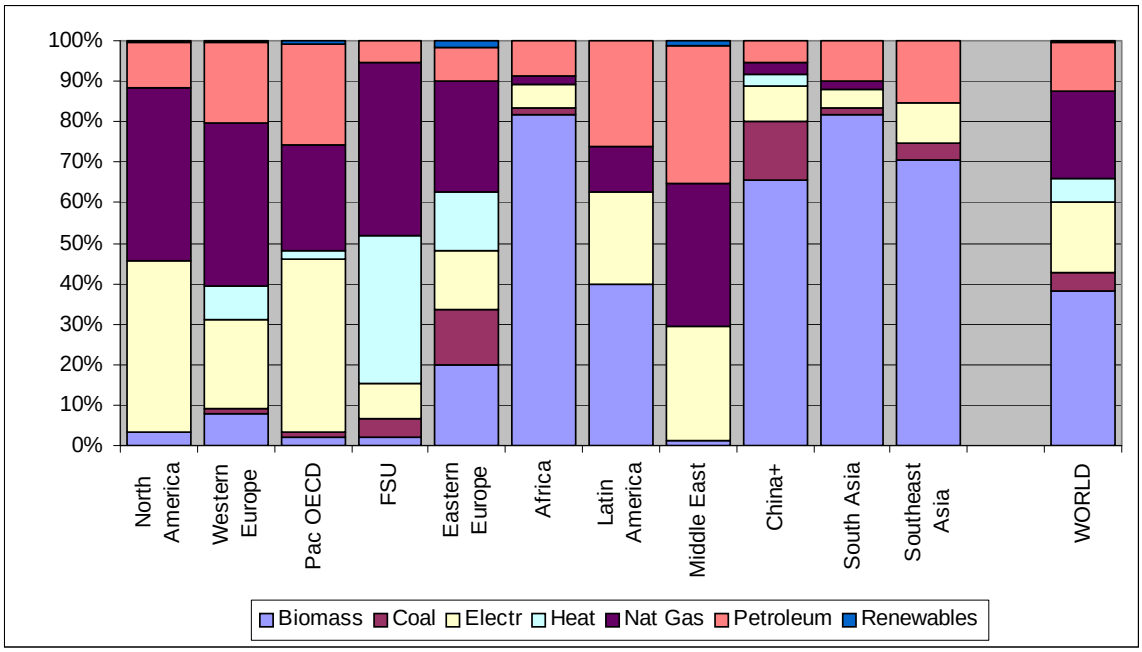
Current regional household sector energy consumption patterns are reported with energy consumption in other sectors in Table 3-2, above. Figure 3-3 shows current household energy consumption per capita by region, underscoring the substantial disparity between industrialized and developing regions. Household per capita energy use in North America, for example, is nearly five times the level in South and Southeast Asia, and more than six times that of Latin America. However, the efficiency of converting fuel into final services (that is, cooking fuel into boiling water, boiler fuel into warm spaces) is generally higher in advanced industrial countries, implying that final energy use figures for a region such as Africa are misleadingly high relative to delivered energy services since a considerable quantity of fuel is wasted in inefficient fuelwood use.

Figure 3-3. Household energy intensities – 2005



A great variation in household fuel use patterns is suggested by the fuel share breakdowns presented in Figure 3-4. Noteworthy are the large shares for biomass in the household energy mix in developing regions, the importance of coal in China+ and Eastern Europe, and the increasing reliance on more convenient energy forms (electricity, natural gas and oil) as household incomes rise to OECD levels. The large share for "heat" in the fuel mix of the FSU is due to the continuing widespread use of centralized district heating systems in this region. However, the Eastern Europe region has seen a decline in the use of district heat energy from approximately 25% of all household energy use in 1995 to only 14.6% in 2005.

Figure 3-4. Household energy shares – 2005



Scenarios

Methodology

The household sector scenario analysis relies on three elements: a measure of end-use activity or service, energy intensity to achieve that level of service, and final fuel mix. The activity measure used is the population in each region. In principle, further disaggregation into household income groups would be desirable in order to illuminate energy trends as a function of changing income distribution, but there is insufficient data for this level of analysis.

Energy Intensity

Since 1973 in industrialized countries, energy intensities per capita have remained almost constant, or in some cases have slowly declined, in spite of increasing household floor space and increasing penetration of electric appliances. In the United States, for example, final energy use per capita in households declined by 11% between 1972/3 and 1988 (Schipper and Meyers, 1992). Part of the decline reflects the increased use of electricity (which is intrinsically more efficient than combusted fossil fuels), but there also appear to have been significant declines in energy intensities for heating (IEA, 1997).

Action to reduce energy use in the built environment was in part spurred by the oil crises of the 1970s. Numerous initiatives of governments, utilities, trade associations and other institutions led to new regulations mandating enhanced efficiency standards and new products such as compact fluorescent lights, more efficient refrigerators and other

appliances, passive solar heating, wider adoptions of double-glazed windows and spectrally selective window glazing. These improvements in energy efficiency can be expected to continue, and this effect is represented to some extent in the *Market Forces* scenario. Nevertheless, to-date the adoption of cost-effective measures to reduce building energy use remains far below its economic potential. Large market barriers remain, preventing a transition to a more energy-efficient future for the household sector. Issues such as imperfect information, high transaction costs, inadequate internalization of pollution costs, and the lack of choice for consumers (who are often faced with the choice of purchasing an energy-efficient appliance versus another less efficient model with a wider range of desired features) all contribute to the problem.

The policies and programs considered for the *Policy Reform* scenario assume concerted action to accelerate the decline in household energy intensities, including: improved appliance and building energy performance standards, business and consumer information programs, targeted government procurement strategies, measures to promote market transformation and overcome market barriers, increased funding of research and development, and initiatives to encourage voluntary action and utility energy management programs.

Scenario energy intensity assumptions for OECD regions in both scenarios are informed by the U.S. study *Energy Innovations* (1997), scenario studies such as the Greenpeace and European Renewable Energy Council (EREC)'s "energy [r]evolution" reports (2007-2008), and regional studies focused on specific countries, such as in the Asia-Pacific Economic Cooperation (APEC) Energy Demand and Supply Outlook (APERC, 2006). The *Energy Innovations* study, based on end-use engineering and econometric analysis, examined changes in household energy intensities in light of expected trends in prices, end-use saturations and household income levels, and by making various assumptions about changes in technology. It modeled the sector using suitably constrained behavioral models that determine the least-cost technology available to meet various service demands. The study created two scenarios, called the *Present Path* and *Innovation Path*, which are broadly compatible with the viewpoints of the *Market Forces* and *Policy Reform* scenarios respectively. The "energy [r]evolution" scenarios have a *reference* scenario and an *energy [r]evolution* scenario which are also broadly compatible with the *Market Forces* and *Policy Reform* scenarios, respectively. Our scenario assumptions in this study are informed by these studies, along with other experts.

In the absence of new policy actions, the *Market Forces* scenario previously had assumed significant reductions in energy intensities in the three OECD regions. Unfortunately, however, the past ten years of data have not supported this level of reduction. In this update, household energy intensities actually have been increased at a rate of 1.0% per year in the Western Europe and Pacific OECD regions through 2025, while the intensities do not decline in North America. All intensities in OECD regions remain steady between 2025 and 2050. While we still assume the introduction of a variety of increasingly efficient appliances and building shells, including improved heating and air conditioning systems, and more efficient lighting and cooking systems, the number of new energy consuming appliances and devices (e.g., computers) are still proliferating in these regions, and are assumed to saturate the market by 2025. The *Policy Reform* scenario

assumes both more rapid and more widespread penetration of efficient new technologies, with OECD intensities declining at a rate of 2% per year for electric appliances, and 1% per year for non-electric household energy uses, such as heating and cooking. In later periods, the *Policy Reform* scenario assumes the introduction of advanced technologies and building designs such as passive solar heating, efficient heat pumps and greater direct use of renewable energy.

Household energy intensities in non-OECD regions are assumed to converge towards the value of the Western Europe energy intensity as average incomes increase towards average OECD levels, using a technology convergence algorithm (see Annex 1). Western Europe's energy intensity is chosen as the level to converge to because it is deemed to be a reasonable model for a developed region. Table 3-3 summarizes the evolution of energy intensities by region in each scenario. In the *Market Forces* scenario, non-OECD energy intensities approach a higher average intensity (38 gigajoules(GJ)/capita), while in the *Policy Reform* scenario, they approach a lower average intensity (18 GJ/capita) as set by Western European patterns. At the same time, there is much greater overall convergence to Western European standards in the *Policy Reform* scenario than in the *Market Forces* scenario, due to the assumption of improving equity and more rapid economic growth in the developing countries in the former scenario. These two effects largely counteract one another, resulting in broadly similar trends in developing country energy intensities in the two scenarios. The exception is the FSU, where household energy intensities start at levels well above the OECD average, and thus the effects of the convergence algorithm and trends in OECD intensities reinforce one another.

Table 3-3. Trends in household energy intensities

GJ/capita		*Market Forces*			*Policy Reform*		
				Growth Rate			Growth Rate
	2005	2025	2100	2005-2100	2025	2100	2005-2100
North America	39	39	39	0.00%	29	21	-0.65%
Western Europe	31	38	38	0.21%	24	18	-0.56%
Pac OECD	16	20	20	0.21%	12	9	-0.65%
FSU	33	34	38	0.16%	30	18	-0.61%
Eastern Europe	16	23	38	0.94%	19	18	0.16%
Africa	10	11	22	0.87%	10	14	0.42%
China+	11	15	38	1.33%	13	18	0.55%
Latin America	6	12	38	1.89%	10	18	1.11%
Middle East	13	18	38	1.16%	16	18	0.38%
South Asia	8	10	32	1.43%	9	18	0.82%
Southeast Asia	8	12	38	1.61%	11	18	0.83%
World	14	16	21	0.45%	14	17	0.24%

Fuel Shares

Total household fuel use is projected by fuel for each region. Since traditional biomass fuels currently dominate household energy use in most developing countries, assumptions as to the future use of modern versus traditional fuels are a key issue in the *Market Forces* and *Policy Reform* scenarios. Household fuel use tends to climb an "energy ladder" with rising income. As incomes increase, wood and dung are replaced by charcoal and kerosene and then by Liquefied petroleum gas (LPG), natural gas, and electricity. Each succeeding rung in the ladder is characterized by greater efficiency of use, but also by higher end-use equipment prices. Consequently, differences in income can imply very different requirements for energy, and very different end-use efficiencies.

An examination of household energy consumption data showed that shares of electricity in total household fuel use and of biomass in non-electric household fuel use vary in a fairly uniform way with income. Biomass and electricity shares in the *Market Forces* scenario are estimated based on patterns seen in national data, while the *Policy Reform* scenario assumes a more rapid penetration of electricity and other renewables in order to reduce CO_2 emissions.

Finally, the shares of each non-electric and non-biomass fuel are computed. In the *Market Forces* scenario, these are guided by household fuel consumption trends. These reflect the effects of changes in prices as resources are depleted and technical change occurs.

Taking the *Market Forces* scenario as a starting point, the *Policy Reform* scenario assumes an accelerated transition away from the more carbon intensive fuels (coal and oil) towards lower carbon and more convenient fuels (electricity, natural gas, and some renewables). This reflects a pattern of higher and more evenly distributed income levels in the developing countries (leading to higher consumption of the more convenient and efficient fuels), and the effects of policies to reduce greenhouse gas emissions.

Results

Household energy demands are shown by fuel in Figure 3-5. In both scenarios, total household energy consumption at the end-use increases dramatically, with a 238% increase in Market Forces from 2005 to 2100. In the *Policy Reform* case, we see only a 44% increase by 2100. Note that in the *Policy Reform* case, households use a lot more renewable resources directly, such as various solar or geothermal technologies for directly generated heat or hot water. And while the total consumption of household electricity in 2050 is about the same in the two scenarios, we will discover later that much more of that electricity is produced by zero-carbon resources such as wind, solar, and biomass. Both greater direct and indirect use of renewables is due to the CO_2 emissions targets that have been established for the household sector separately for each region. By 2100, Carbon constraints result in a household energy sector composed purely of electricity and renewable sources. (See Figure 7-5 on page 270 for sectoral allocations of CO_2.)

Figure 3-5. Global household energy demand by fuel

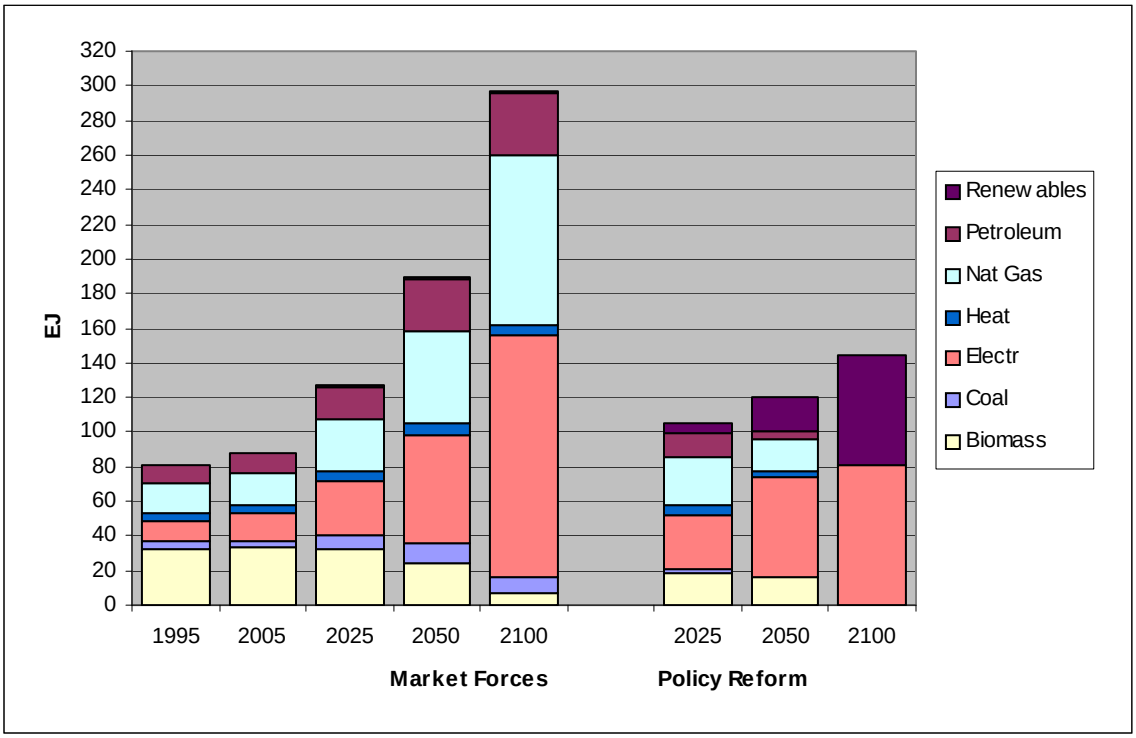
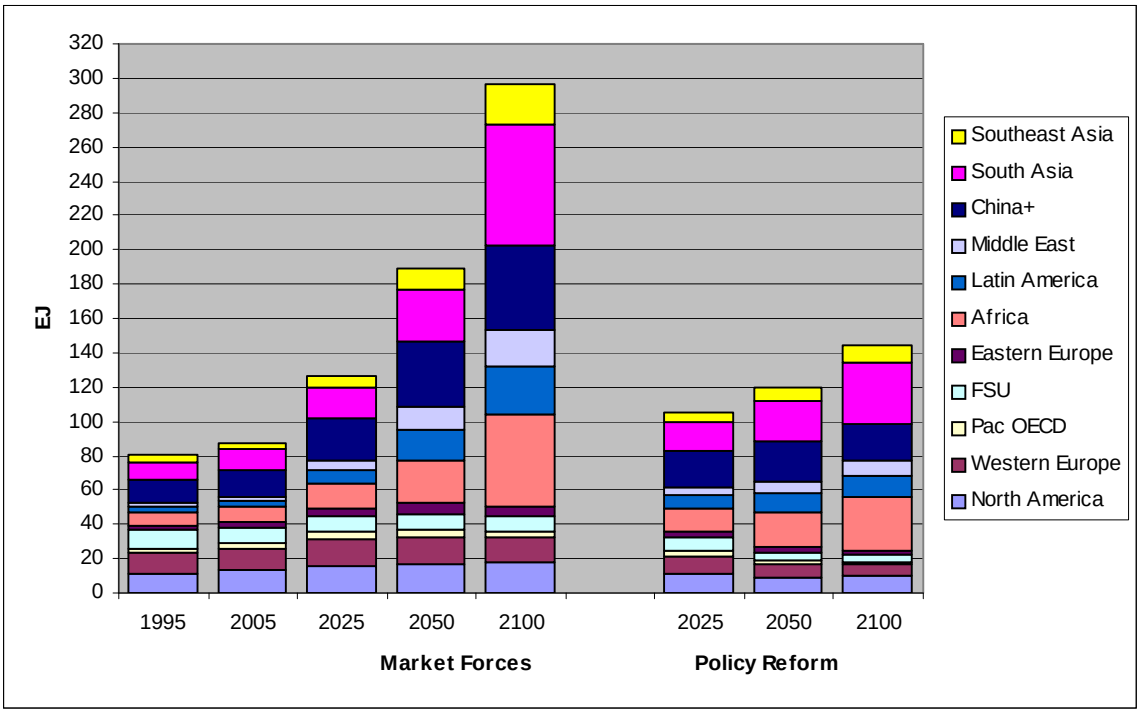


Figure 3-6. Global household energy demand by region



Household energy demands are shown by region in Figure 3-6 and Figure 3-7. In the *Market Forces* scenario, the fairly stable or slowly increasing household energy demands in the OECD regions are the result of low population growth, relatively high initial appliance saturations, and some efficiency improvements (here, the decline in household energy use for the FSU is the exception). The developing regions experience dramatic increases in household energy demand, largely due to higher population growth and the gradual transition to modern patterns of higher household energy use. Biomass energy use continues to dominate household demand in Africa and, to a lesser extent, in South and Southeast Asia, while coal continues to dominate in China+.

As discussed above, consumption of biomass fuels by households decreases over time in most regions, as increasing incomes allow people to move up the "energy ladder" to more convenient forms of household energy. However, this trend is counterbalanced by the continuing expansion of biomass use by households in Africa, in which rapid population growth and continuing poverty combine so that biomass fuels continue to dominate in the household sector until well past 2025. The overall effect is a slight decline in global household biomass use from 1995 or 2005 to 2050, but a significant reduction by 2100 in the *Market Forces* scenario.

In the *Policy Reform* scenario, energy consumption is significantly lower than in the *Market Forces* scenario and is distributed differently between fuels. In particular, the scenario sees a more rapid decline in biomass consumption and a more rapid transition towards less carbon-intensive fuels and renewable energy than the *Market Forces* scenario.

The regional distribution of consumption is also different, as illustrated in Figure 3-6. In the OECD regions, additional energy intensity improvements produce reductions in consumption compared to the *Market Forces* scenario. In most non-OECD regions, energy consumption levels are only slightly lower in the *Policy Reform* scenario compared to the *Market Forces* scenario, due to two counteracting effects. First, faster economic growth leads to increased consumption. However, it also leads to greater convergence of energy intensities increasing towards Western Europe's intensity values, which are lower in the *Policy Reform* scenario than in the *Market Forces* scenario, as their incomes approach average OECD 2005 incomes (See Annex 1). The exception to the general pattern is the FSU, where consumption declines are much greater – a result of the high initial energy intensities in the region. Thus, much fewer fossil fuels are consumed in the *Policy Reform* case by 2050 as one would naturally assume, and by 2100, no fossil fuels are consumed at the household level in order to comply with the strict Carbon targets set in the scenario. Additionally, no biomass fuel is used at the household level by 2100 to avoid the huge land-use implications resulting from extensive biomass fuel use.

Figure 3-7. Regional household energy demand

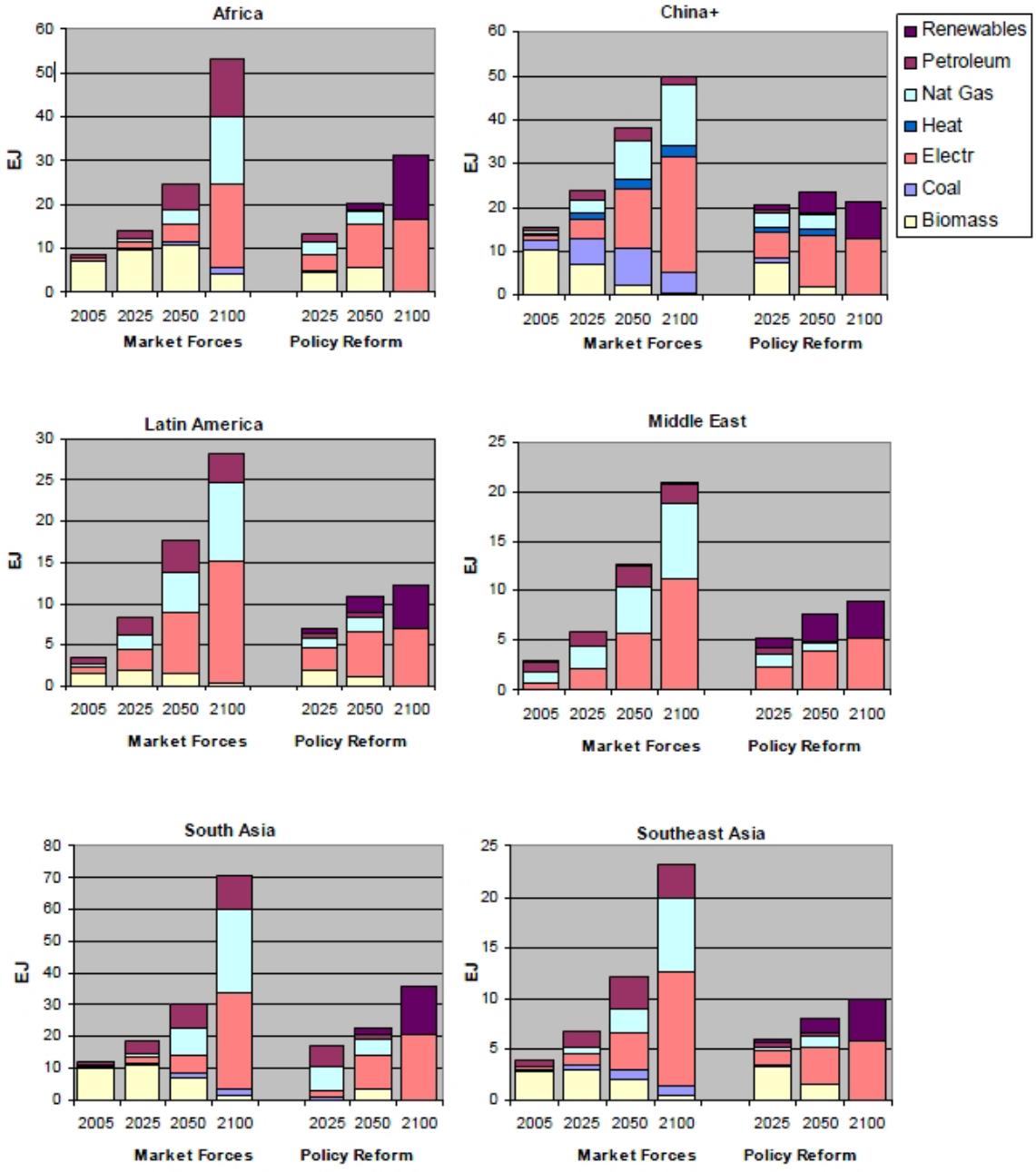
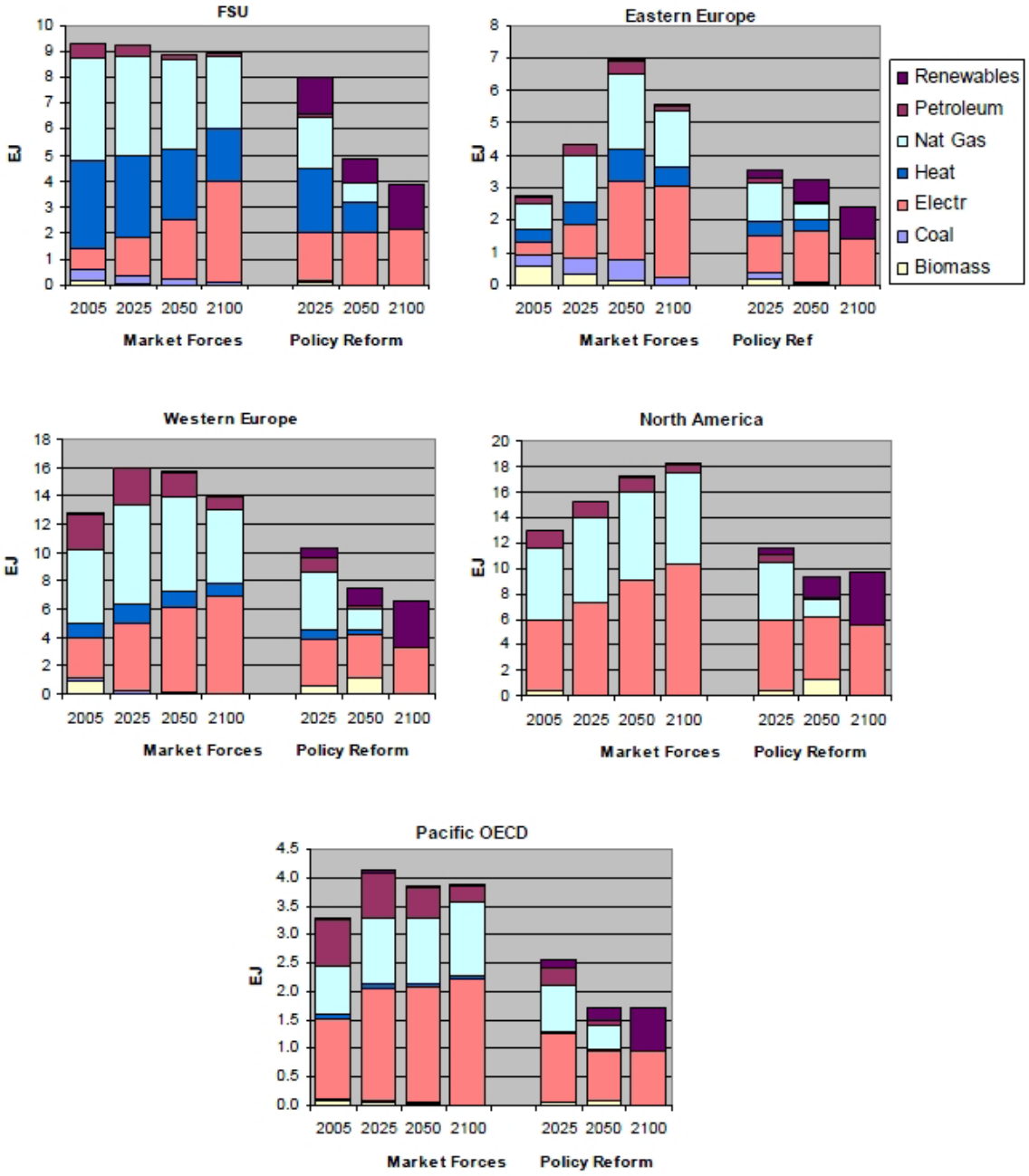


Figure 3-7 Continued. Regional household energy demand



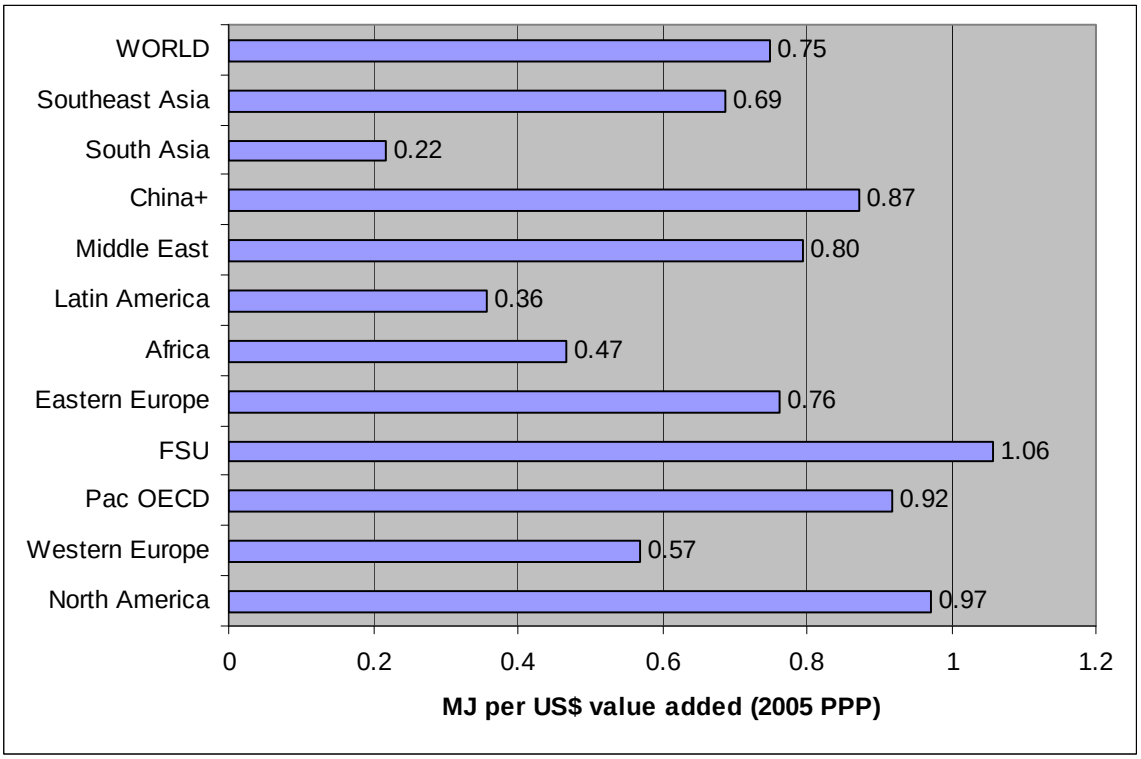
Services

The service sector is broadly defined to include such economic activities as offices, retail, education, hospital and other non-industrial enterprises. Service sector energy use is largely related to building end-uses: lighting, HVAC (heating, ventilation, and air conditioning) and other electrical equipment. The assessment would benefit from sub-sectoral and end-use disaggregation, but, again, the absence of reliable survey and statistical data makes this infeasible.

Current Accounts

Regional service sector energy consumption is reported along with the energy use in other sectors in Table 3-2 (page 38). There is a striking difference between service energy use in industrialized and other regions. North America's per capita demand for energy in the service sector is more than four times that of the developing regions, reflecting both higher incomes and the greater share of the service sector of overall economic activity seen in high-income regions. Figure 3-8 shows service sector energy consumption per dollar of service sector value added.

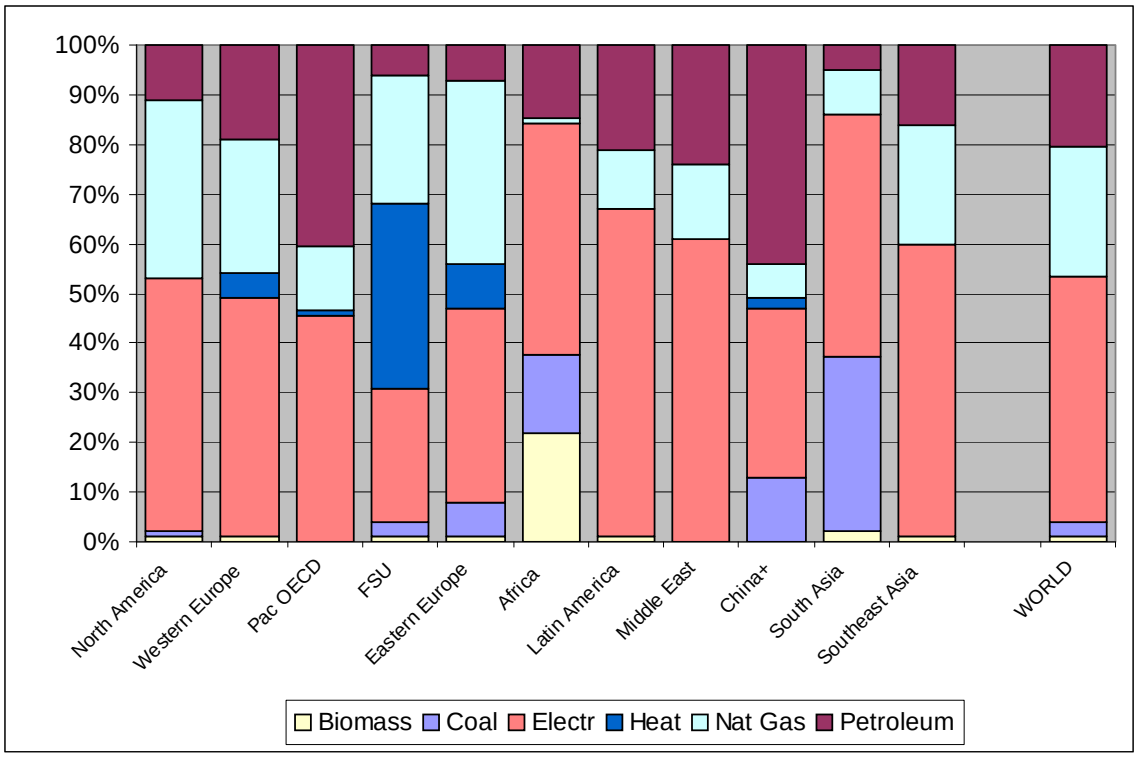
Figure 3-8. Service sector energy intensities - 2005



Current account fuel shares for the service sector are shown in Figure 3-9. Electricity, petroleum, and natural gas are the dominant fuels, accounting for more than 90% of global service sector energy consumption. Coal remains important in China+ –

accounting, at least in part, for that region's relatively high service sector energy intensity. Note that it is likely that the heavily biomass-reliant *informal sector*, the small and often unregistered enterprises in many developing regions, are not fully reflected in service sector energy statistics (O'Keefe et al., 1984). However, in some cases, this consumption may be included within household statistics. District heat is again significant in Eastern Europe and the FSU countries and to a lesser extent in Western Europe. It remains largely undeveloped in North America and the rest of the world.

Figure 3-9. Service sector fuel shares - 2005



The current determinants of service sector energy use, and the variables that will condition future usage patterns, include the scale of service sector activity, the mix of activities at the sub-sectoral level, end-use energy efficiency, building and architectural standards, trends in office automation, and fuel availability and price. Detailed consideration of these factors is difficult because of an unusually sparse data base for this sector.

Scenarios

Methodology

The service sector scenario analysis relies on three key elements: measures of activity, energy intensity and final fuel mix. The activity measure is defined as service sector value added, the product of regional GDP and the sectoral share of GDP. The energy intensity is expressed as the service sector final energy demand divided by value added for the sector.

Energy Intensity

Historically, service sector energy intensities per dollar value added have been declining in industrialized nations since 1973. In nine OECD countries, these intensities declined by 27% over the period 1973 to 1988 (Schipper and Meyers, 1992). Declines in the energy intensity of space heating appears to be the major reason for these overall declines, as business switched from less efficient fuels and devices (e.g., fuel-oil systems) to natural gas and electricity. Additions of new buildings with lower heating requirements, retrofit improvements to existing building envelopes and improved energy management also contributed to the decline. Structural shifts between service sectors appear to have had relatively little effect (Schipper and Meyers, 1992).

The historical improvements in energy intensity are expected to continue in the future even without new policy interventions, and this is reflected in the *Market Forces* scenario. Nevertheless, the adoption of cost-effective measures to reduce service sector energy use remains far below its economic potential. The *Policy Reform* scenario reflects concerted action to accelerate the decline in service sector energy intensities. Many of the policies and programs required to achieve this are common with those in the household sector, and were described in the previous section.

Scenario intensities for the Service sector in OECD regions are also guided by the findings of the U.S. *Energy Innovations* study (Energy Innovations, 1997), scenario studies such as the Greenpeace and EREC's "energy [r]evolution" reports (2007, 2008), and regional studies focused on specific countries, such as in the APEC Energy Demand and Supply Outlook (2006). In the *Market Forces* scenario, OECD service sector energy intensities decline at a rate of 1.3% per year, while in the *Policy Reform* scenario, they decline at a rate of 1.8% per year (Table 1-4). Both scenarios require increasingly energy-efficient building shells, as well as improvements in areas such as space heating and cooling, water heating and commercial appliances. The *Policy Reform* scenario requires both more rapid and more widespread penetration of efficient technologies and, in later periods, the introduction of advanced technologies and building designs.

In each scenario, intensities in non-OECD regions are converged towards the average values of the OECD region as average incomes in non-OECD regions increase, using a convergence algorithm (see Annex 1). In the *Policy Reform* scenario there is greater overall convergence to a lower average intensity, in accordance with the exogenous

assumptions of improving equity and more rapid economic growth in the developing countries compared with the *Market Forces* scenario.

Table 3-4. Trends in service sector energy intensities (MJ/$ VA)

MJ/$ VA		*Market Forces*				*Policy Reform*			
					Growth Rate				Growth Rate
	2005	2025	2050	2100	2005-2100	2025	2050	2100	2005-2100
North America	1.0	0.6	0.4	0.4	-1.00%	0.5	0.2	0.2	-1.48%
Western Europe	0.6	0.4	0.2	0.2	-0.89%	0.3	0.2	0.2	-1.37%
Pac OECD	0.9	0.8	0.5	0.5	-0.66%	0.5	0.2	0.2	-1.48%
FSU	1.1	0.9	0.6	0.6	-0.61%	0.9	0.4	0.4	-1.14%
Eastern Europe	0.8	0.7	0.4	0.4	-0.79%	0.6	0.2	0.2	-1.37%
Africa	0.5	0.5	0.5	0.5	-0.02%	0.5	0.4	0.4	-0.07%
China+	0.9	0.8	0.6	0.6	-0.35%	0.8	0.5	0.5	-0.60%
Latin America	0.4	0.4	0.4	0.4	0.05%	0.4	0.3	0.3	-0.25%
Middle East	0.8	0.8	0.6	0.6	-0.37%	0.7	0.4	0.4	-0.74%
South Asia	0.2	0.2	0.3	0.3	0.16%	0.2	0.2	0.2	0.05%
Southeast Asia	0.7	0.7	0.6	0.6	-0.17%	0.7	0.5	0.5	-0.34%
WORLD	0.7	0.6	0.4	0.2	-1.27%	0.5	0.3	0.1	-1.75%

Results

Multiplying service sector value added and the intensity figures we derive service sector energy demand. Service sector energy demand by fuel is shown in Figure 3-10. In both scenarios, the size of the global service sector (measured in PPP dollars of value added) increases by a factor of more than 10 from 2005 to 2100.

Service sector energy demands are shown by region in Figure 3-11. Energy requirements for the service sector grow rapidly in the *Market Forces* scenario, increasing globally by a factor of 2.4 over the scenario time-frame (2005-2100), and by a factor of 6.6 in the non-OECD regions as a whole. Increased energy efficiency results in lower growth in service sector energy demand in the *Policy Reform* scenario. This growth is concentrated in the developing regions. However, OECD service sector energy consumption declines, and in 2100 is about 60% its 2005 value. In the non-OECD regions consumption roughly quadruples in the same time period.

Fuel Shares

In the *Market Forces* scenario, fuel share assumptions are guided by expert judgment of the recent trends, which leads to the fuel mix being even more dominated by electricity and natural gas. Taking the *Market Forces* scenario as a starting point, the *Policy Reform* scenario assumes an accelerated transition towards lower-carbon fuels. Given the stringent CO_2 reduction targets of the *Policy Reform* scenario, by 2050 the service sector becomes dominated by electricity and, to a lesser extent, renewables, and by 2100, all fossil fuel use is eliminated (See Figure 3-10)

Figure 3-10. Global service sector energy demand by fuel

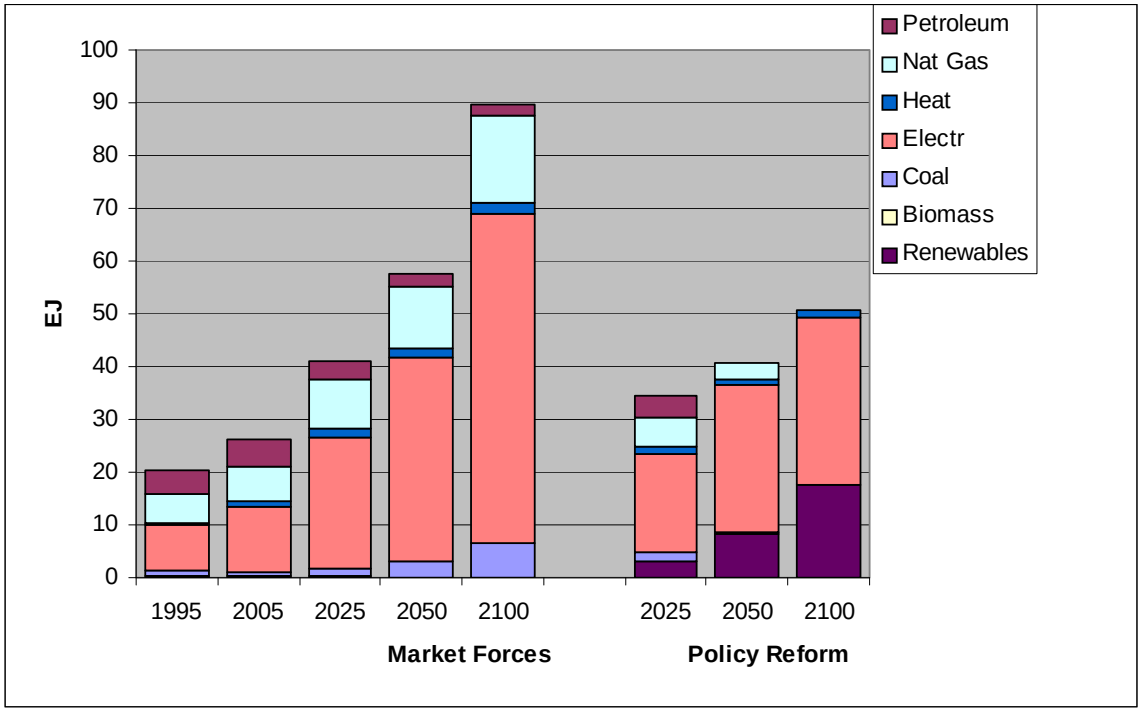
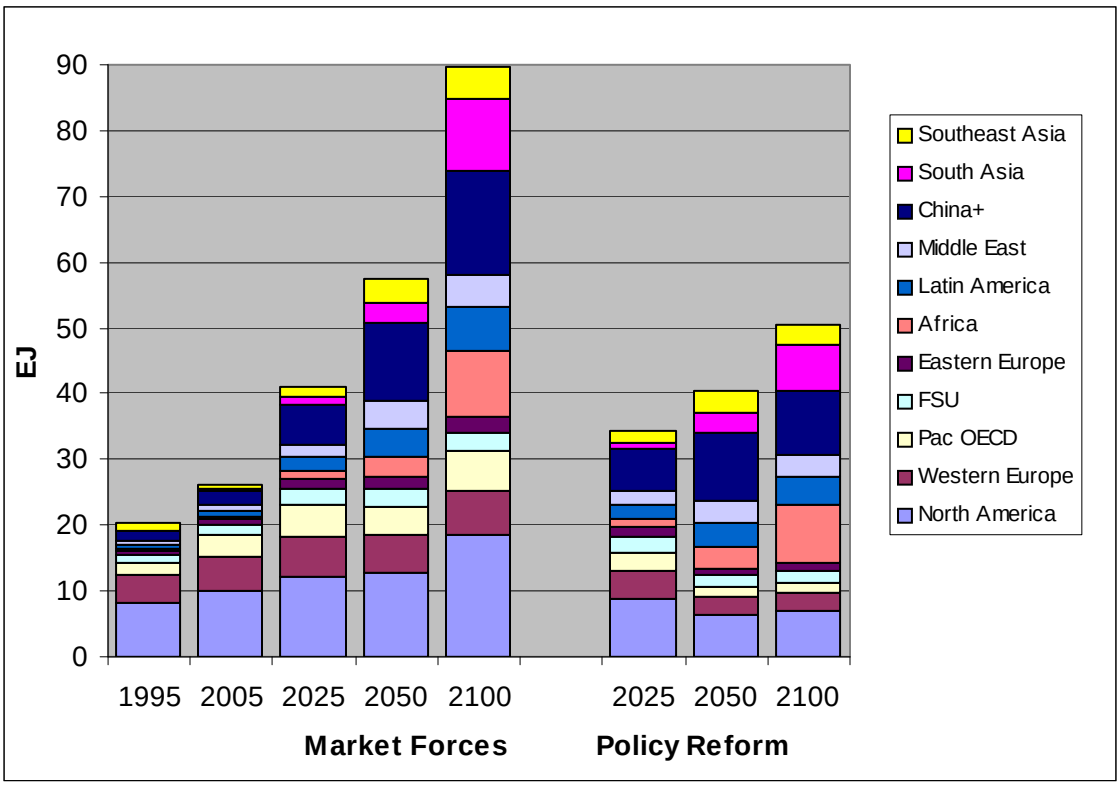


Figure 3-11. Global service sector energy demand by region



Service sector energy demands are shown for each region in Figure 3-12. In all non-OECD regions, service sector energy consumption in 2100 is lower in the *Policy Reform* scenario than in the *Market Forces* scenario because energy intensity improvements, as they are converging to more efficient OECD target efficiency values, outweigh the effect of increased growth of the sector.

Figure 3-12. Regional service sector energy demand

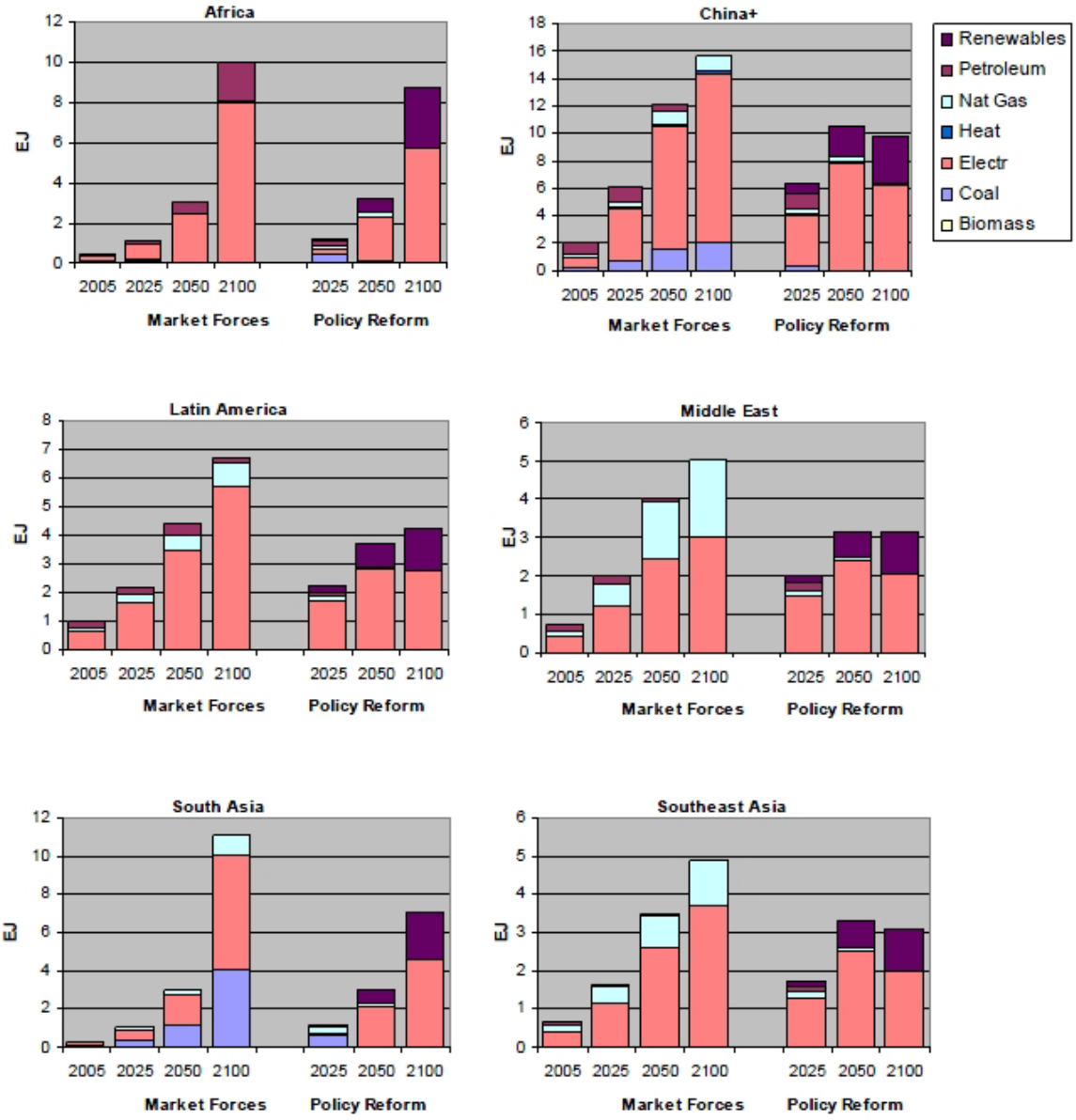
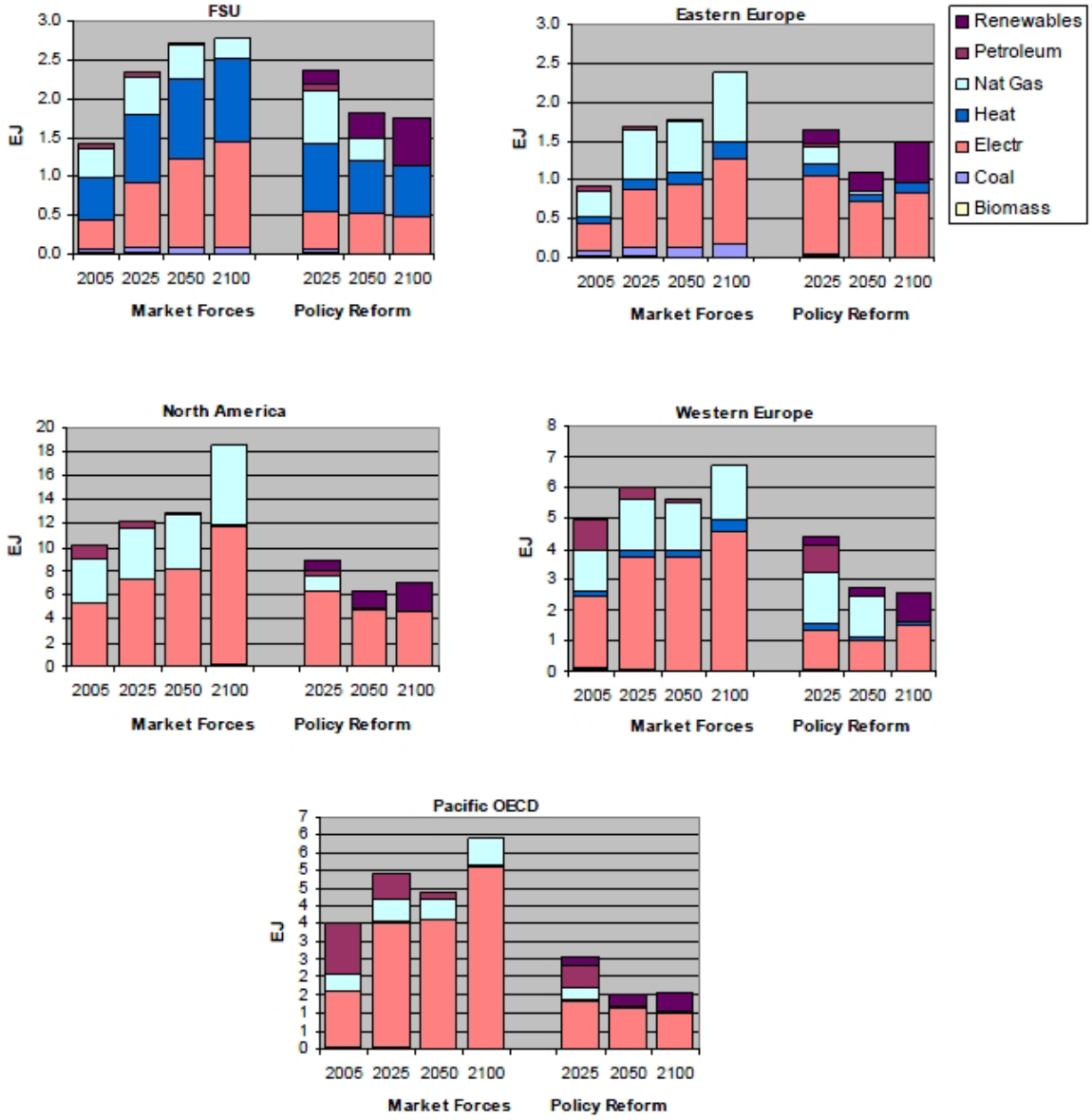


Figure 3-12 Continued. Regional service sector energy demand



Agriculture

The agriculture sector includes activities in farming, livestock and forestry systems. Agricultural energy consumption reflects the final use of fuels (especially, fossil fuels and electricity) consumed at the end-use, e.g., for field operations, irrigation, drying and so on. With this definition, energy used in the agricultural sector accounts for about 3% of world final energy consumption.

Current Accounts

Regional agricultural energy consumption is reported in Table 3-2 (page 38). Energy use in the agricultural sector is dominated by petroleum products, which account for 63% of global agricultural energy consumption (See Figure 3-13). In fact, in nine of the eleven regions petroleum products account for more than 50% of agricultural energy demand. Energy use per dollar value added is reported in Figure 3-14. In general, energy intensities are much higher in the OECD and FSU where agriculture is far more mechanized. Other significant variations across regions may be related to underlying differences in agricultural practices due to irrigation levels and geophysical factors. However, variations may also be related to uncertainty in agriculture energy statistics and accounting procedures. For example, it remains unclear (even with recent revisions to IEA databases) whether FSU agricultural statistics include energy consumed for food processing and transportation of agricultural products, or whether these are assigned to the appropriate industry and transportation sectors, respectively, as is the practice in OECD regions. Failure to follow the appropriate accounting practice may help to explain the unusually high intensities for agricultural energy use in the FSU. (Note, however, that FSU industrial energy intensities are also very high.)

Figure 3-13. Agriculture sector fuel shares - 2005

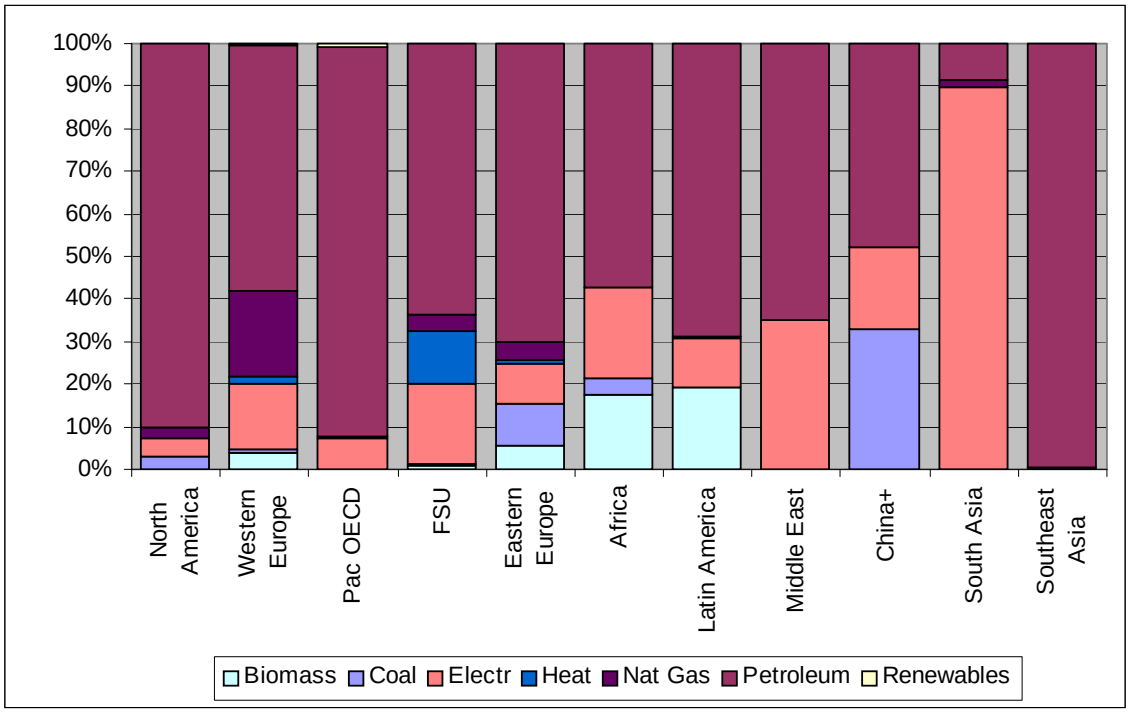
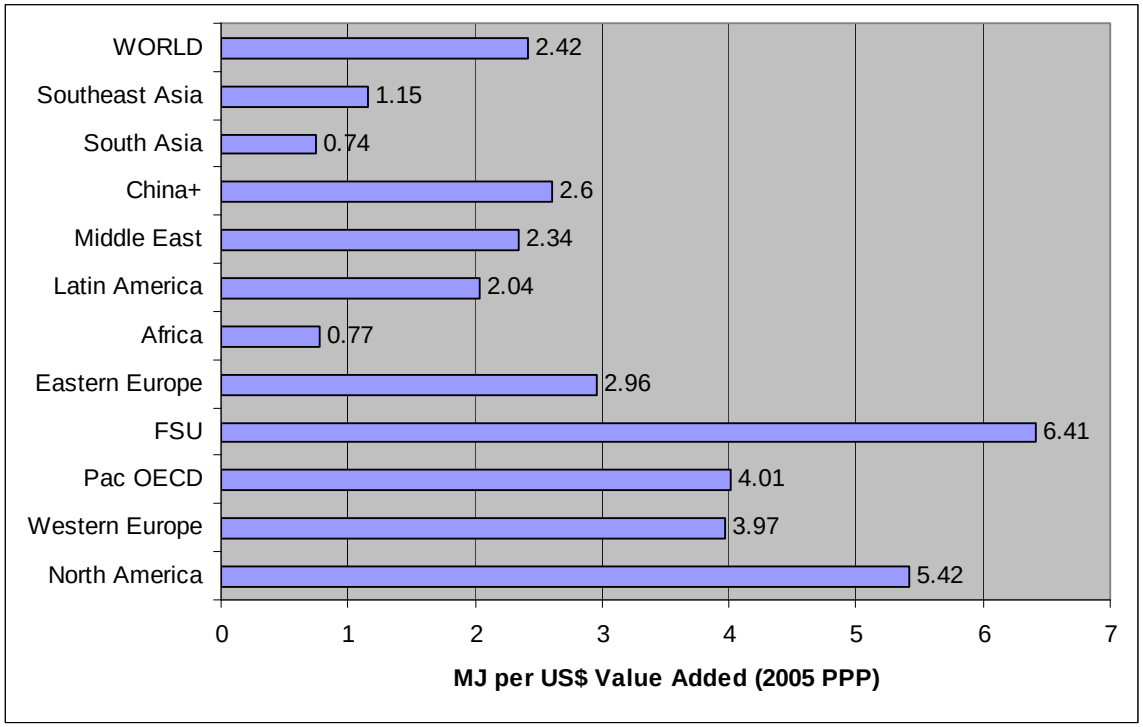


Figure 3-14. Agriculture sector energy intensities - 2005 (MJ/$)



Scenarios

Methodology

The agriculture sector energy scenarios are based on the usual three-step analysis of activity levels, energy intensities, and final fuel mix. The activity measure is agricultural sector value added – the product of regional GDP and the sectoral share. Energy intensity is expressed as the agricultural sector final energy demand divided by value added for the sector.

Energy Intensity

As a first step in the analysis, trends in agricultural energy intensity (expressed per dollar value added) are developed for the three OECD regions. In the absence of more detailed studies of the trends in the agriculture sector, improvements in agricultural energy intensities are guided by our assumptions for the industrial sector (described in the next section), with more modest rates of improvement assumed.

Agricultural sector energy intensities are summarized in Table 3-5. Just as in the service and industrial sectors, the interpretation of intensity trends would be more transparent if they were expressed in physical units, e.g., energy consumption per unit of agricultural product. Then, in the transition to modern high-input agriculture, energy intensities would be driven by the interplay of two counterbalancing processes, increasing energy use per unit area and increasing product per unit area. But data inadequacies prevent conducting such an energy analysis. In relying on agriculture sector GDP, an additional variable and additional uncertainty is introduced – the relationship between physical product and the value added in the sector.

In the *Market Forces* scenario, OECD agricultural sector energy intensities decline at a modest 0.5% per year (see Table 3-5). This is roughly consistent with average trends in OECD countries over the last few decades where the limited available data (e.g., WRI, 1992, IEA, 2006b) suggest that agriculture energy intensities have been declining only very slowly. (Note, however, that North American intensities have increased.) In the *Policy Reform* scenario, agricultural energy intensities are assumed to decline on average at more than 1% per year.

For the non-OECD regions we apply a convergence algorithm (see Annex 1), which assumes that agricultural practices and energy intensities approach OECD average figures as each region's GDP per capita approaches the OECD average GDP per capita in 2005.

Table 3-5. Trends in agriculture sector energy intensities

MJ/$ VA		*Market Forces*				*Policy Reform*			
					Growth Rate				Growth Rate
	2005	2025	2050	2100	2005-2100	2025	2050	2100	2005-2100
North America	5.4	4.9	4.3	3.4	-0.50%	3.6	2.2	1.5	-1.32%
Western Europe	4.0	3.6	3.2	2.5	-0.50%	2.7	1.6	1.4	-1.08%
Pac OECD	4.0	3.6	3.2	2.5	-0.50%	2.7	1.6	1.4	-1.09%
FSU	6.4	5.8	4.5	2.8	-0.86%	5.4	2.6	1.5	-1.55%
Eastern Europe	3.0	3.3	3.6	2.8	-0.05%	3.0	1.8	1.5	-0.74%
Africa	0.8	0.9	1.1	1.7	0.86%	0.9	1.0	1.2	0.47%
China+	2.6	2.8	3.2	2.8	0.09%	2.7	2.2	1.5	-0.61%
Latin America	2.0	2.4	2.9	2.8	0.35%	2.3	2.0	1.5	-0.35%
Middle East	2.3	2.7	3.1	2.8	0.20%	2.5	2.1	1.5	-0.50%
South Asia	0.7	0.9	1.3	2.4	1.26%	0.9	1.0	1.5	0.71%
Southeast Asia	1.2	1.5	2.1	2.8	0.95%	1.4	1.6	1.5	0.25%
WORLD	2.4	2.4	2.4	2.5	0.03%	2.1	1.6	1.4	-0.58%

Fuel Shares

An examination of fuel share patterns over the time period 1970 to 1995 (IEA, 2006a, b) shows year-to-year fluctuation in the reported agriculture energy statistics, but no discernible regional trends. Thus for the *Market Forces* scenario, agricultural fuel shares are held roughly constant. In the *Policy Reform* scenario, as for other sectors, we impose a transition to less carbon-intensive fuels, principally through much greater penetration of electricity and natural gas for tractors, irrigation and other end-uses, as well as limited penetration of biomass and renewable energy for use in such applications as space heating and drying of agricultural commodities. Thus, electricity becomes the dominant end-use form of energy in all regions in the *Policy Reform* scenario, and by 2100, all fossil fuel use is eliminated. Also by 2100, all biomass fuel use is also eliminated to prevent undue pressure on land resources.

Results

Agricultural energy demand by fuel is shown in Figure 3-15. Significant growth in demand is seen in the *Market Forces* scenario, increasing by over 50% by 2100. In contrast, a decrease of 20% in agricultural energy demand is seen in the *Policy Reform* scenario. While a small part of the global total, the importance of coal in the sector actually increases in the *Market Forces* scenario. This is due to the large growth of

agriculture in developing regions, and the importance of coal use in China (see Figure 3-15), rather than to a general pattern of switching to coal in other regions.

Figure 3-15. Global agricultural energy demand by fuel

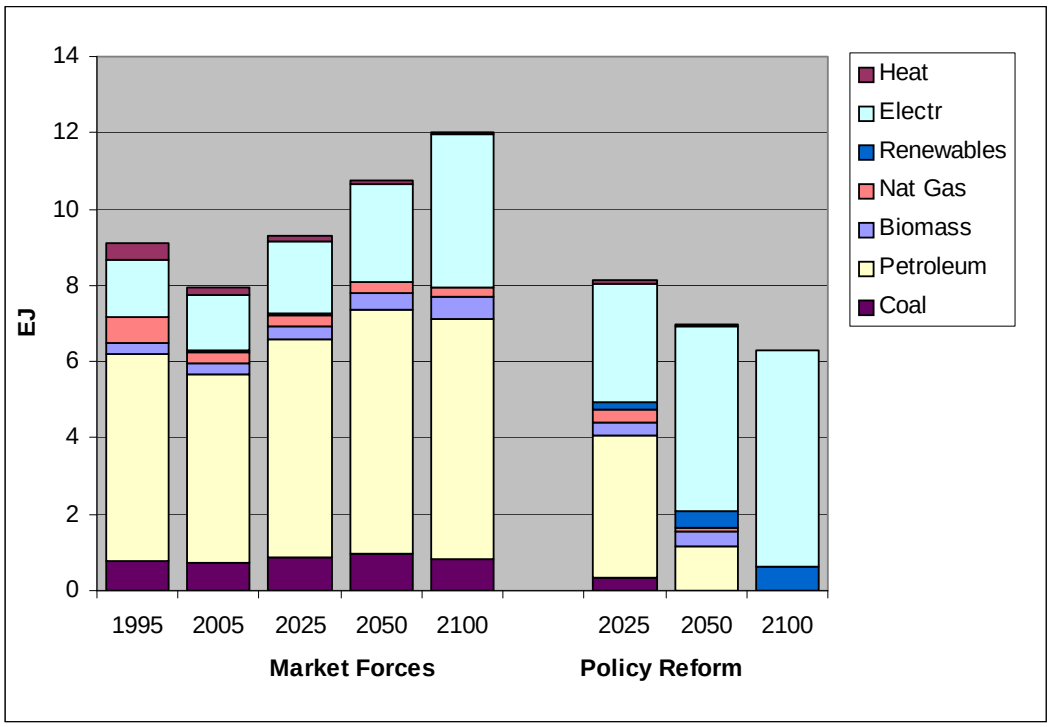
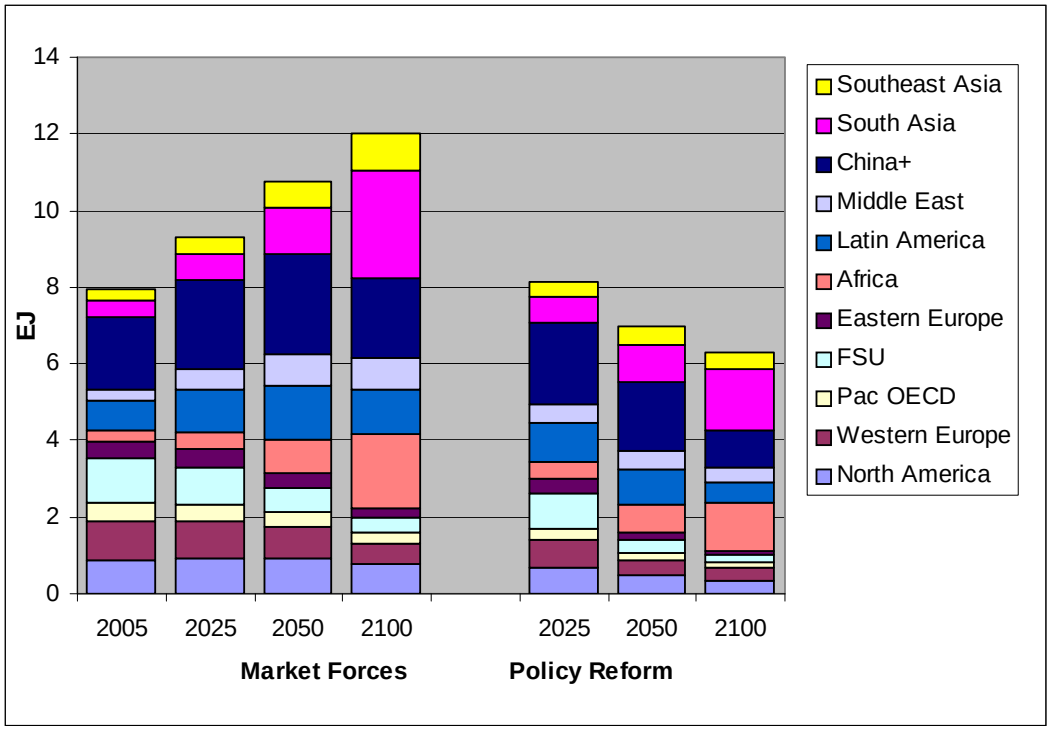


Figure 3-16. Global agricultural energy demand by region



Agricultural sector energy demands, totaled for all fuels, are shown by region in Figure 3-16. In the *Market Forces* scenario, the non-OECD regions increase their agricultural energy demand by 88% relative to 2005, while the OECD regions decrease their demand by 35%. In the *Policy Reform* scenario, the OECD regions decrease their demand by 65%, and even the non-OECD regions begin to decrease their demand by 2100 after years of increasing demand between 2005 and 2050.

Energy demands for the agricultural sector are shown by fuel and by region in Figure 3-17. In all regions, agricultural energy consumption in 2100 is lower in the *Policy Reform* scenario than in the *Market Forces* scenario, as energy intensity improvements outweigh the effect of increased growth in the sector.

Figure 3-17. Regional agricultural energy demand

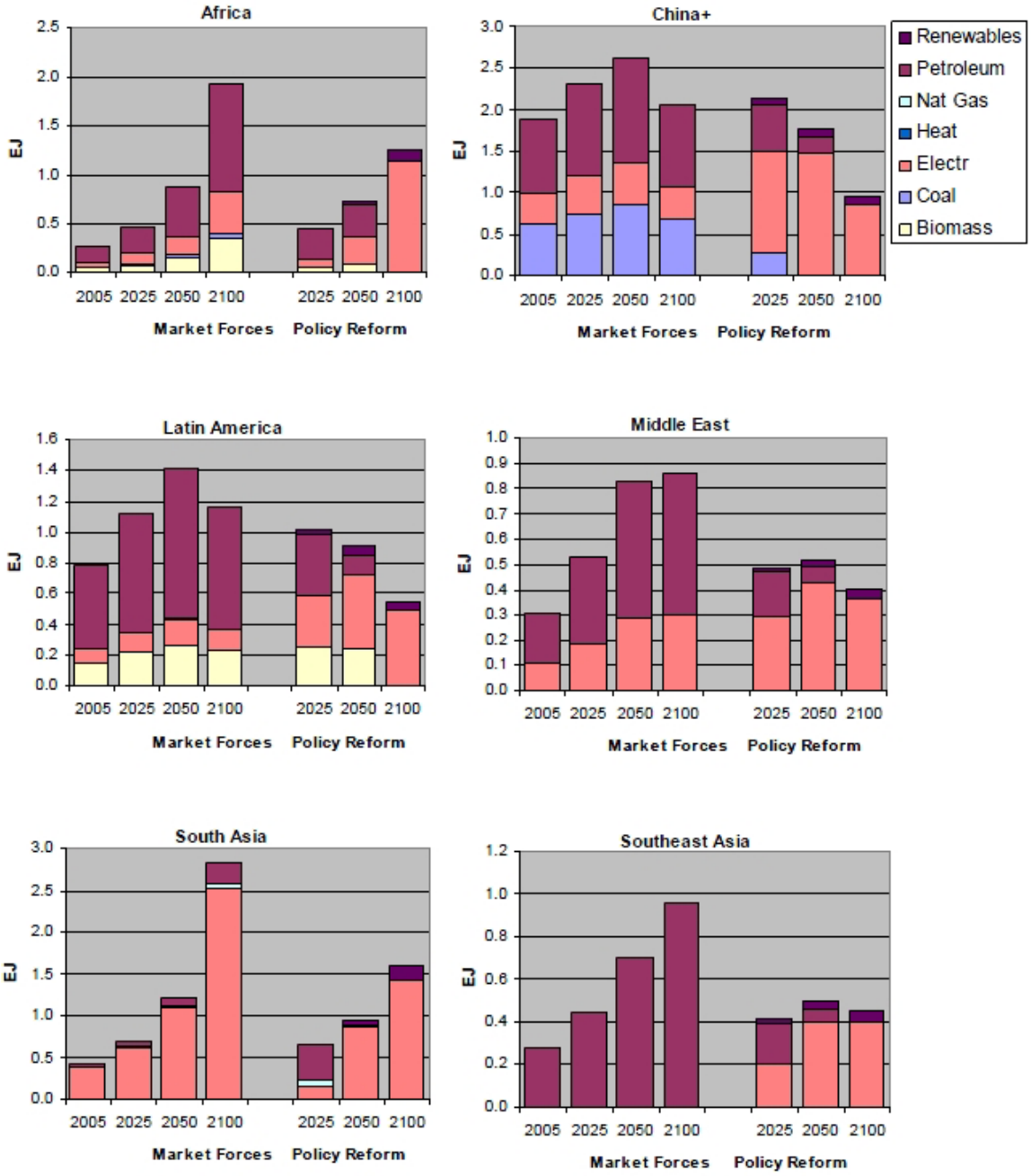
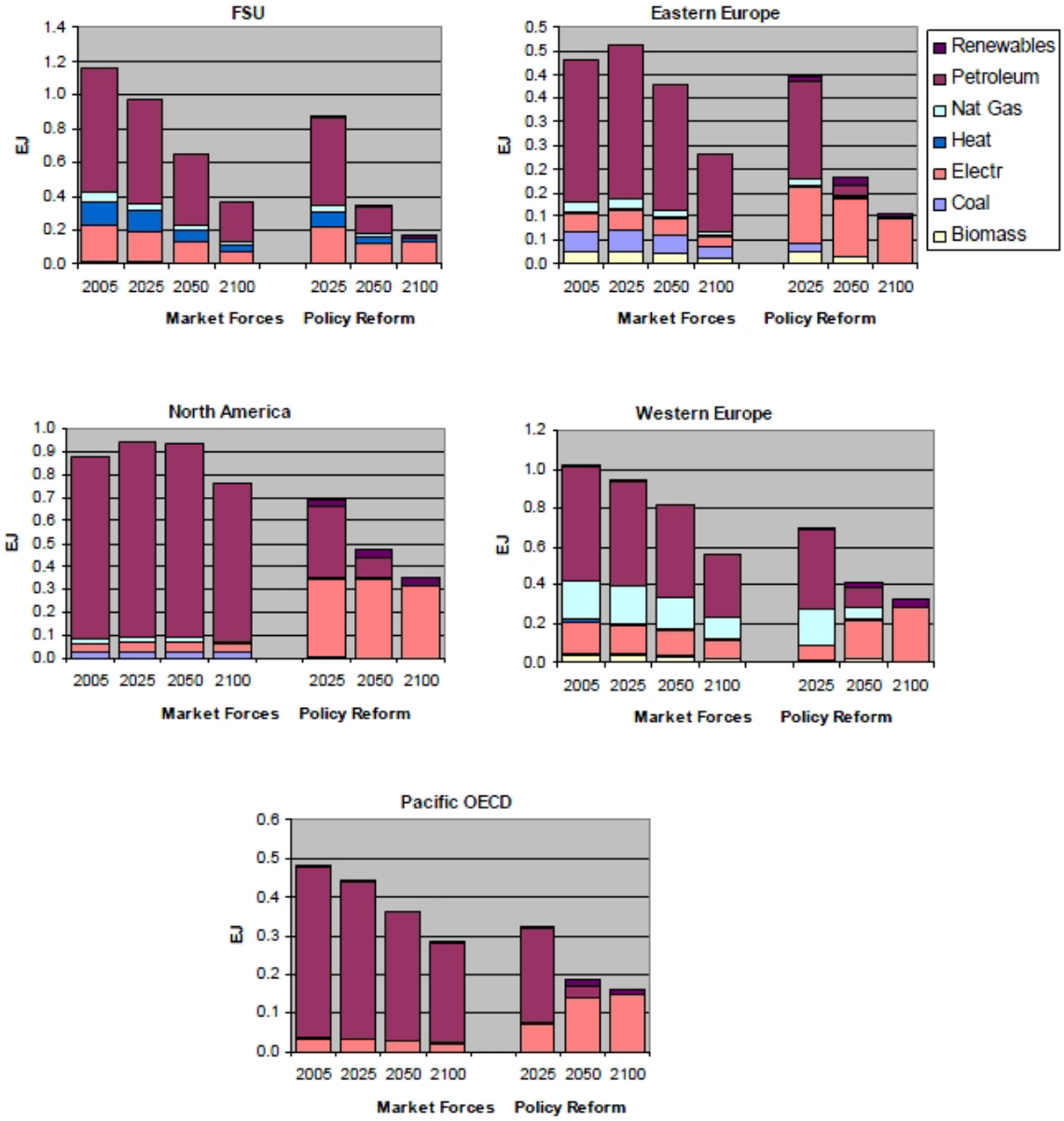


Figure 3-17 Continued. Regional agricultural energy demand

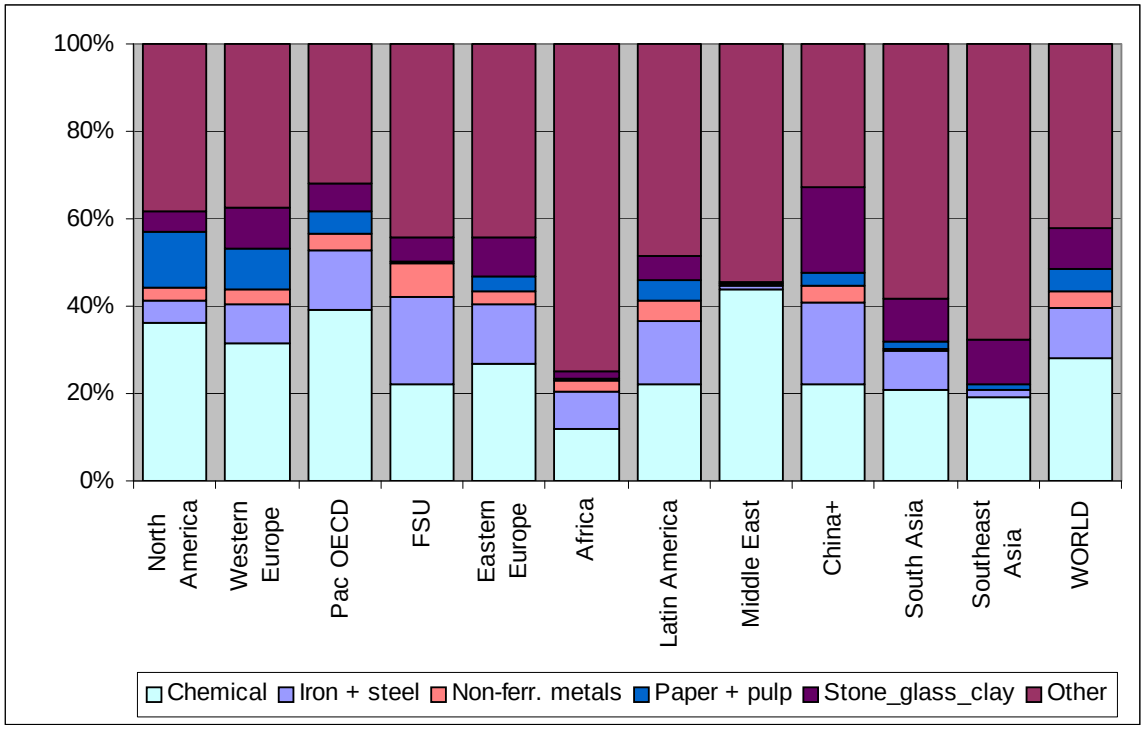


Industry

Current Accounts

Regional industrial energy consumption is reported in Table 3-2 (page 38). The industrial sector accounts for almost 40% of global final energy consumption. Energy consumption in this sector is dominated by five sub-sectors: chemicals; paper and pulp; stone, glass and clay; non-ferrous metals; and iron and steel (Lazarus et al., 1993). The regional breakdown of consumption by sub-sector is provided in Figure 3-18. These five highly energy-intensive industries account for almost 60% of global industrial energy use. Future industrial requirements will be strongly influenced by both projected output and energy intensities in these sub-sectors, although the relative importance of smaller sectors (included in the "other" category) is expected to increase due to the saturation in the consumption of the types of raw materials produced by heavy industries.

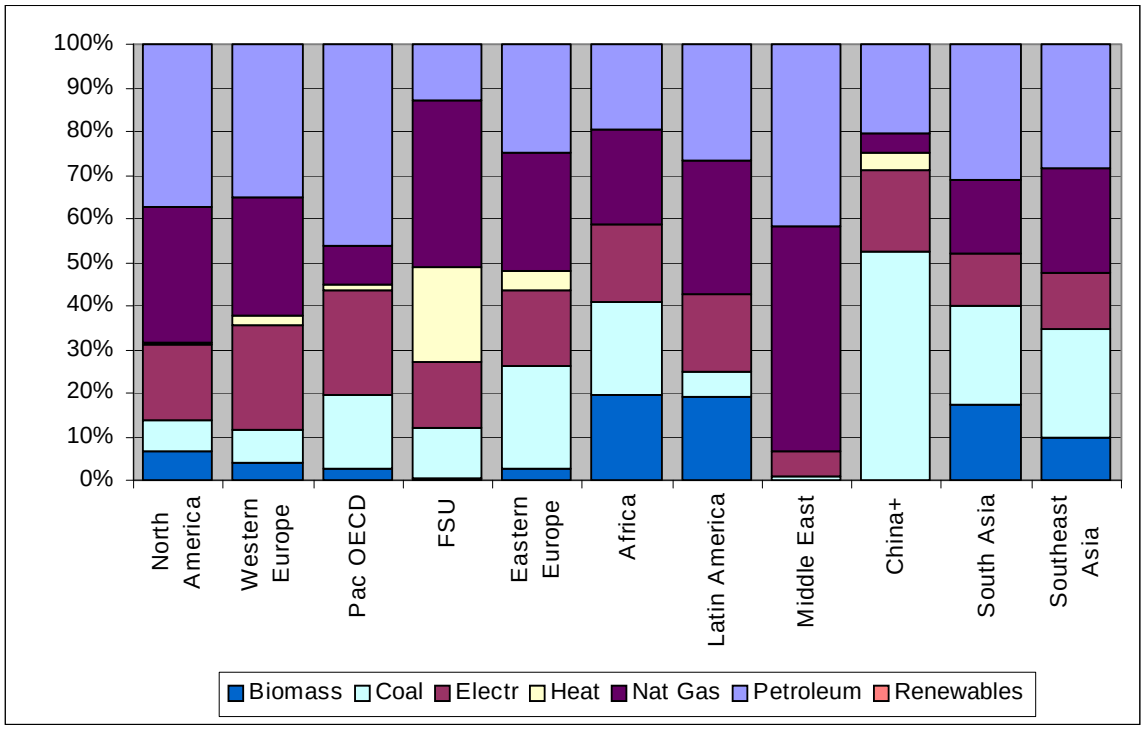
Figure 3-18. Industrial sector energy use by sub-sector - 2005



Global industrial energy demand is currently dominated by fossil fuels and electricity, with significant variation across regions with regard to the choice of fossil fuels (Figure 3-19). Industries tend to rely on domestically available and relatively inexpensive fuels. For example, in China+, coal is the dominant industrial fuel, accounting for over 50% of industrial fuel use, while in the Middle East, oil and natural gas together account for over

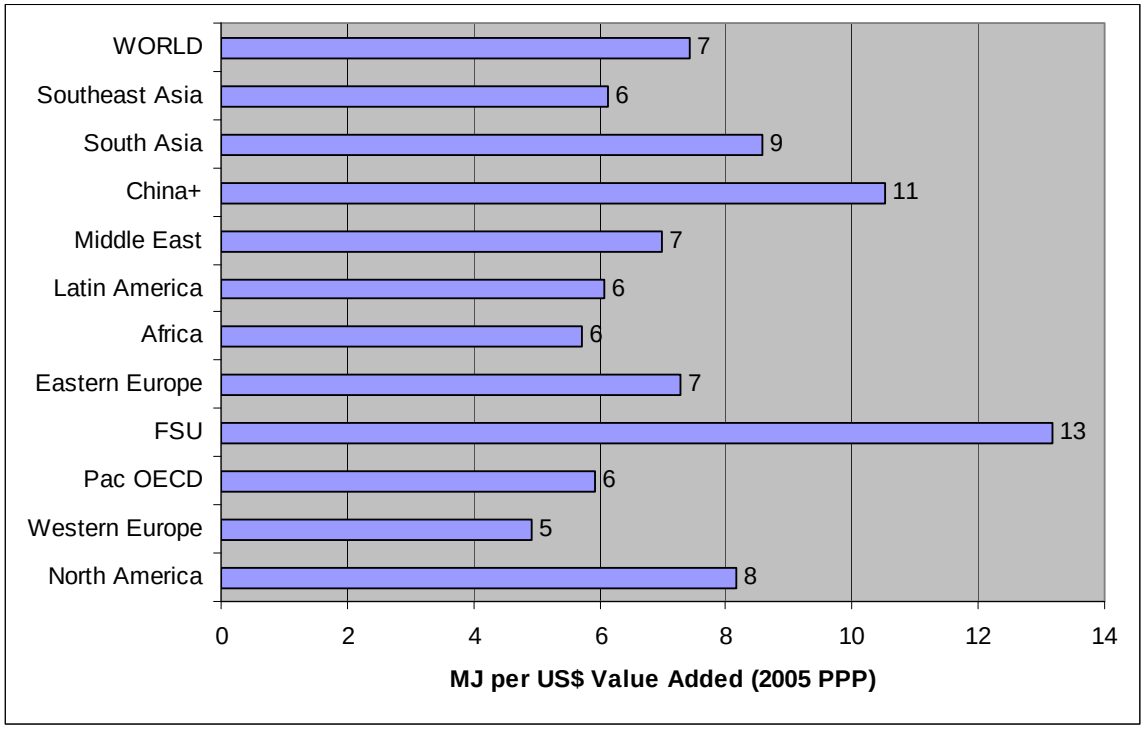
90% of industrial fuel use. Industrial energy use is driven largely by the requirements for process heat, although electricity for motors is also substantial.

Figure 3-19. Industrial sector energy use by fuel – 2005



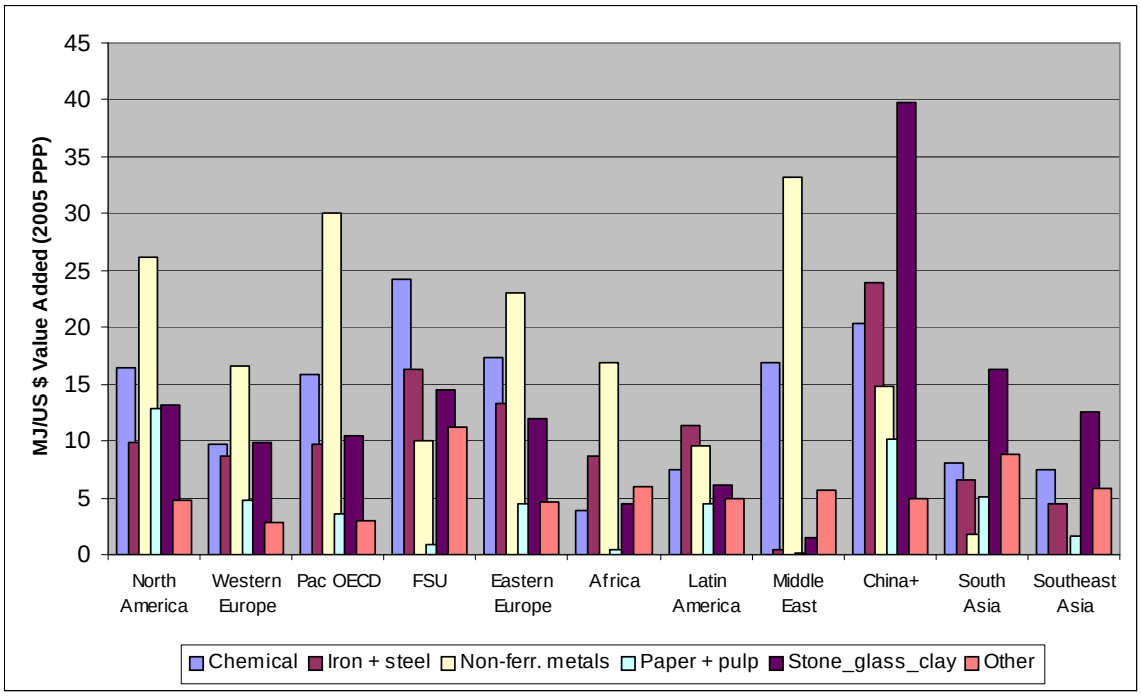
Industrial energy intensities, defined as industrial energy use divided by value added in the industrial sector, are shown in Figure 3-20. These provide only a crude measure of the efficiency of converting a unit of energy input to a unit of economic output. Ideally, it would be desirable to examine industrial energy intensities in physical units of output (e.g., tonnes of steel) rather than in monetary terms, since this more closely reflects the actual physical activities that consume energy. However, the lack of data on physical outputs for the myriad products comprising an industrial sector rules out this possibility for a comprehensive representation of current energy demands. It should also be noted that additional uncertainty is introduced in cross-regional comparisons as shown in Figure 3-20, where exchange rates are needed to express national economic statistics in common units.

Figure 3-20. Industrial energy intensities - 2005



These problems notwithstanding, the high values for FSU and China+ are worth noting. In principle, gross industrial energy intensities depend on three major factors: type of process technology, energy management and the mix of industrial activities. To shed some light on the latter, we display intensities for each major sub-sector in Figure 3-21, showing that the variation in intensity for a given industrial sub-sector varies across regions in roughly the same manner as it does for industry as a whole. Consequently, it appears that process technology and management are the primary determinants of regional industrial energy intensities today. Moreover, the analysis suggests that policies to steer regions toward state-of-the-art practices could significantly decrease the energy needed per unit of industrial activity.

Figure 3-21. Industrial energy intensities by sub-sector – 2005



Scenarios

Methodology

As with the other sectors, industrial sector scenario energy patterns are defined by future activity levels, trends in energy intensities and future fuel shares. Activity levels are expressed in terms of overall value added in industry, and, further, by the shares among the industrial sub-sectors.

Energy Intensity

As the first step in projecting energy consumption in each scenario, OECD industrial energy intensities are developed, and are expressed as energy consumption per dollar value added at the industrial sub-sectoral level. Future energy intensities for each industrial sub-sector depend on changes in process efficiencies and the product mix. Historically, industrial energy intensities have been declining steadily in the industrial sectors of OECD countries. Aggregate manufacturing intensities (measured across all industrial sub-sectors) decreased by an average of 40% between 1973 and 1988 across eight OECD countries. Approximately three quarters of this decline was due to improvements in the energy efficiency of industrial processes, while the remaining quarter was due to structural shifts to less energy-intensive sub-sectors and to the production of less energy-intensive products (Schipper and Meyers, 1992).

Shifts toward sub-sectors and products with a lower energy intensity reflect a process of dematerialization, in which less physical material is required to provide a given function to consumers, an example of which is the increasing miniaturization of semiconductors and related products (Ross et al., 1993). Declining intensities in industrialized nations were also spurred in part by the high fuel prices seen during the oil crises of the 1970s. Increased competition between national industries also appears to have spurred intensity improvements as a means of reducing costs (IEA, 1997). This trend towards lower industrial energy intensities in OECD regions from 1973 onwards has clearly continued from 1995-2005, as can be seen in Table 3-6.

In the two *Conventional Worlds* scenarios, these historically significant improvements are expected to continue in the future even without new policy interventions (although at a slower rate than in the past). Sub-sectoral energy intensity assumptions are again guided by the findings of the *Energy Innovations* study (Energy Innovations, 1997) and the Greenpeace "energy [r]evolution" scenarios (2007, 2008), and the APEC Energy Demand and Supply Outlook report (2006).

In the *Market Forces* scenario, they decrease by a world average rate of nearly 1% per year over the scenario period; faster in the OECD countries and much slower in most other countries, so that on average, the global industrial energy intensity is declining at about 0.7% per year.

Table 3-6. Trends in industry sector energy intensities

MJ/$value added		*Market Forces*				*Policy Reform*			
					Growth Rate				Growth Rate
	2005	2025	2050	2100	2005-2100	2025	2050	2100	2005-2100
North America	8.2	6.1	4.4	3.2	-0.98%	5.2	3.0	2.0	-1.47%
Western Europe	4.9	3.6	2.6	1.9	-0.99%	3.2	2.0	1.3	-1.39%
Pac OECD	5.9	4.5	3.2	2.3	-0.99%	4.0	2.4	1.6	-1.34%
FSU	13.2	11.1	7.4	3.8	-1.30%	9.4	4.6	1.9	-2.01%
Eastern Europe	7.3	6.8	5.2	3.3	-0.84%	5.9	3.1	1.7	-1.55%
Africa	5.7	5.6	5.4	4.5	-0.25%	5.1	4.7	3.4	-0.56%
China+	10.5	8.7	7.0	3.8	-1.07%	7.6	5.3	1.9	-1.78%
Latin America	6.1	5.8	5.2	4.4	-0.34%	5.6	4.0	2.2	-1.06%
Middle East	7.0	6.5	5.5	4.3	-0.51%	5.7	4.0	2.2	-1.22%
South Asia	8.6	8.4	7.7	5.3	-0.51%	7.8	7.1	3.3	-1.00%
Southeast Asia	6.1	5.8	5.2	4.7	-0.28%	5.1	4.1	2.4	-0.99%
WORLD	7.4	6.5	5.5	3.9	-0.67%	5.8	4.3	2.4	-1.19%

*Note that in 1995, the regional aggregations differ slightly from the 2005 and scenario year values. This is shown just for illustration of the declining overall energy intensities in the industrial sector.

Beyond these rates of decline, the adoption of cost-effective measures to reduce industrial energy use remains far below its economic potential. Estimating the magnitude of potential energy savings is difficult because of the heterogeneity of technologies, processes and products, even within a particular industrial sub-sector. Nevertheless, it is clear that significant cost-effective savings are available even in modern, efficiently-run industries (Elliot, 1994). Some generic areas in which energy can be saved include the increased adoption of efficient combined heat and power systems, retrofitting of efficient lighting and motors, improved maintenance of boilers, the "right-sizing" of compressed air and process heat delivery systems, and increased use of recycled feedstocks. In the longer term, capital stock turnover is capable of bringing even more dramatic reductions in energy intensities, as older, more energy-intensive processes are replaced completely. For example, in the iron and steel sector, blast furnaces fired with coke could be replaced with electric arc furnaces.

Overcoming market barriers will be key to achieving large reductions in industrial energy intensities. In part this will require changing the structure of energy prices to better reflect their full social and environmental costs. It will also require a broad package of policies such as incentives for investment in new energy efficient equipment; increased funding of research, development, demonstration and education programs; changing tax structures to eliminate subsidies for the use of virgin materials; and changing environmental regulations and electric market structures to expedite the adoption of industrial combined heat and power.

The *Policy Reform* scenario reflects this type of concerted action. Global average energy intensities decrease by an annual rate of about 1.2% per year. In the *Policy Reform* scenario OECD regions have a steeper decline in energy intensity, than in the non-OECD regions.

We apply the convergence algorithm (see Annex 1), assuming sub-sectoral energy intensities approach the projected OECD average energy intensity as GDP per capita approaches the current OECD average GDP per capita. This treatment captures technological leapfrogging to some extent, since developing regions, rather than recapitulating OECD patterns of energy efficiency transmission, approach intensities which reflect the better practices assumed for OECD regions in the future. Scenario intensity results are shown in Table 3-6 above.

Fuel Shares

We complete the characterization of scenario industrial energy use by adjusting the current mix of fuel shares. In the *Market Forces* scenario, the current mix is adjusted over time, guided by expert judgment. In most regions, fuel shares are assumed to remain largely unchanged. In the *Policy Reform* scenario, as with other energy-consuming sectors, we impose a transition to less carbon-intensive fuels, principally through greater penetration of electricity and natural gas at the expense of coal and petroleum products. Increased use of renewables and modern biomass fuels is also assumed, particularly in the paper and pulp sector. By 2100, all fossil fuels have been phased out for energy use.

Biomass fuels are phased out for energy uses by 2100, and are only used where they are of highest value as for chemical feed-stocks.

Results

Global industrial sector energy consumption patterns are summarized by region in Figure 3-22. Global industrial energy demand increases from 121 EJ in 2005, to nearly 215 EJ by 2050, in the *Market Forces* scenario before decreasing to 185 EJ in 2100. In the *Policy Reform* scenario, industrial energy demand reaches 173 EJ in 2050, before decreasing to 135 EJ in 2100. The reductions in overall energy demand in both scenarios are due to decreased industrial activity as the economy shifts towards services, as well as efficiency gains in the various subsectors.

Energy intensity improvements reduce overall growth in industrial energy demand between the *Market Forces* and *Policy Reform* scenarios to only a small extent. As with other sectors of the economy, the developing regions account for most of the growth in demand in the *Market Forces* scenario due to their faster rates of growth and their low average base year intensities compared to the OECD regions. Industrial energy use in the OECD regions and FSU stays almost exactly constant from 2005 to 2050, before dropping more noticeably in 2100. In the *Policy Reform* scenario, industrial energy consumption in the OECD and FSU decreases more steadily between 2005 and 2100 as energy the higher intensity improvements outweigh the effects of growth in the sector.

Industrial fuel shares are summarized in Figure 3-23. In the *Market Forces* scenario there is little change from 2005 to 2100, though there is a gradual fuel switching away from coal and district heat, and toward electricity and natural gas, reflecting ongoing trends in the OECD regions and a gradual convergence to OECD patterns. More dramatic fuel switching is seen in the *Policy Reform* scenario, with substantially increased shares for electricity and biomass, and a large drop in the share for coal, natural gas, and oil, all of which reflect the need to reduce the carbon emissions associated with industrial energy consumption. By 2100, industrial energy use is largely electricity and heat, with biomass used as feedstocks representing some 25% of all industrial energy requirements.

Figure 3-22. Global industrial energy demand by region

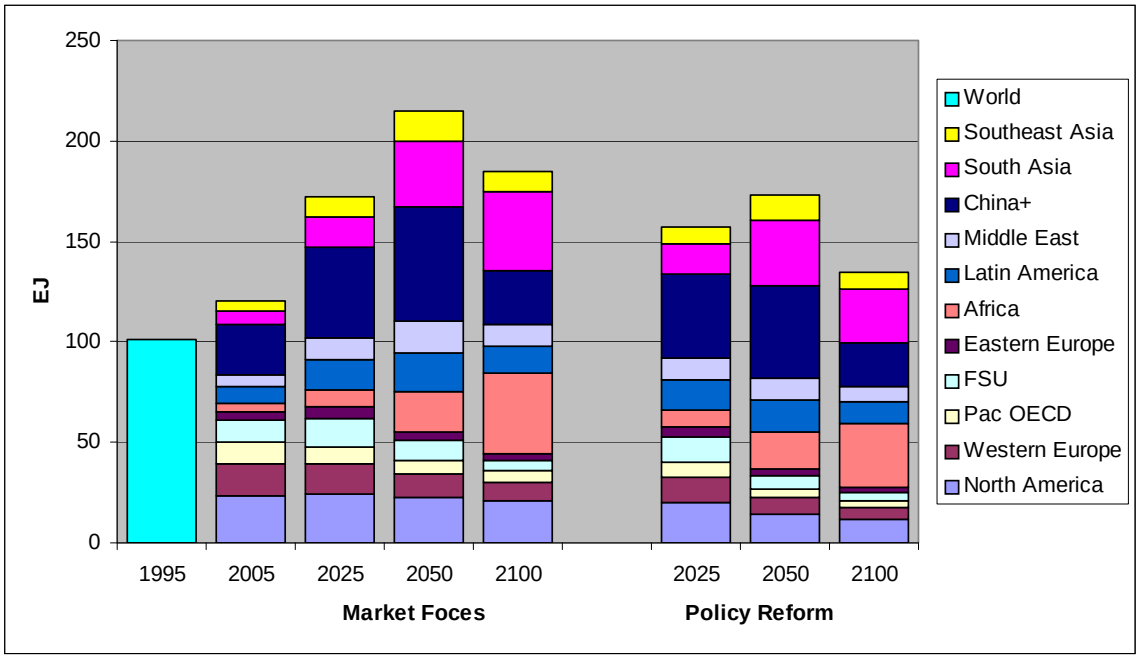
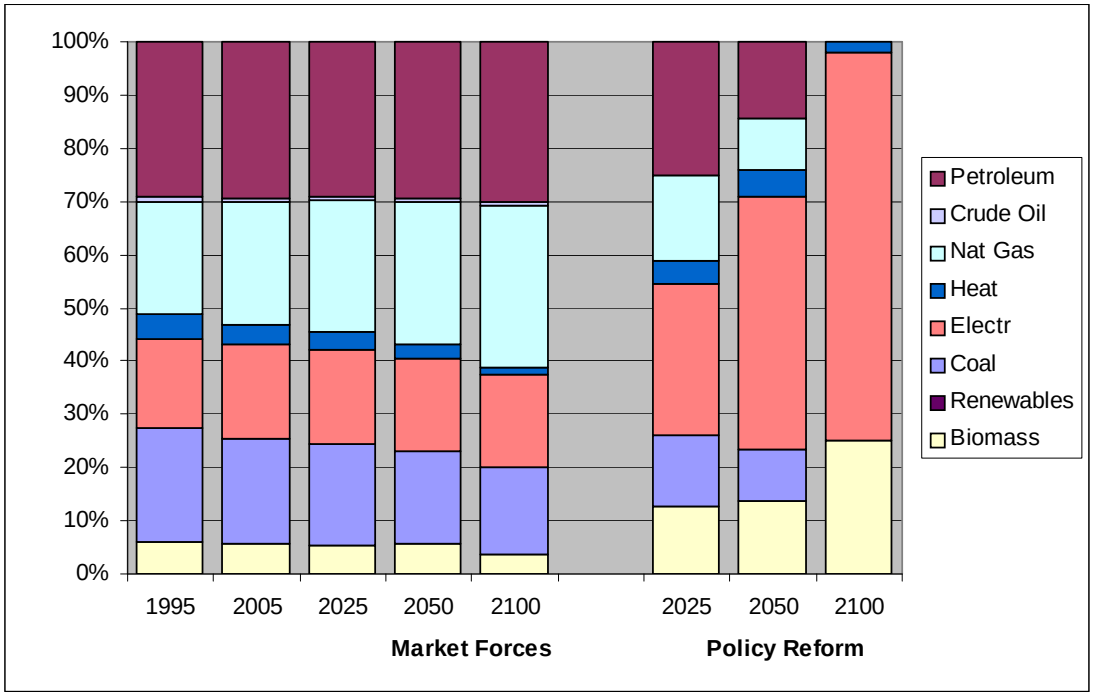


Figure 3-23. Global industrial fuel shares



Industrial sector energy demands are shown by region in Figure 3-24. In the *Market Forces* scenario, energy consumption grows in most non-OECD regions between 2005 and 2050, after which some of these regions begin showing decreased energy demand.

The exceptions are Eastern Europe and the FSU, which behave like the OECD regions, showing decreasing industrial energy demand from 2025 – 2100, as the effects of increases in industrial sector activity are outweighed by the effects of gradually decreasing energy intensities. The *Policy Reform* scenario exhibits similar patterns as the *Market Forces* scenario, however, overall energy use is curbed in all regions, and energy consumption in 2100 is lower in the *Policy Reform* scenario than in the *Market Forces* scenario. In OECD regions, the FSU, and Eastern Europe, the energy consumption in the *Policy Reform* scenario in 2100 is significantly lower than the base year value.

Figure 3-24. Regional industrial energy demand

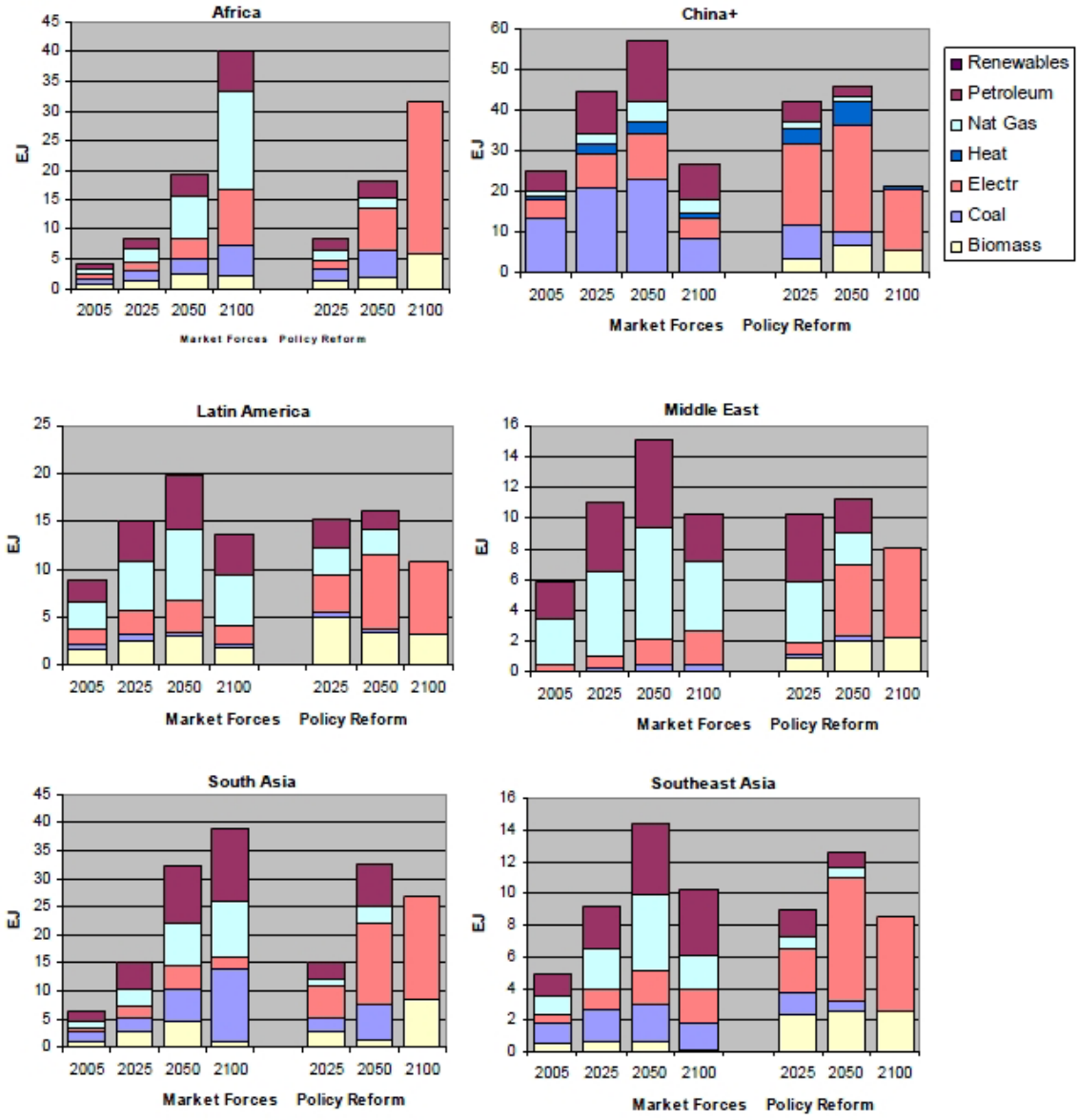
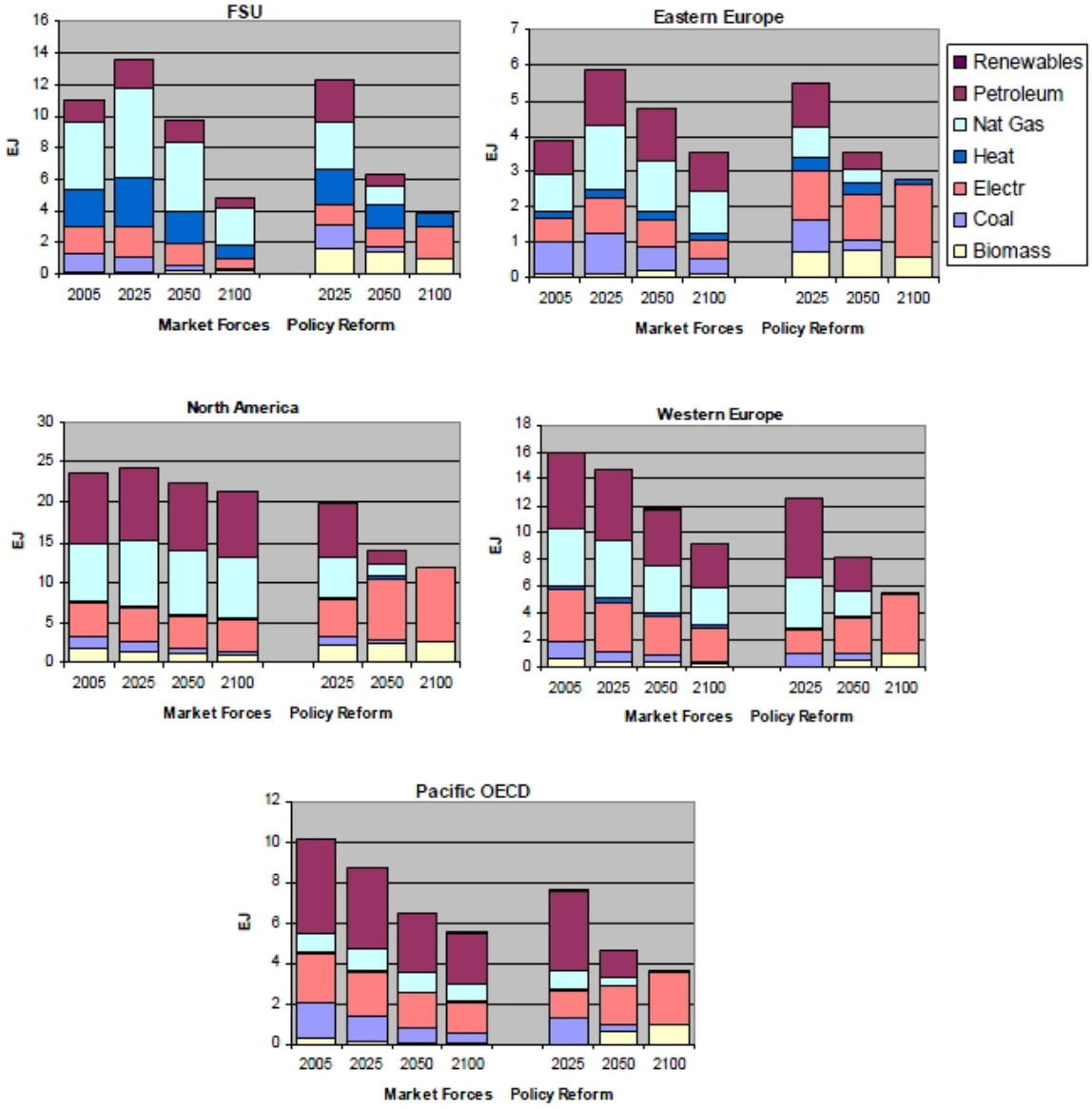


Figure 3-24 Continued. Regional industrial energy demand



Transportation

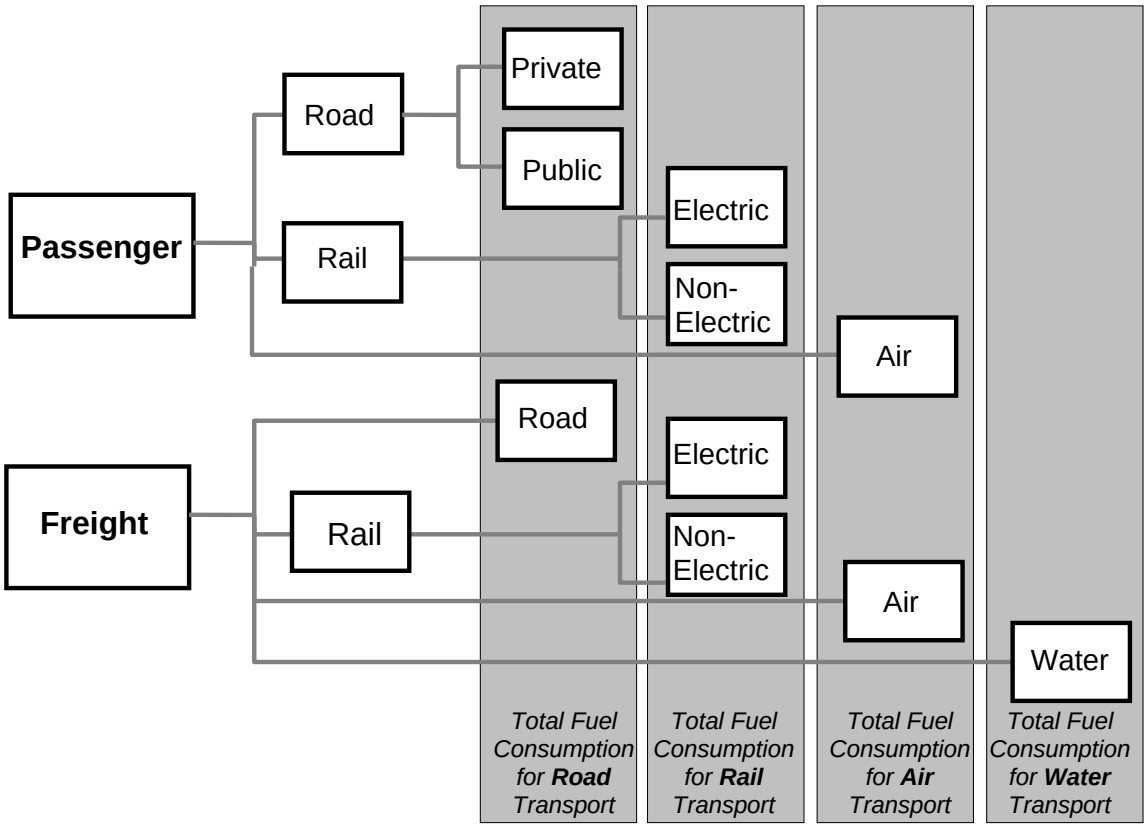
The methodology used for developing the Current Accounts and Scenario projections in the transportation module has changed significantly since the last version of Polestar, through the incorporation of data and forecasts from a model developed by the International Energy Agency (IEA) and the World Business Council for Sustainable Development's (WBCSD's) Sustainable Mobility Project (SMP) (IEA/WBCSD, 2004a-b). Thus, comparing the inputs to and results of the older transportation scenarios and these updated scenarios is not as straightforward as it is with most of the other sectors, since the disaggregation of the transportation modes has changed slightly.

Current Accounts

Regional transportation energy consumption is reported in Table 3-2 (page 38). Current accounts are based on standard statistical compilations of transport activity levels and energy use. Energy use is taken from IEA (2006a-b). The measure of activity for passenger transportation adopted in this study is the passenger-kilometer, while for freight it is the tonne-kilometer. For the current accounts, activity levels have been synthesized from a variety of sources, as described below.

The analysis considers passenger and freight transportation separately, since they are determined by very different factors. Within each major category, transport is analyzed separately by mode and vehicle type, as shown in Figure 3-25. The modes are: road, rail, air and water (freight only). To focus on the important case of the private automobile, passenger road transport is further divided into private (e.g., cars and taxis, light trucks, motorcycles) and public (buses) sub-modes of transportation. Additionally, because the SMP model was structured this way, we have distinguished between electric rail transport and non-electric rail transport which use fossil fuels or could potentially run on hydrogen or biofuels. Figure 3-25 illustrates both the categories used in this analysis and those used by the IEA (the vertical gray bars). The figure highlights the degree of aggregation in the IEA data: energy data from IEA are available only as totals for each mode. However the SMP spreadsheet model has disaggregated data which we use to construct the current accounts energy figures for passenger and freight transport modes, including the sub-categories of Electric and Non-Electric Rail, and within passenger transport, for public and private road travel.

Figure 3-25. Transport mode decomposition



Note: Items in gray bars are reported together in the IEA energy statistics. The white boxes represent the disaggregated levels used in the SMP model and in our analysis. The methodology is described in the text. Water borne passenger travel is ignored, since it is very small.

Total passenger and freight transportation energy demand is shown for each region on a per capita basis in Figure 3-26. North America, the highest-consuming region, consumes 20 times more energy per capita for all transportation than the China+ region, almost 30 times more than Africa, and more than 40 times more energy per capita than South Asia. Furthermore, per capita transport energy consumption in North America is more than two times that in the other two OECD regions. Insight into the causes of this disparity can be gleaned from examining automobile travel more closely. Here we find that average distance traveled per person (Figure 3-27) is significantly higher (almost twice) in North America than in other OECD regions. Also, fuel intensities, which increase as efficiencies decrease, are somewhat higher in North America than in other OECD regions (IEA, 1997; Watson et al., 1996). Part of the disparity, then, can be attributed to the annual distance traveled per capita and factors affecting fuel economy, such as the weight of vehicles. Other factors that contribute to higher overall transport energy use in North America is vehicle load factor (the average number of vehicle occupants), which is relatively low in North America, and the long-term decline in the U.S. of more energy-efficient mass transit systems. These factors are in turn affected to varying degrees by variables such as average income levels, gasoline prices, and other transportation policies.

Figure 3-26. Total transport energy demand per capita by region - 2005

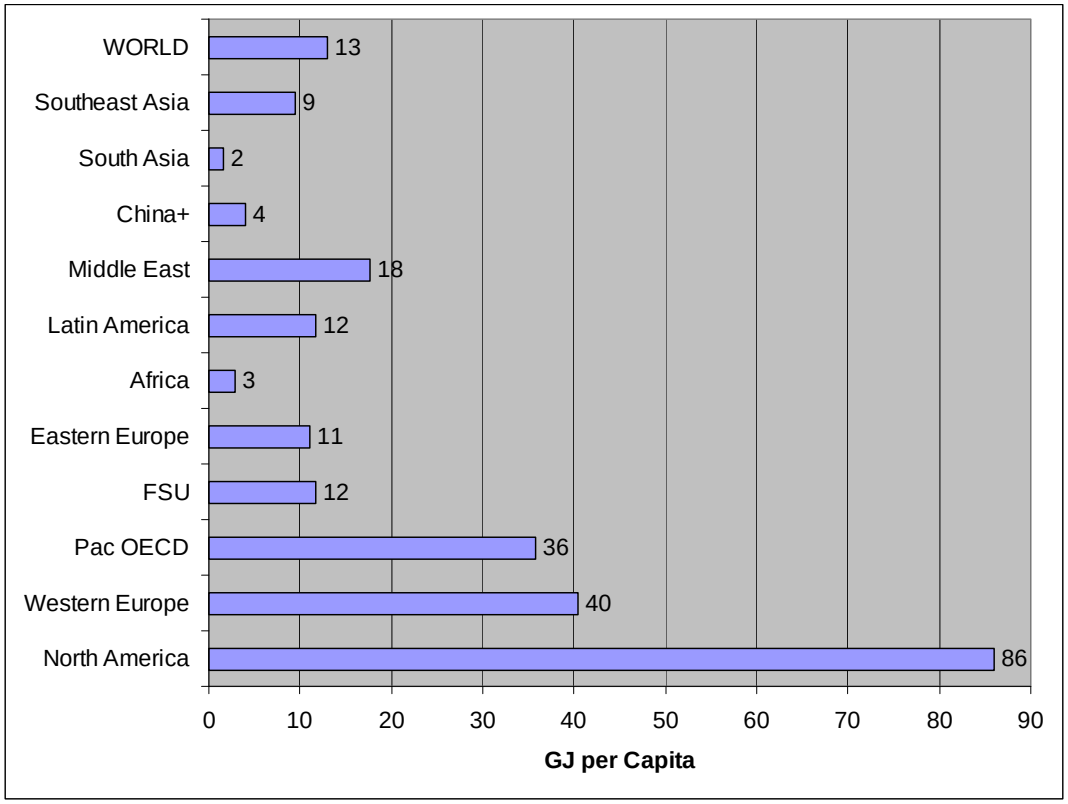
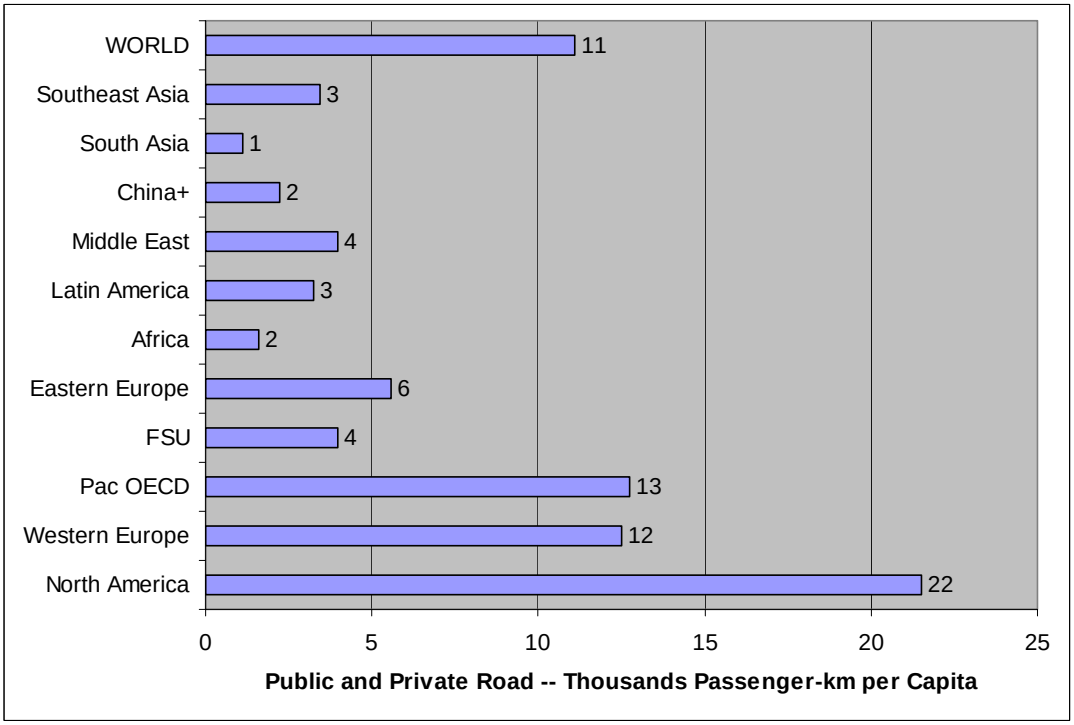


Figure 3-27. Automobile travel per capita - 2005



Patterns of transportation energy use are more difficult to interpret in the developing regions, due to the lack of any but the most basic information. In particular, there are few reliable data describing vehicle fuel economy and vehicle load factors in developing countries. In most developing countries, poor road infrastructure and vehicle maintenance practices, older vehicle designs and older vehicle vintages combine to force up vehicle fuel use. However, smaller vehicle sizes, which are thought to be coupled with higher average load factors, likely bring down energy use per pass-km.

The approach followed for disaggregating the current accounts energy data is described below.

Road

As shown in Figure 3-25, road travel is split into freight and passenger, as is the case for other modes, and then within passenger transportation total road travel is split between public and private transport. Disaggregating the IEA energy consumption data to this level of detail requires the introduction of additional data and assumptions. Passenger and freight road activity levels have been compiled from the SMP spreadsheet model data and projections for 2005, which included figures on car, bus, and two- and three-wheel vehicles. Data on intensities has been compiled from the same source. The data was available by region, however the SMP regions did not match the Polestar regions exactly. For this reason, we had to adjust the data to match the Polestar regions. To do this, passenger transport activity was shifted between regions in proportion to the population of the countries that were being shifted between regions. Similarly, freight transport activity was shifted from the SMP model regions to the Polestar regions in proportion to the GDP that was shifted between regions when matching the Polestar regional definitions.

Efficiencies and load factors for passenger road transport vary within a fairly narrow range, as reported, e.g., in Schipper and Meyers (1992), IPCC/OECD/IEA (1996), Watson et al. (1996) and IEA (1997c). In contrast, freight transport intensities vary over a broad range, influenced by the condition and size of trucks, the condition of roads, and load factors. Transportation energy intensities also come from the SMP model. The approach taken for developing the current accounts is to correct the Passenger Travel Intensity and the Freight Travel Intensity levels that result from the regional shifts (described in the above paragraph) in order to adjust the total to equal the total energy requirement for road transport as reported in the IEA data. This is done by dividing the travel intensities for both passenger and freight by the ratio of energy use in the modified SMP/Polestar regions to the IEA data on consumption (aggregated by Polestar region). These modified Travel Intensities are used as the Current Accounts values.

Rail

Energy consumption for rail transport is reported in the IEA statistics for coal, diesel and electric trains (although coal use for railways is now very limited and is important only in China+). Again, for this analysis, total consumption is separated into passenger and freight transport. As with road transport, country-level data are used where possible. Activity levels for both passenger and freight are taken from the SMP spreadsheet model,

with regional activity values shifted in the same manner described above for road transport so that the aggregated regions correspond to the Polestar regions.

To develop passenger and freight energy consumption for the current accounts, energy intensities for electric trains are assumed to be one-fourth the energy intensity of coal and diesel trains, (based on figures from Schipper and Meyers, 1992). It is also assumed that for a given type of train (coal, electric or diesel), energy consumption is proportional to gross hauled tonne-km (that is, the total weight of the train and cargo). Using the SMP model assumptions on the share of electric rail in each region, passenger and freight rail modes were disaggregated into the electric and non-electric sub-categories.

Air

Statistics on air transport activity come from the IEA/SMP model. Because of the difficulty of separating passenger and freight travel, all energy use for all types of air transportation is attributed to passenger activity, and freight activity levels are not counted explicitly, but are implicit in passenger air results. To allocate energy use between freight and passenger transport, the relative energy intensity between the two would be required, and for this purpose the available statistics are relatively poor. Uncertainties arise, in part, from the wide variety of aircraft in use, as well as the flexibility airlines possess in the density of seating for passenger flights. Thus, we encompass all energy use for air transport in the passenger transport sub-module. Also, a simplifying assumption is made that since most air transport is now international and inter-regional, it will depend on approximately the same types of airplanes. This results in assigning energy intensities to be equal across regions.

Water

Data on freight activity levels for water transport are scarce. Statistics on inland water transport fuel use (national water-borne travel) and Bunker fuel use (international water-borne travel) are taken from the SMP model.

For this analysis, fuel requirements for water transport as reported in IEA are combined with the requirement for bunker fuels – i.e., fuels used for international transport and an important source of petroleum demand. Activity levels for water-borne transportation are not projected in the SMP model, so the basic convergence methodology is used for projecting the freight travel intensities in the scenarios, and freight energy intensities stay at their base-year levels.

Results

The breakdown of energy use by mode is shown for passenger and freight transportation in Figure 3-28 and Figure 3-29, respectively. Road transport is clearly the dominant energy-consuming mode for both passenger and freight transportation. It accounts for more than 60% of total passenger transportation energy consumption in all regions. For freight transport, road transport dominates in all regions except China+, where water freight transport dominates with 45% of the energy consumption. Note that because water transport has a higher efficiency on an energy/tonne-km basis than road and other modes, it accounts for a higher share of physical transport than its share of energy consumed.

Figure 3-28. Passenger transport energy use: modal shares - 2005

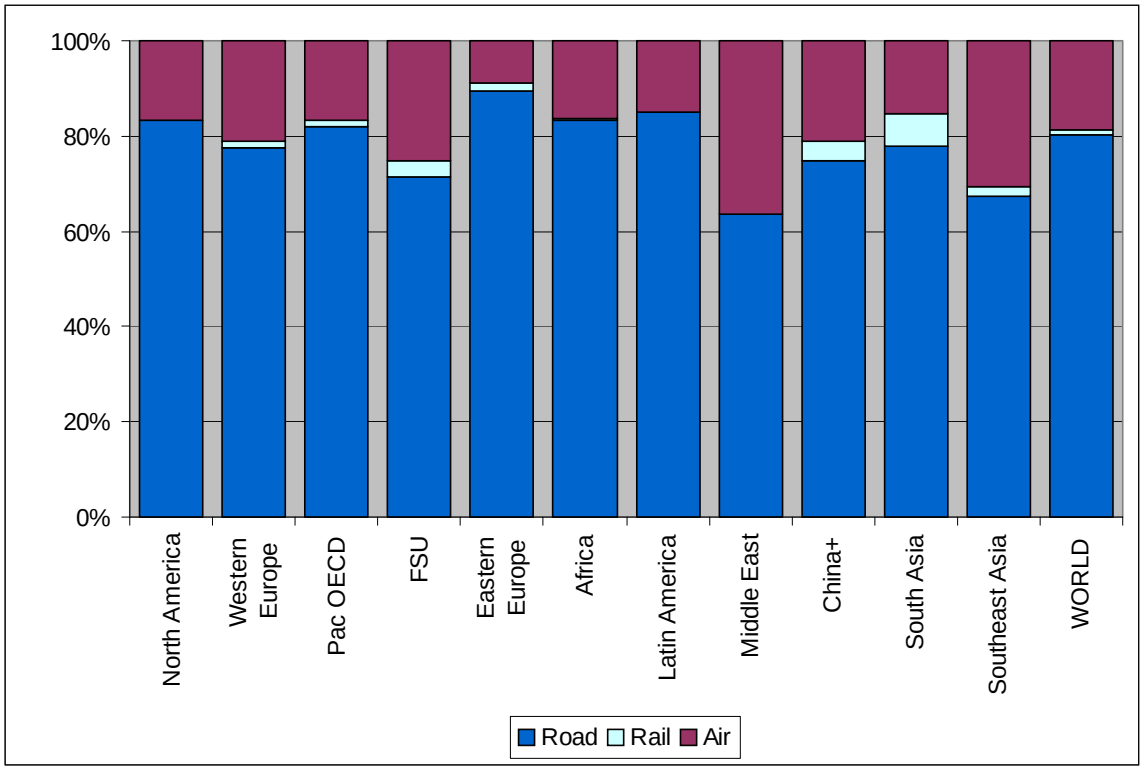


Figure 3-29. Freight transport energy use: modal shares - 2005

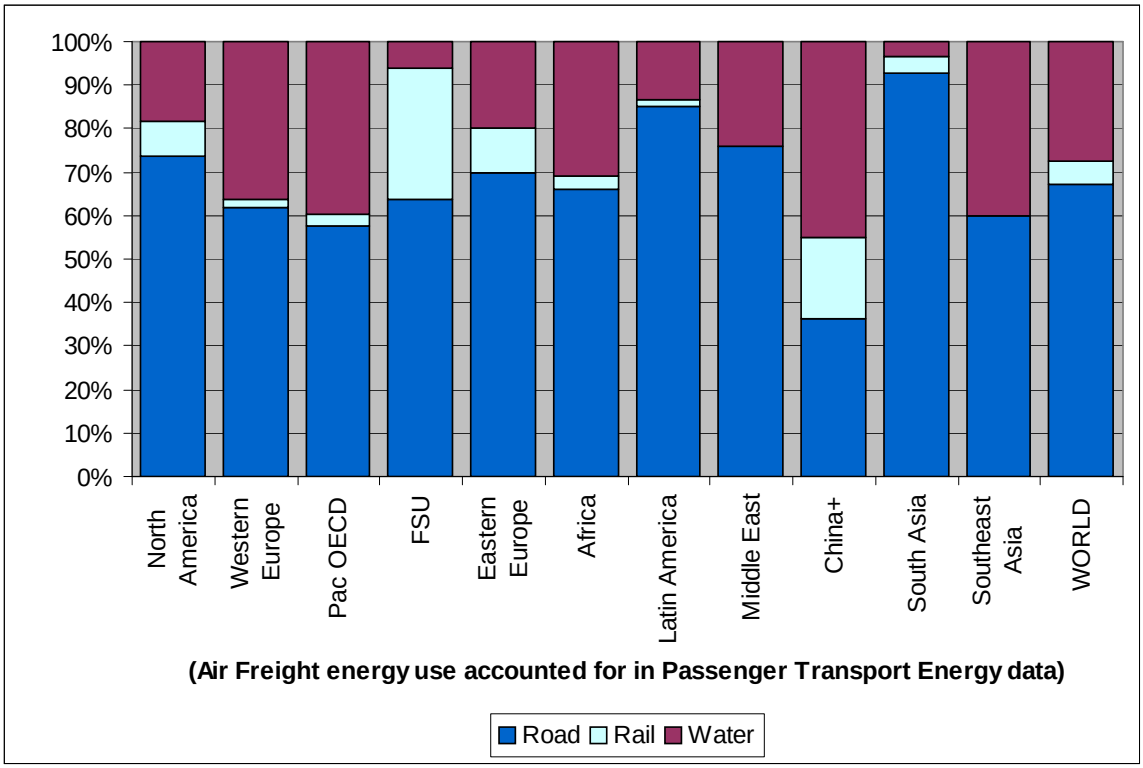
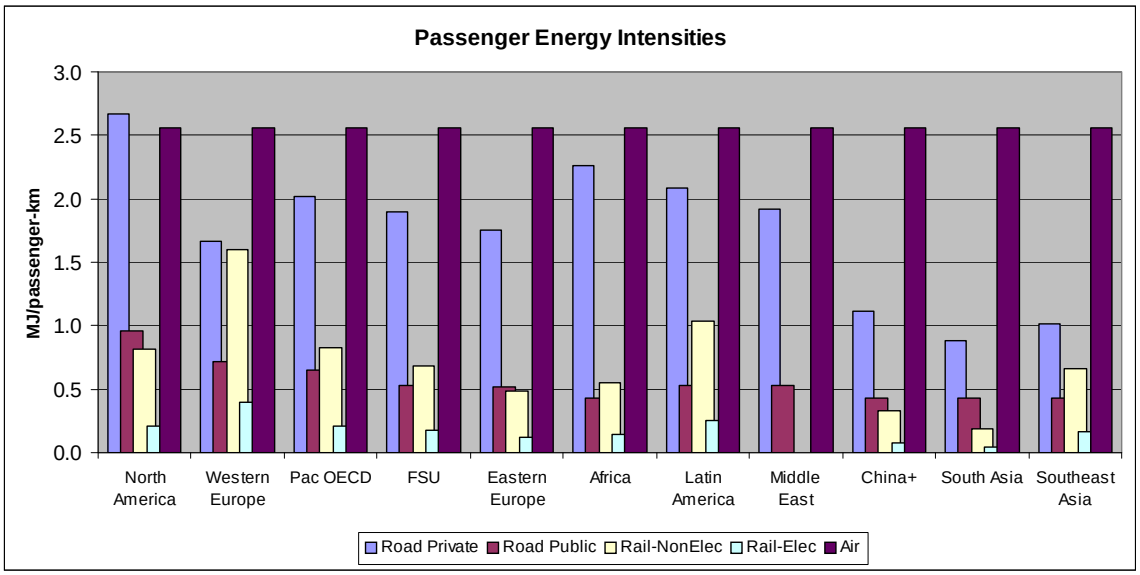
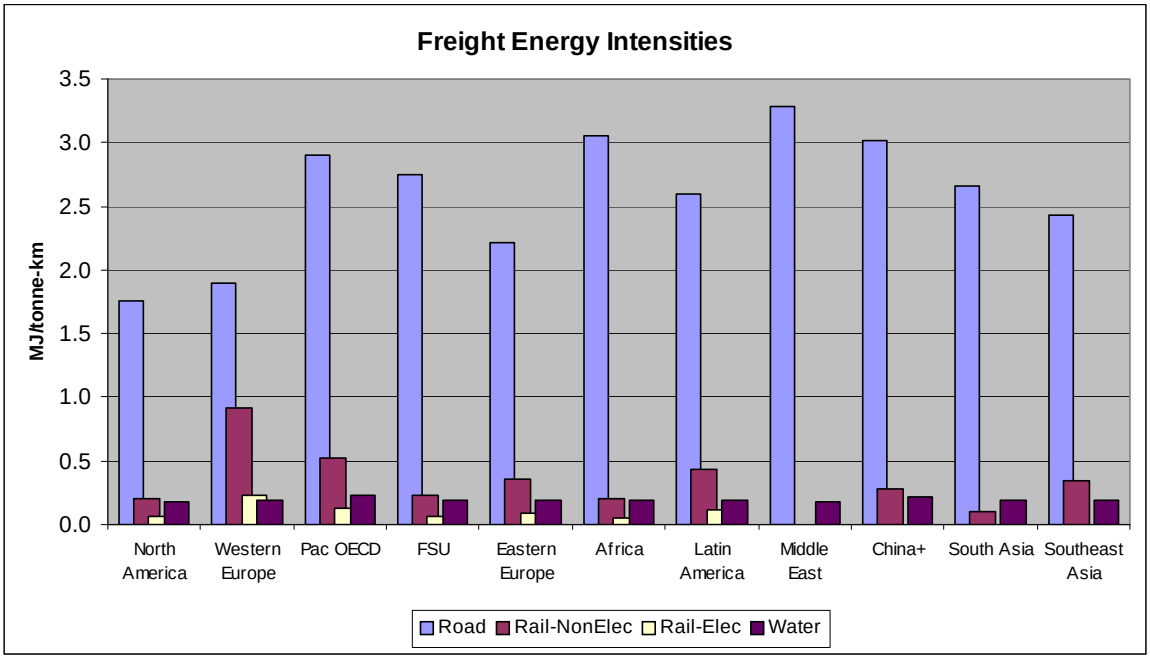


Figure 3-30 displays passenger and freight energy intensities by region. For passenger transport, the charts show the energy-efficiency benefits of public mass transport modes (bus and rail) over private cars, except in Western Europe. Similarly, for freight transport, they show the even much larger energy-efficiency benefits of rail and water over road transport. Perhaps more surprisingly, air passenger transport intensities are quite close to those for road transport in North America. This is due to the high load factors that apply in the air transport sector.

The transportation sector is almost entirely dependent on petroleum products, which account for nearly 99% of global transportation fuel demand. The remainder of its energy consumption is primarily due to electricity for rail transport and to alcohol fuels for road vehicles, especially in Brazil.

Figure 3-30. Transport energy intensities by mode - 2005





Methodology - Transportation Data and Scenario Development

A new and improved model was used for developing the transport projections for the two *Conventional Worlds* scenarios. The SMP model (IEA) was used. The following is an overview of how the model results were utilized and prepared for Polestar:

1) Because the model used regions that were different than the Polestar regions, we first had to modify the projections by rearranging the data set to reflect our 11 regions.

Passenger travel was shifted between regions in proportion to the population, and freight travel was moved as a fraction of the GDP.

2) Once everything is in Polestar regions, we sum up the passenger and freight "travel intensities" (TI).

- Energy consumption = travel intensity * driver * energy intensity

  = TI * EI * driver

  - For passenger travel, the driver is population
  - For freight, the driver is GDP
  - The energy intensity comes from the SMP model.

3) Next we forecast the total activity levels to get a consumption figure for all types of travel, and then we compare this to the IEA consumption figures. We then get a ratio, showing how close/far off the original estimates are, and then we use this ratio to correct the totals. South Asia and Southeast Asia were the farthest off because the SMP data on the 2- and 3-wheeled vehicles for passenger travel is basically a "guess" – they admit this.

4) We derive the final current accounts results, which we use to generate travel intensities (pass-km per capita) and freight intensities (freight / $ value added GDP). We use these results to develop the regression equations discussed below and to project the total passenger km per capita, and the breakdown into different modes for each scenario.

Note that while we do not model it explicitly in Polestar, energy intensity is very sensitive to load factor (number of people in a car). If you have two people in two cars, they burn twice as much fuel as two people in one car, in this methodology. Again, for air travel, we assume the same EI for each passenger. Hence, for our purposes, passenger EI's do not change, only TI's change.

Results for All Modes of Transport

Energy demand for all transportation in the scenarios is presented in Figure 3-31 and Figure 3-32, but are discussed in the following sections that disaggregate the methodology and results by Passenger and Freight transport.

Figure 3-31. Global transport energy demand by fuel

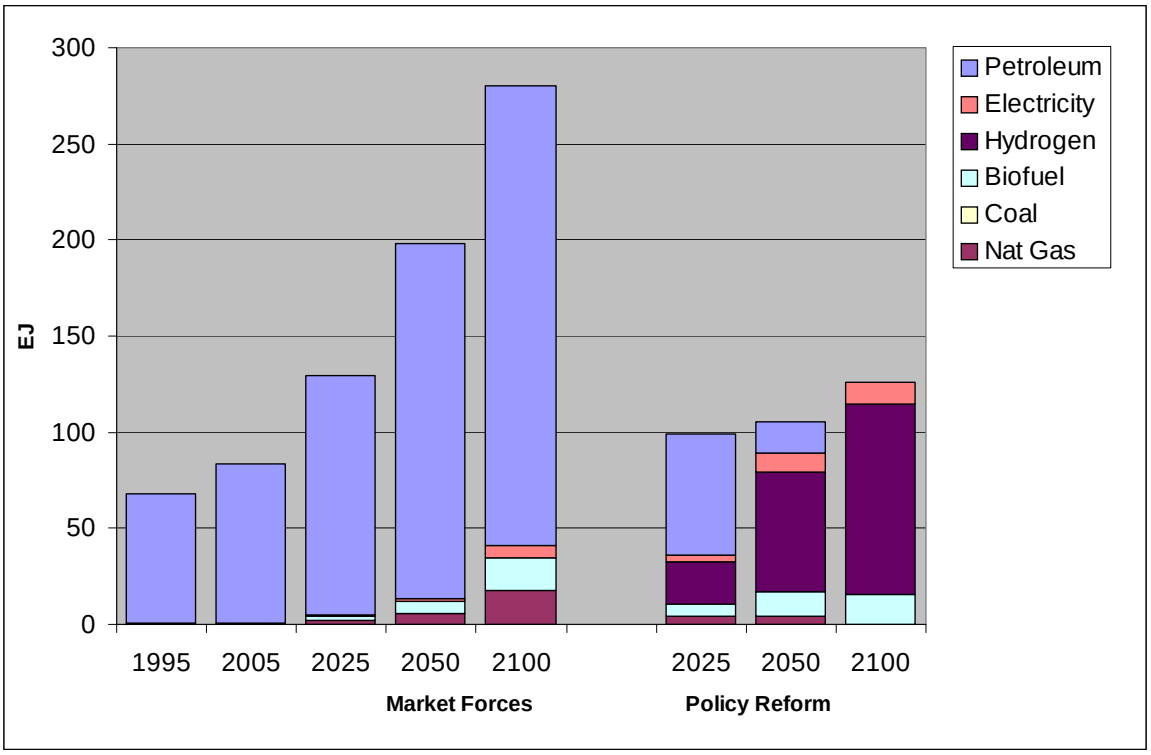
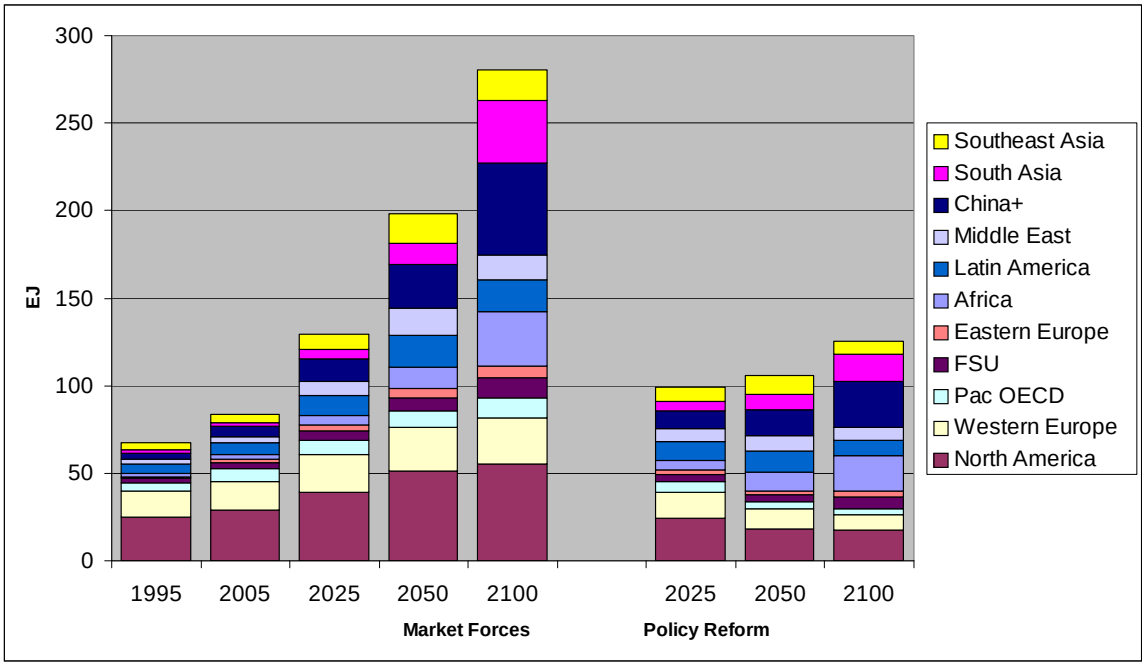


Figure 3-32. Global transport energy demand by region



Passenger Transport Scenarios

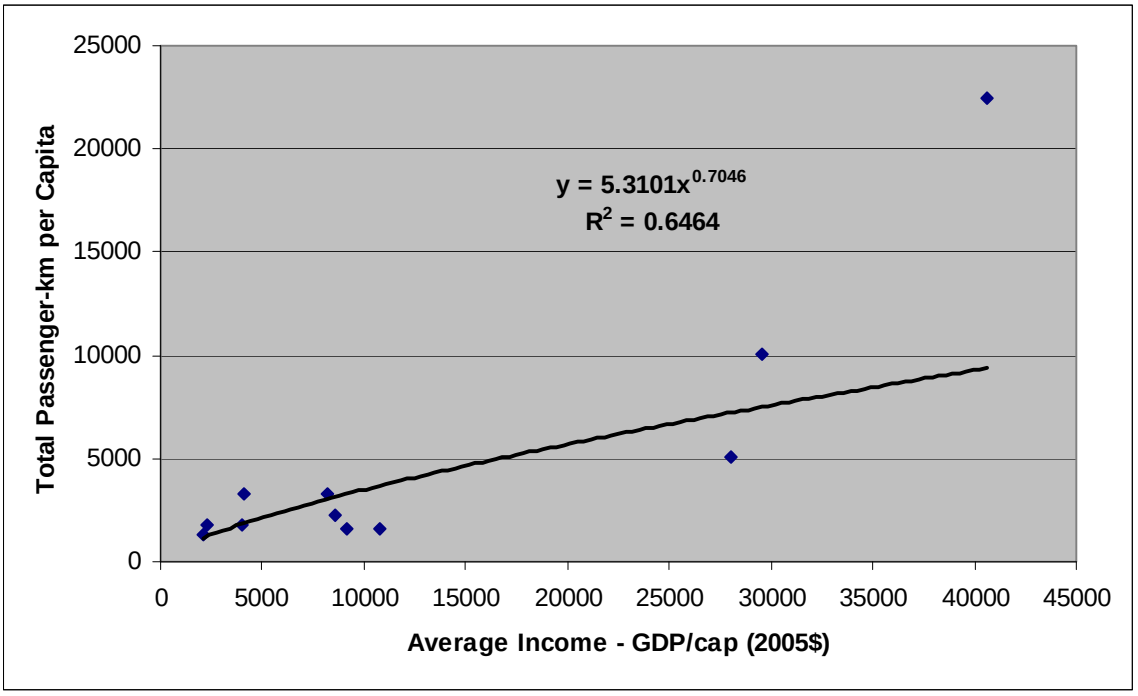
Methodology

Passenger transport energy patterns are defined by future activity levels, trends in energy intensities and fuel shares. While the projections for the future are done slightly differently for the *Market Forces* and *Policy Reform* scenarios, we first specify the distance traveled per capita under each mode (Road Private, Road Public, Rail-Electric, Rail-NonElectric, Air) for each region. To these modal activity levels, we then apply energy intensities (MJ per passenger-kilometer). Finally, we multiply by total population and specify fuel shares to calculate energy consumption for passenger transport.

Total Travel Volume

We start by determining passenger transport requirements across all modes (road, rail and air). Figure 3-33 plots total passenger-kilometers traveled against GDP per capita for the 11 regions. The regression equation shown in the figure is used to project overall transport requirements in both the *Market Forces* and *Policy Reform* scenario. In the *Market Forces* scenario, the amounts of travel by individual modes of transport are projected separately, while in *Policy Reform*, the amounts of travel by individual modes are allocated as a share of the total passenger transport projected here.

Figure 3-33. Regression analysis of average income versus per capita passenger transport (all modes)



While this simple cross-sectional analysis seems to be sufficient for drafting broad sustainability scenarios, it is worth questioning whether it will tend to overstate total passenger transport requirements, especially over the longer term in OECD countries if

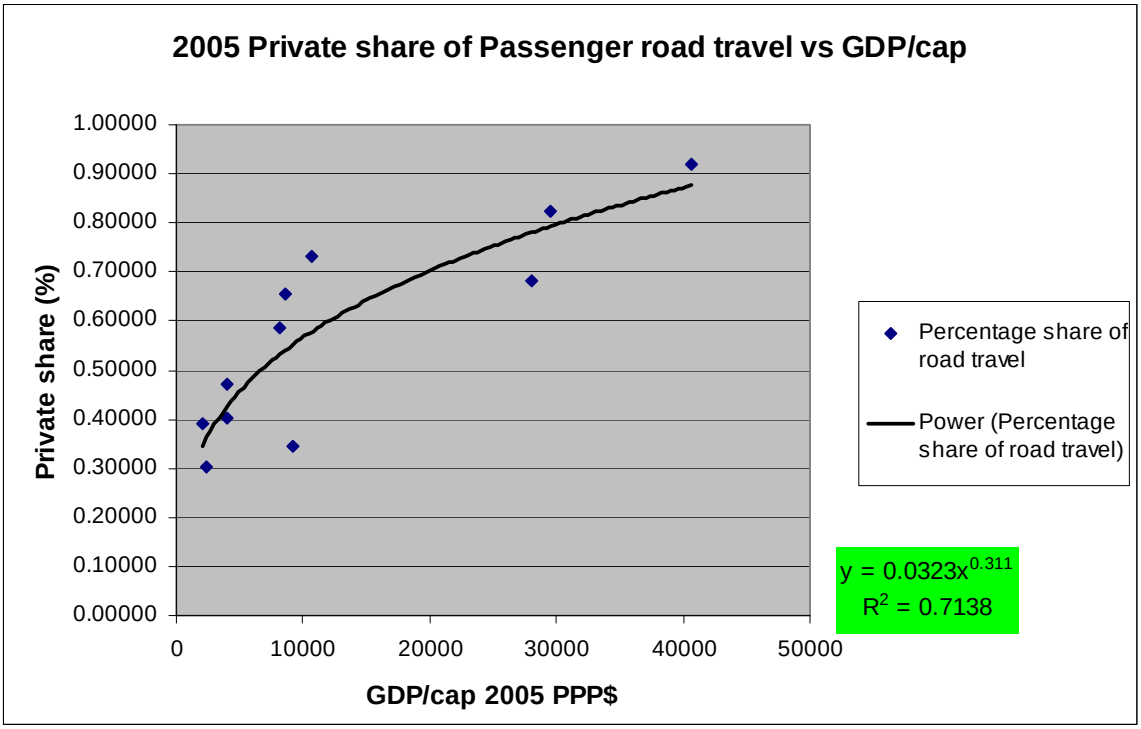
incomes rise dramatically. With an income elasticity of 0.7046, the projections foresee per capita passenger transport requirements continuing to increase with average income growth. No further adjustments are made for saturation effects, since there is no evidence for impending saturation in per capita transport requirements, even in the richest economies, especially North America. However, we did not try to fit the curve to North America's datapoint since the lack of mass transit leading to intense suburbanization may have led North America to be a permanent outlier. We also do not include the effects of factors such as better land-use planning and telecommuting, which might allow the same level of consumer benefits via reduced overall transport requirements. The effect of these issues on per capita passenger transport requirements is controversial and poorly understood.

Modal Shares

In the *Market Forces* scenario, each mode of transport is projected separately. The regressions shown in Figure 3-34, Figure 3-35, and Figure 3-36 are used to project road, rail and air transport requirements in the *Market Forces* scenario. Modal share patterns across countries also suggest a correlation with income. This is illustrated for region-level data in these regressions, which shows the relationship between the share of total road passenger-kilometers traveled by private vehicles, rail travel, and air travel and GDP per capita. As incomes grow, not only does total per capita travel grow, but so too do the shares of travel by private car and by air.

In the *Policy Reform* scenario, the total passenger transportation activity that was projected using the regression shown in Figure 3-33 is allocated to the various modes using shares that are selected to illustrate the scenario's future passenger transport composition. Private Road transportation is the residual share in the *Policy Reform* scenario. These shares were developed after reviewing the *Market Forces* shares that are a result of the scenario projection methodology described above.

Figure 3-34. Average income vs. share of road transport in private vehicles



For *Market Forces*, road transport requirements are calculated as the remainder after all other transport modes are determined (see below) using the total passenger transport results from the regression shown in Figure 3-33. Then, within road transport, the split between road transport with private vehicles and public vehicles is projected using the regression analysis shown in Figure 3-34, with an income elasticity of 0.311.

Figure 3-35. Average income and rail travel

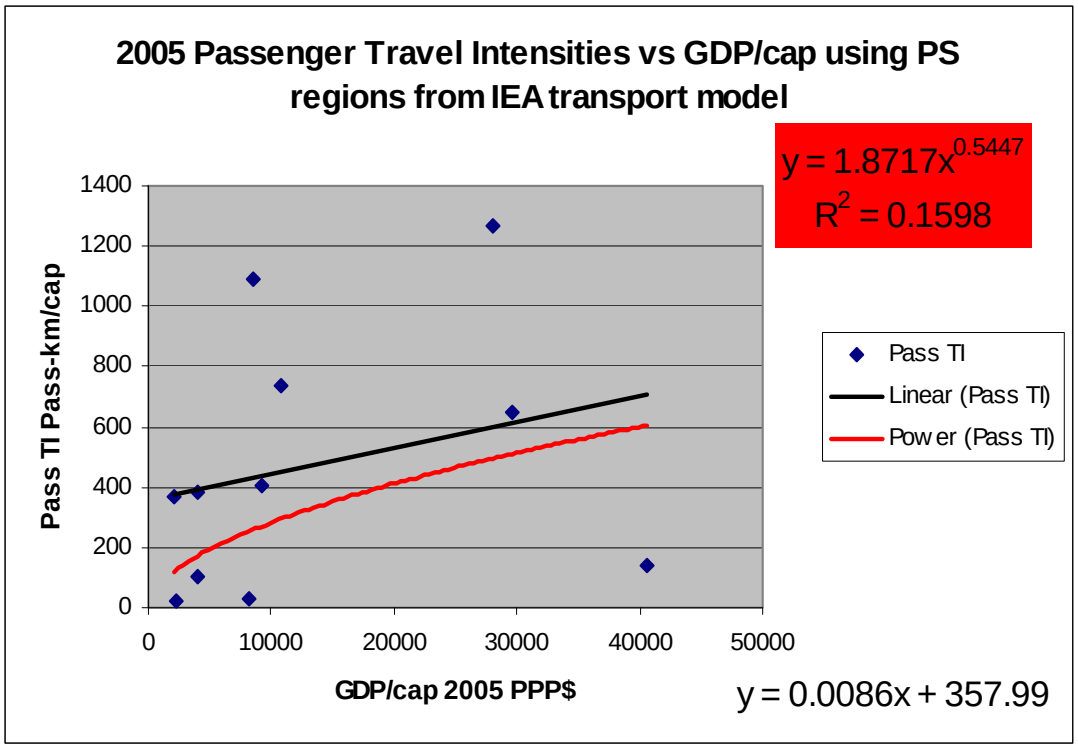
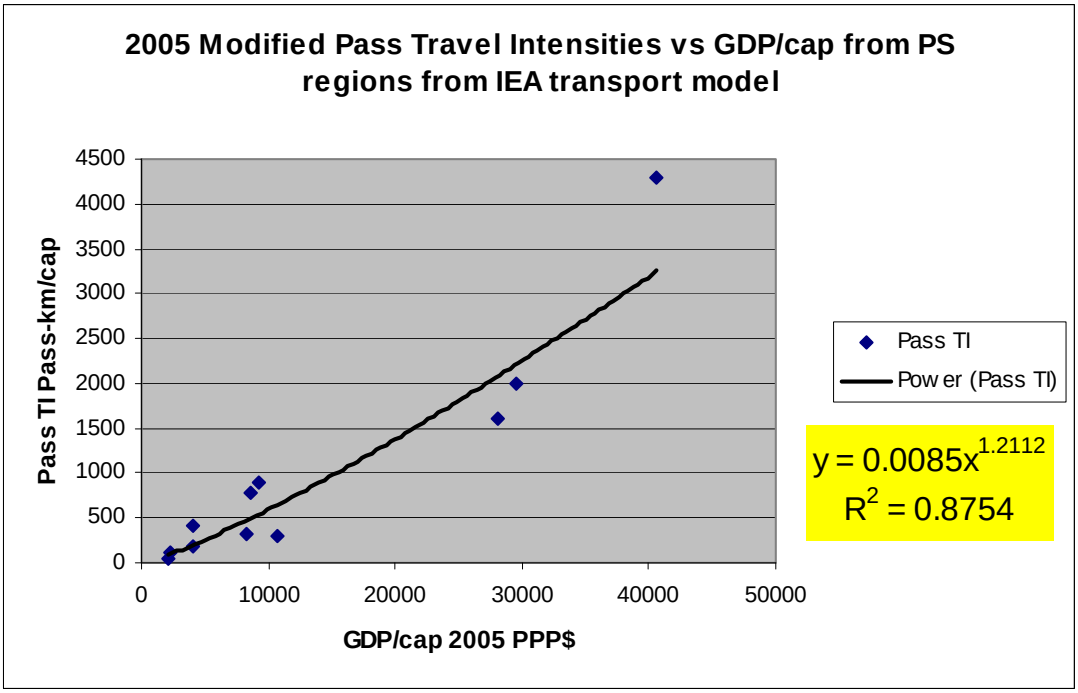


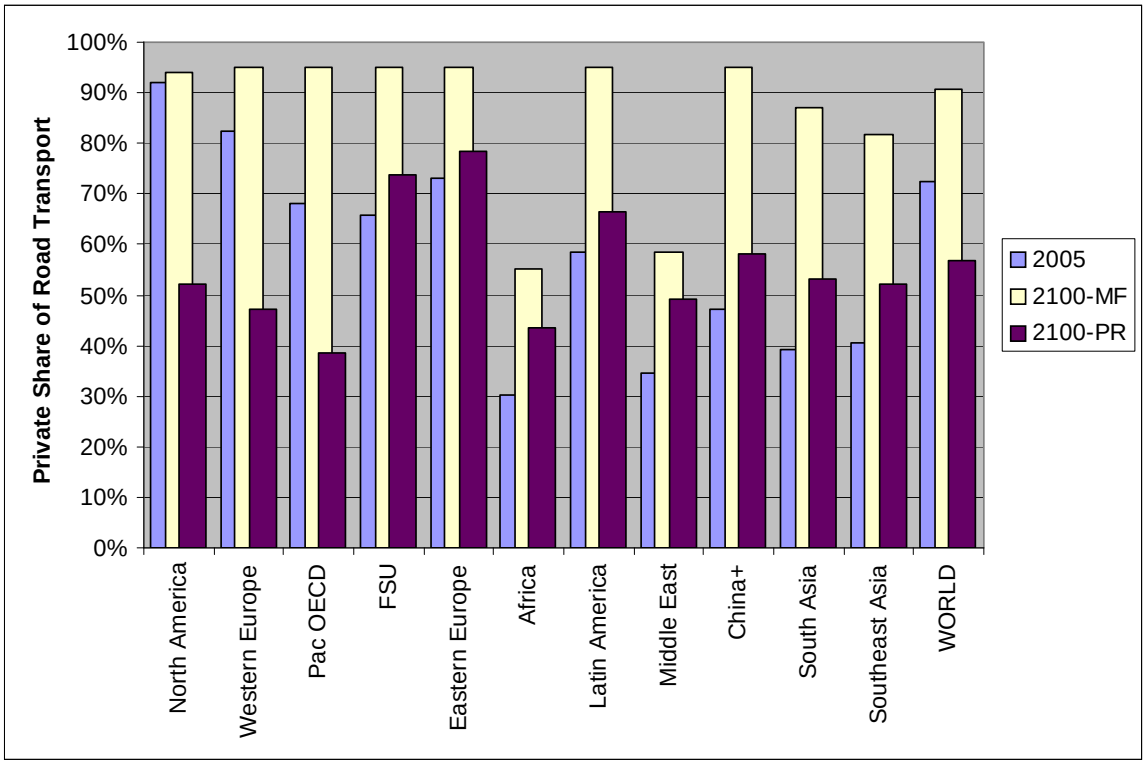
Figure 3-36. Average income and air transport



In the *Market Forces* scenario, rail travel per capita is assumed to vary with GDP per capita based on the regression curve shown in Figure 3-35, with an income elasticity of 0.5447. Air travel per capita is assumed to vary with GDP per capita based on the regression curve shown in Figure 3-36, with an income elasticity of 1.2112. In absolute terms, the *Market Forces* scenario requires a large expansion in transport infrastructure, with total pass-km increasing by a factor of 4.7 globally over the scenario from 33,800 billion pass-km in 2005 to 160,000 billion pass-km in 2100 (See Table 3-7). In the non-OECD regions, transport requirements increase by a factor of 6.6 over the same time period. Absolute increases in road transport requirements are more dramatic. In one region, Africa, passenger transport requirements increase from 1,560 billion pass-km in 2005 to 16,000 billion pass-km in 2100, a factor of 10. Rail transportation sees increases from 2,250 billion pass-km in 2005 to 8,860 billion pass-km in 2100, with most growth happening in non-electric rail modes. On the other hand, passenger air transport is expected to mushroom from 3,880 billion pass-km in 2005 to 44,260 billion pass-km in 2100, over a factor of 11 times the current activity.

The *Policy Reform* scenario makes alternative assumptions, compatible with the notion of creating a less resource-intensive and more environmentally acceptable transport system. Specifically, the declining importance of public transport systems in the *Market Forces* scenario is reversed or slowed (relative to economic growth rates) in all regions to take advantage of the energy-efficiency benefits of public transport compared to private vehicles. In the OECD regions, the share of rail passenger transportation increases. In the developing regions, railways are assumed to maintain their existing shares, or decline at a slower rate than in the *Market Forces* scenario. The share of total rail transport (both electric and non-electric) increases for most regions, resulting in an increase in 15,800 rail pass-km being traveled in 2100, an increase of over 7 times the 2005 value. Similarly, an increase in the public vehicle share of passenger road transport is assumed (Figure 3-37).

Figure 3-37. Private vehicle shares of road transport



The resulting passenger transport requirements are shown in Table 3-7 and Table 3-8. In absolute terms, the *Policy Reform* scenario assumes similar global levels of passenger transport requirements (150,000 billion pass-km in 2100 compared to 160,000 billion pass-km in the *Market Forces* scenario in 2100). The developing regions' share of this total in 2100 increases from 64% in the *Market Forces* scenario to 71% in the *Policy Reform* scenario. The non-OECD regions' overall transport requirements increase by a factor of 6.8 between 2005 and 2100. In spite of policies to promote rail transport, the absolute increases in road transport requirements are still dramatic. Compared to 2005, in Africa, South Asia, and the Middle East the private road transport requirements are projected to be more than ten times greater in 2100. The assumed revival of rail transport in the *Policy Reform* scenario leads to a dramatic increase in total rail transport requirements – by a factor of 7 globally. Air transport requirements increase by a factor of 3.4 – less than a third of the increase of the *Market Forces* scenario (which increased by a factor of 11.4).

Table 3-7. Passenger transport requirements total

10^9 pass km	Road - Private				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	6,633	14,315	17,577	10,684	9,730
Western Europe	4,244	8,080	10,623	5,134	3,862
Pac OECD	1,764	3,336	5,705	1,965	1,652
FSU	741	1,723	2,625	1,660	3,139
Eastern Europe	723	2,112	3,142	1,878	2,964
Africa	435	2,271	7,132	2,492	6,721
Latin America	1,064	3,590	6,886	3,340	5,882
Middle East	308	1,409	3,012	1,730	3,843
China+	1,511	7,330	15,857	6,155	12,946
South Asia	622	3,767	12,779	3,393	8,679
Southeast Asia	659	2,703	6,413	2,670	5,740
World	18,704	50,635	91,751	41,101	65,160

10^9 pass km	Road - Public				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	573	753	1,145	2,585	8,947
Western Europe	898	425	559	1,432	4,302
Pac OECD	822	577	300	1,114	2,627
FSU	388	147	138	654	1,118
Eastern Europe	267	111	165	558	812
Africa	997	3,339	5,828	3,721	8,707
Latin America	758	1,017	362	1,854	2,979
Middle East	583	1,667	2,129	2,079	3,989
China+	1,698	2,323	835	4,949	9,261
South Asia	968	2,583	1,914	3,455	7,679
Southeast Asia	972	1,917	1,431	2,766	5,261
World	8,922	14,862	14,807	25,168	55,682

Table 3-7 Continued. Passenger transport requirements total

10^9 pass km	Air				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	1,434	4,979	13,037	2,844	4,281
Western Europe	824	2,235	4,779	1,262	1,569
Pac OECD	327	744	1,761	443	616
FSU	221	711	2,072	373	638
Eastern Europe	55	221	565	115	167
Africa	108	705	2,917	403	942
Latin America	179	770	2,028	439	705
Middle East	202	1,249	3,837	721	1,383
China+	263	1,834	6,866	768	1,436
South Asia	74	569	2,532	264	586
Southeast Asia	192	1,098	3,865	548	1,042
World	3,880	15,114	44,258	8,179	13,366

10^9 pass km	Rail-NonElectric				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	10	20	32	258	389
Western Europe	27	42	55	191	237
Pac OECD	26	36	53	86	119
FSU	55	86	135	93	159
Eastern Europe	26	51	68	55	80
Africa	5	16	34	17	40
Latin America	4	10	16	11	18
Middle East	92	312	565	328	630
China+	367	917	1,513	1,070	2,001
South Asia	415	1,312	2,570	1,481	3,293
Southeast Asia	41	106	183	117	223
World	1,068	2,908	5,224	3,708	7,189

Table 3-7 Continued. Passenger transport requirements total

10^9 pass km	Rail-Electric				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	38	78	124	862	2,594
Western Europe	241	378	498	1,528	1,899
Pac OECD	231	326	482	687	955
FSU	220	343	542	372	635
Eastern Europe	105	202	269	220	319
Africa	14	51	110	54	127
Latin America	13	30	45	31	50
Middle East	0	0	0	0	0
China+	189	471	777	549	1,028
South Asia	122	385	755	435	967
Southeast Asia	7	18	32	20	38
World	1,180	2,282	3,633	4,758	8,614

10^9 pass km	TOTAL PASS TRANSPORT - ALL MODES				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	8,688	20,145	31,914	17,233	25,942
Western Europe	6,233	11,160	16,514	9,547	11,871
Pac OECD	3,170	5,020	8,302	4,295	5,970
FSU	1,625	3,009	5,513	3,153	5,688
Eastern Europe	1,176	2,697	4,210	2,825	4,343
Africa	1,558	6,382	16,021	6,687	16,536
Latin America	2,018	5,417	9,336	5,676	9,634
Middle East	1,185	4,637	9,543	4,858	9,845
China+	4,028	12,876	25,848	13,491	26,672
South Asia	2,201	8,616	20,549	9,027	21,204
Southeast Asia	1,871	5,842	11,924	6,121	12,305
World	33,753	85,801	159,674	82,914	150,010

Table 3-8. Passenger transport requirements per capita

pass-km/capita	Road				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	21,510	34,015	40,000	29,952	39,905
Western Europe	12,480	20,543	30,457	15,861	22,240
Pac OECD	12,740	20,170	30,803	15,870	21,951
FSU	3,960	7,632	11,740	9,945	20,094
Eastern Europe	5,560	11,889	22,497	13,711	28,539
Africa	1580	2,896	5,345	3,376	7,070
Latin America	3270	5,922	9,746	7,029	13,238
Middle East	3,960	6,601	9,356	8,605	15,838
China+	2,230	6,196	12,702	7,502	18,778
South Asia	1,096	2,866	6,620	3,254	8,189
Southeast Asia	3,440	7,219	12,821	8,941	19,979
World	4,273	7,217	11,488	7,638	14,299

pass-km/capita	Rail				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	143	221	332	2,529	6,374
Western Europe	649	1,015	1,507	4,151	5,820
Pac OECD	1,264	1,868	2,745	3,985	5,511
FSU	966	1,748	2,879	1,997	3,747
Eastern Europe	738	1,350	2,293	1,546	3,021
Africa	21	34	59	38	76
Latin America	31	51	81	57	101
Middle East	409	669	1,029	742	1,274
China+	386	892	1,742	1,094	2,561
South Asia	370	766	1,498	911	2,132
Southeast Asia	102	195	351	226	476
World	348	572	955	976	1,870

Table 3-8 Continued. Passenger transport requirements per capita

pass-km/capita	Air				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	4,280	11,239	27,856	6,420	9,148
Western Europe	2,000	5,398	13,016	3,049	4,274
Pac OECD	1,610	3,836	9,032	2,283	3,157
FSU	776	2,902	8,803	1,604	3,010
Eastern Europe	309	1,182	3,844	647	1,265
Africa	119	364	1,203	219	432
Latin America	322	990	2,726	594	1,054
Middle East	898	2,680	6,984	1,628	2,797
China+	183	1,177	5,225	519	1,214
South Asia	51	257	1,141	125	293
Southeast Asia	406	1,715	6,316	901	1,892
World	600	1,665	4,772	943	1,582

Figure 3-38. Global passenger transport requirements by macro-region

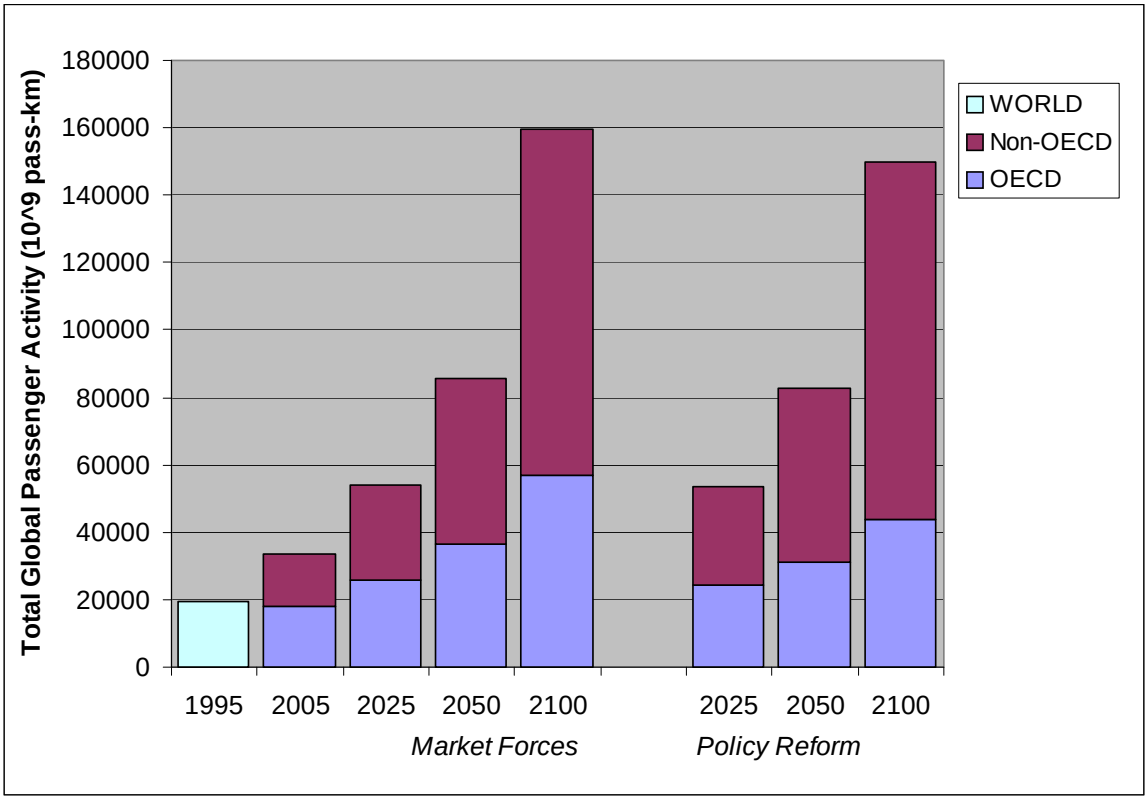
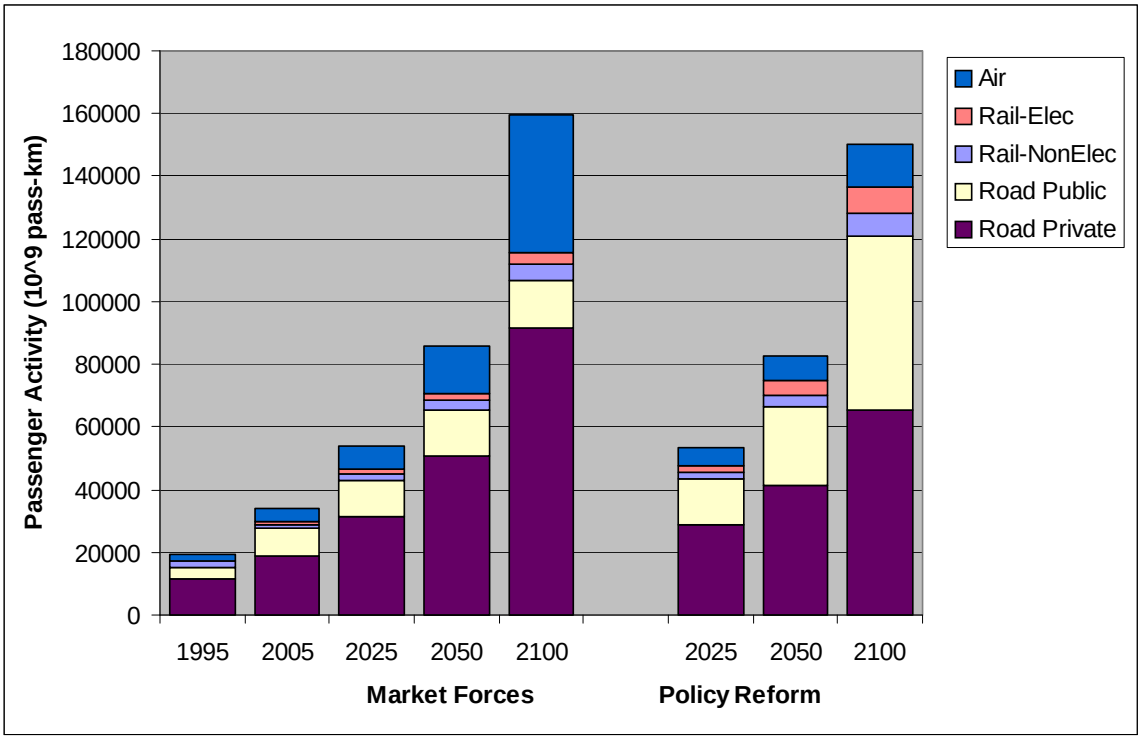


Figure 3-39. Global passenger transport requirements by mode



Energy Intensity

Transport energy intensity assumptions for OECD countries are summarized in Table 3-9, again guided by the SMP model (IEA/WBCSD, 2004a-b). Improvements in the transport energy intensities in *Policy Reform* scenarios assume the introduction of progressively stronger vehicle emissions standards, pricing reforms for vehicles and fuels, investments in research and development, and a range of market-based incentives to promote more efficient vehicles. In the longer term, the intensity projections assume the introduction of advanced vehicles and fuels, gradually replacing the petroleum-based internal combustion engine with technologies such as fuel cells and electric powered vehicles.

Table 3-9. Transport intensities for fossil energy use in OECD regions

	Market Forces		Policy Reform	
	% Change per year	2100/2005 Intensity Ratio	% Change per year	2100/2005 Intensity Ratio
Passenger Transport				
Road	-0.6%	0.56	-2.0%	0.15
Rail - non-Electric	-0.2%	0.83	-1.0%	0.40
Air	-0.9%	0.41	-0.8%	0.45
Freight Transport				
Road	-0.4%	0.72	-0.7%	0.51
Rail - non-Electric	-0.5%	0.62	-0.9%	0.43
Water	-0.4%	0.67	-0.4%	0.67
Air *(Energy accounted for as part of Passenger Air Travel)*				

Notes: Annual percentage improvement in Energy Intensities and ratio of 2100 to 2005 values.

Passenger transport energy intensities for non-OECD regions are assumed to converge towards the average values of the OECD region as average incomes increase, using the convergence algorithm (see Annex 1). The overall pattern of convergence in the two scenarios is shown in Table 3-10. In the *Policy Reform* scenario there is greater overall convergence to a lower average intensity, in accordance with the exogenous assumptions of improving equity and more rapid economic growth in the developing countries, compared with the *Market Forces* scenario. Note that the efficiency of electric rail trains can not be significantly improved.

Table 3-10. Passenger transport energy intensities

MJ/pass-km	Road-Private				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	2.7	2.0	1.5	0.7	0.4
Western Europe	1.7	1.3	0.9	0.7	0.4
Pac OECD	2.0	1.5	1.1	0.9	0.5
FSU	1.9	1.7	1.2	1.0	0.5
Eastern Europe	1.8	1.6	1.2	0.8	0.5
Africa	2.3	2.2	1.8	2.1	1.3
Latin America	2.1	1.9	1.2	1.3	0.5
Middle East	1.9	1.8	1.2	1.1	0.5
China+	1.1	1.4	1.2	1.0	0.5
South Asia	0.9	1.0	1.2	0.9	0.5
Southeast Asia	1.0	1.3	1.2	1.0	0.5

MJ/pass-km	Rail-Non Electric				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	0.8	0.7	0.7	0.5	0.3
Western Europe	1.6	1.5	1.3	1.1	0.6
Pac OECD	0.8	0.8	0.7	0.6	0.3
FSU	0.7	0.9	0.9	0.7	0.4
Eastern Europe	0.5	1.0	0.9	0.7	0.4
Africa	0.6	0.6	0.7	0.6	0.5
Latin America	1.0	1.0	0.9	0.8	0.4
Middle East	0.0	0.6	0.9	0.5	0.4
China+	0.3	0.7	0.9	0.6	0.4
South Asia	0.2	0.3	0.8	0.3	0.4
Southeast Asia	0.7	0.8	0.9	0.7	0.4

Table 3-10 Continued. Passenger transport energy intensities

MJ/pass-km	Air				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	2.6	1.9	1.0	1.9	1.2
Western Europe	2.6	1.9	1.0	1.9	1.2
Pac OECD	2.6	1.9	1.0	1.9	1.2
FSU	2.6	1.9	1.0	1.9	1.2
Eastern Europe	2.6	1.9	1.0	1.9	1.2
Africa	2.6	1.9	1.6	1.9	1.5
Latin America	2.6	1.9	1.0	1.9	1.2
Middle East	2.6	1.9	1.0	1.9	1.2
China+	2.6	1.9	1.0	1.9	1.2
South Asia	2.6	1.9	1.3	1.9	1.2
Southeast Asia	2.6	1.9	1.0	1.9	1.2

Fuel Shares

Finally, we determine the fuel shares for each mode of transportation. Given the current prototype status of alternative fueled vehicles it is hard to make predictions of future transport fuel shares. In the scenarios we assume a mix of non-conventional fuels and technologies are introduced alongside conventional petroleum-based technologies. Scenario assumptions are guided by a range of studies, including the IEA's SMP model, as well as *Energy Innovations* (1997), EC (1996) and Lazarus et al. (1993), which indicate the broad potential for non-conventional fuels to replace conventional petroleum-based transport.

For road transport, the range of possible technologies include conventional internal combustion engine vehicles based on alcohol fuels and natural gas, hybrid vehicles using more than one drive train, electric vehicles, and advanced vehicles powered by fuel cells and using hydrogen. In the *Market Forces* scenario, we assume only very modest penetration of alcohol and electric vehicles in the OECD countries (5% each for biofuels, electricity, and natural gas by 2050; by 2100, 13% biofuels, 14% electricity, 13% natural gas). Hydrogen-based vehicles do not emerge in the Market Forces scenario. In the *Market Forces* scenario, fuel shares in non-OECD regions gradually approach OECD patterns.

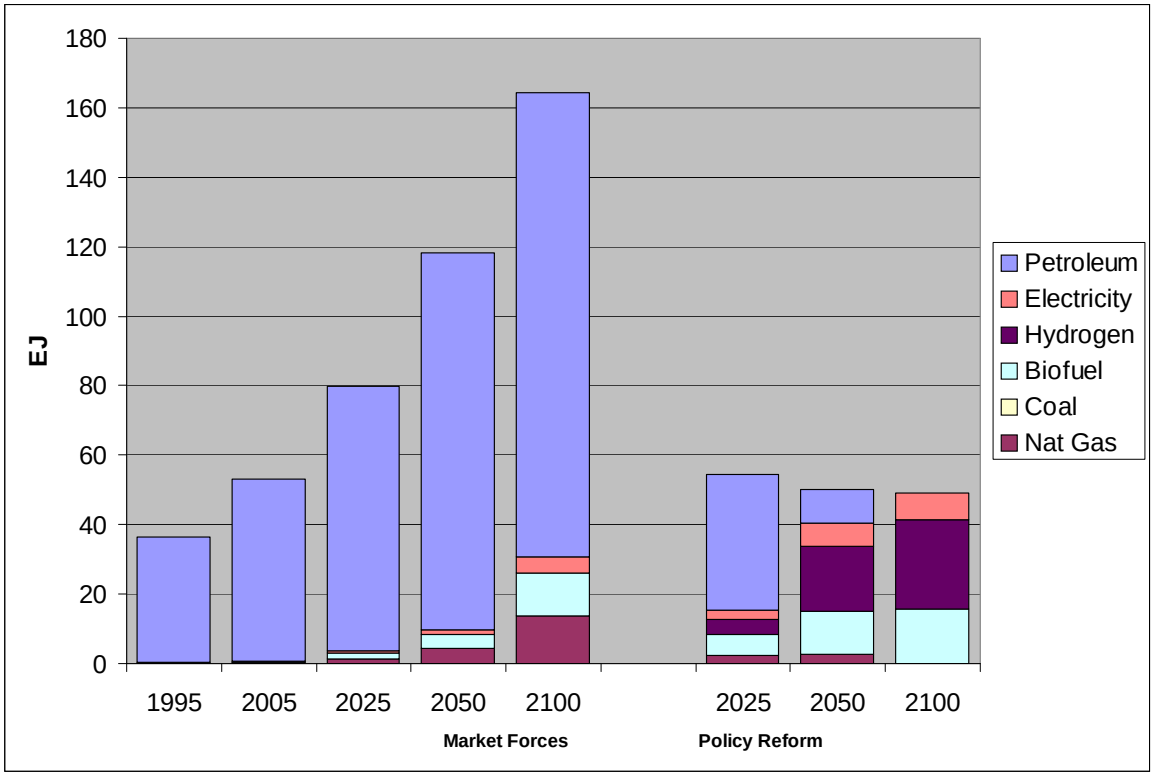
The *Policy Reform* scenario assumes more dramatic shifts in road transport fuel shares away from petroleum-based fuels towards lower-carbon fuels (electricity, natural gas and biomass-based ethanol and biodiesel). In the OECD regions, the share of petroleum and natural gas private vehicles are eliminated by 2100, with the share hydrogen reaching 50%, and the remaining 50% of vehicles running on electricity, which could be supplied by renewables. Biofuels are used as a transition fuel but basically phased out by 2100 in

all transport modes, except air transport which is set to reach 100% biofuel, where the technical challenges of alternative fuels may warrant the use of biomass-based ethanol or biodiesel. In the *Policy Reform* scenario, more growth of non-conventional transport fuels is also assumed in non-OECD regions, although the levels of adoption of non-conventional fuels generally stay below the levels of adoption in OECD regions until 2100, when the transition to carbon-neutral fuels is complete. These fuel mix results follow from the CO_2 emissions constraints imposed on the transportation sector (See Chapter 7 for details on how these carbon targets are set for each sector and how the sector shares are adjusted to meet the targets).

For rail transport the historical trend toward electrification persists in the *Market Forces* scenario. This leads to an increase in electrification of the rail system. Slightly more rapid electrification for rail transport is assumed in the *Policy Reform* scenario, especially in non-OECD regions, in line with the general spirit of the scenario in which policies are assumed that encourage fuel switching away from fossil fuels and towards electricity. In the *Market Forces* scenario, non-electric rail transport is assumed to be 100% petroleum-based, with the exception of the China+ and South Asia regions which still use the same share of coal as the base year for this purpose in 2100. In the *Policy Reform* scenario, hydrogen is assumed to gain market share for non-electric rail, reaching 100% by 2100, and coal is quickly phased out of all regions.

Air transport in the *Market Forces* scenario is assumed to remain 100% petroleum-based. In the *Policy Reform* scenario, biofuels for airplane travel are assumed to gain significant market share, amounting to close to 100% of the total fuel mix by 2100. Air transport is assumed to be an essentially global industry, with similar fuel shares in OECD and non-OECD regions.

Figure 3-40. Passenger transportation fuel use



Note: 1995 does not include Air Freight Energy Use, but future years do.

Freight Transport Scenarios

Methodology

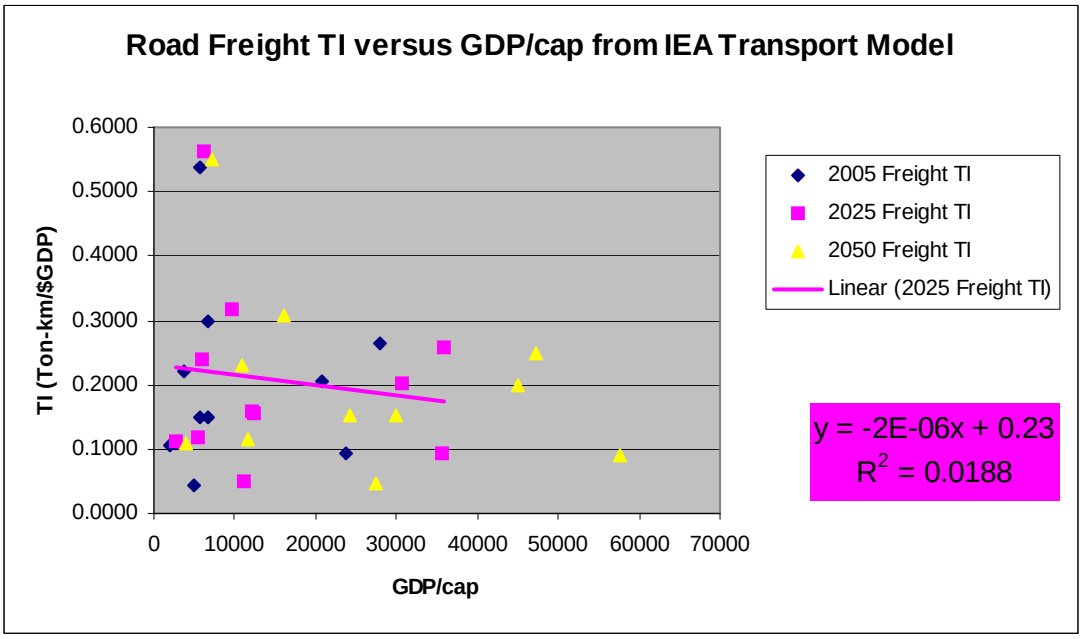
Regional freight activity is the product of regional GDP and the freight activity intensity (tonne-km per dollar of GDP). This is disaggregated by applying mode shares for road, rail (electric and non-electric), and water. The resulting freight activities by mode are then multiplied by energy intensities (MJ per tonne-km). Finally, specifying fuel shares completes the energy picture for freight transport.

Freight Transport Activity

In both scenarios, freight transport requirements per dollar (freight intensities) are assumed to stay at the base-year value for rail transport modes (both electric and non-electric). For water freight transport, the freight intensities of the OECD regions remains at the base year values for both scenarios, however the non-OECD freight intensities converge to the OECD average intensities as their income levels increase. The road freight intensities are assumed to decline linearly as the income levels rise. This is weakly supported by the regression shown in Figure 3-41, which plots average income against road freight intensities by the IEA SMP Transportation Model projections (IEA/WBCSD, 2004a-b) for 2025. With a linear growth rate of -2×10^{-6}, the road freight transport requirements per dollar tend to decrease as income levels rise, probably

reflecting the increasing share of economic value added which derives from those services that do not require transportation.

Figure 3-41. Road freight travel intensity versus income



Total global freight transport requirements continue to increase as the global economy expands in both scenarios, as shown in Table 3-11. In the *Market Forces* scenario, the requirements for road, rail and water transport increase by a factor of 7 from 59,600 billion tonne-km in 2005 to 420,000 billion tonne-km in 2100. In the *Policy Reform* scenario, they increase by a factor of 6.8, reaching 403,000 billion tonne-km in 2100.

Table 3-11. Freight transport

10^9 tonne-km	TOTAL FREIGHT TRANSPORT - ALL MODES				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	12,455	34,108	70,879	28,117	45,200
Western Europe	15,030	33,038	57,909	26,882	36,601
Pac OECD	4,553	8,493	16,938	6,946	10,742
FSU	2,355	8,372	22,457	9,711	24,748
Eastern Europe	696	5,022	10,871	5,528	12,056
Africa	1,781	9,567	32,097	10,442	35,315
Latin America	3,654	14,437	29,478	16,171	32,729
Middle East	3,993	14,761	22,157	14,564	24,598
China+	7,189	32,946	89,825	35,281	99,359
South Asia	960	7,534	46,559	8,655	58,543
Southeast Asia	6,954	23,223	21,068	23,564	23,404
World	59,620	191,501	420,238	185,861	403,295

10^9 tonne-km	Road				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	2,900	6,068	8,206	5,651	5,970
Western Europe	2,170	3,705	4,111	3,377	2,927
Pac OECD	449	461	569	509	490
FSU	246	493	1,187	504	1,509
Eastern Europe	128	232	1,002	211	1,274
Africa	191	972	3,176	1,047	3,670
Latin America	1,120	3,671	2,885	3,935	3,670
Middle East	590	2,822	2,209	3,030	2,809
China+	299	904	6,700	858	8,521
South Asia	382	2,079	5,310	2,238	6,018
Southeast Asia	711	3,021	2,114	3,267	2,689
World	9,186	24,428	37,469	24,627	39,547

Table 3-11 Continued. Freight transport

10^9 tonne-km	Rail				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	2,645	7,762	17,349	6,219	10,859
Western Europe	260	594	1,088	476	680
Pac OECD	164	321	654	257	410
FSU	1,759	4,493	10,791	4,905	11,790
Eastern Europe	155	492	1,025	537	1,120
Africa	130	701	2,356	766	2,574
Latin America	144	509	1,121	555	1,225
Middle East	33	171	444	186	485
China+	1,650	8,305	23,981	9,066	26,206
South Asia	372	2,161	7,414	2,359	8,102
Southeast Asia	23	103	289	112	316
World	7,335	25,612	66,512	25,438	63,767

10^9 tonne-km	Water				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	6,910	20,278	45,324	16,247	28,371
Western Europe	12,600	28,739	52,710	23,029	32,994
Pac OECD	3,940	7,711	15,715	6,180	9,842
FSU	350	3,386	10,479	4,302	11,449
Eastern Europe	413	4,298	8,844	4,780	9,662
Africa	1,460	7,894	26,565	8,629	29,071
Latin America	2,390	10,257	25,472	11,681	27,834
Middle East	3,370	11,768	19,504	11,348	21,304
China+	5,240	23,737	59,144	25,357	64,632
South Asia	206	3,294	33,835	4,058	44,423
Southeast Asia	6,220	20,099	18,665	20,185	20,399
World	43,099	141,461	316,257	135,796	299,981

Energy Intensity

Energy intensity assumptions are similar to those described for the passenger transport analysis. The overall pattern of convergence to the OECD averages in the two scenarios is shown in Table 3-12. (See Annex 1 for discussion of the general convergence algorithm).

Fuel Shares

Finally, we introduce fuel shares for each mode of freight transport. In both *Conventional Worlds* scenarios, we assume similar patterns of penetration for alternative fuels (natural gas, biomass-based alcohol, hydrogen, electricity) as in the passenger transport analysis. All non-electric rail freight transport is assumed to be petroleum driven. The global fuel shares for freight transportation is shown in Figure 3-42. By 2100, *Market Forces* is still mostly petroleum, while in *Policy Reform*, all freight is run on electricity and hydrogen.

Table 3-12. Freight Transport Energy intensities

MJ/tonne-km	Road				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	1.76	1.50	1.26	1.12	0.89
Western Europe	1.90	1.62	1.36	1.21	0.97
Pac OECD	2.90	2.48	2.08	1.85	1.48
FSU	2.75	2.16	1.57	1.63	1.11
Eastern Europe	2.21	1.88	1.57	1.39	1.11
Africa	3.05	2.92	2.43	2.83	2.03
Latin America	2.60	2.24	1.57	1.86	1.11
Middle East	3.28	2.48	1.57	1.96	1.11
China+	3.01	2.45	1.57	2.07	1.11
South Asia	2.66	2.52	1.81	2.40	1.15
Southeast Asia	2.43	2.24	1.57	2.01	1.11

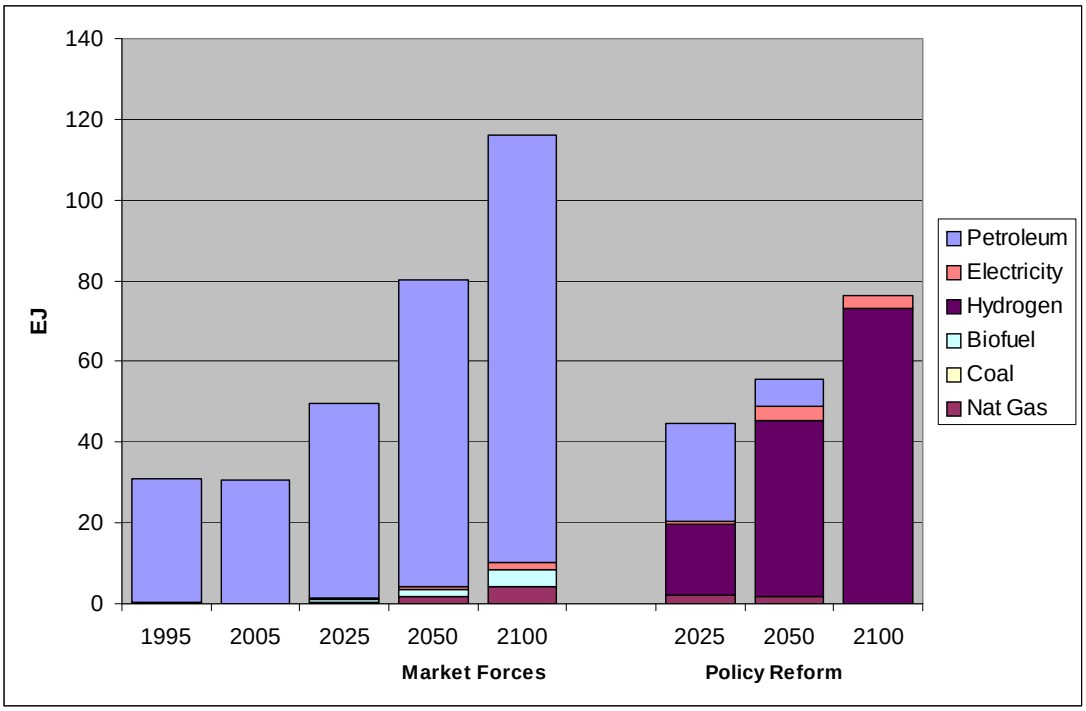
MJ/tonne-km	Rail - Non-Electric				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	0.21	0.17	0.13	0.11	0.09
Western Europe	0.92	0.75	0.60	0.49	0.39
Pac OECD	0.53	0.43	0.34	0.28	0.22
FSU	0.23	0.38	0.36	0.29	0.23
Eastern Europe	0.36	0.45	0.36	0.29	0.23
Africa	0.20	0.23	0.28	0.22	0.23
Latin America	0.43	0.45	0.36	0.35	0.23
Middle East	0.00	0.26	0.36	0.22	0.23
China+	0.28	0.37	0.36	0.30	0.23
South Asia	0.11	0.17	0.31	0.16	0.23
Southeast Asia	0.35	0.39	0.36	0.33	0.23

Table 3-12Continued. Freight Transport Energy intensities

MJ/tonne-km	Rail - Electric				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	0.18	0.15	0.12	0.10	0.08
Western Europe	0.19	0.16	0.12	0.10	0.08
Pac OECD	0.23	0.19	0.15	0.12	0.10
FSU	0.19	0.17	0.13	0.12	0.08
Eastern Europe	0.19	0.16	0.13	0.11	0.08
Africa	0.19	0.18	0.17	0.18	0.13
Latin America	0.19	0.18	0.13	0.14	0.08
Middle East	0.18	0.17	0.13	0.13	0.08
China+	0.21	0.19	0.13	0.15	0.08
South Asia	0.19	0.19	0.14	0.17	0.09
Southeast Asia	0.19	0.18	0.13	0.15	0.08

MJ/tonne-km	Water				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	0.18	0.15	0.12	0.10	0.08
Western Europe	0.19	0.16	0.12	0.10	0.08
Pac OECD	0.23	0.19	0.15	0.12	0.10
FSU	0.19	0.17	0.13	0.12	0.08
Eastern Europe	0.19	0.16	0.13	0.11	0.08
Africa	0.19	0.18	0.17	0.18	0.13
Latin America	0.19	0.18	0.13	0.14	0.08
Middle East	0.18	0.17	0.13	0.13	0.08
China+	0.21	0.19	0.13	0.15	0.08
South Asia	0.19	0.19	0.14	0.17	0.09
Southeast Asia	0.19	0.18	0.13	0.15	0.08

Figure 3-42. Freight transportation fuel use



Note: 1995 includes Air Freight Energy Use, while the remaining years coming from the current update do not. Air Freight energy use is included in the Passenger Air transportation energy use.

Energy Conversion

Energy conversion refers to the transformation of primary sources of energy into products suitable for final use in each sector of the economy. Energy conversion categories also include the transmission and distribution of final energy forms to end-uses. The major energy conversion sectors include electric power generation, petroleum refining, alcohol production, and district heating.

Current Accounts

Table 3-13 summarizes the global energy balance for 2005. Global final demand for energy is approximately 483 EJ. In addition, 141 EJ of energy are consumed in the production and distribution of final energy forms. These “conversion” losses are dominated by electric power generation, and by transportation and distribution losses and own-use.

Coal, oil, hydro, nuclear and, to an increasing extent, natural gas-fired power plants dominate in electricity generation. Recent decades have seen a virtual halt in the expansion of nuclear power in OECD countries – a technology that grew rapidly in the decades of the 1950s to the 1970s. This decline has been due to concerns over siting, safety, security, waste disposal and cost. Nevertheless, it seems likely that nuclear power

will form an important part of the plans of a number of developing regions to expand their generation of electricity.

In addition to electricity generation, the current accounts data also includes other types of energy conversion: the conversion of crude oil to petroleum products in oil refineries, the combustion of coal, oil and natural gas in district heating plants, the conversion of sugarcane and cellulose to ethanol in alcohol plants, and losses and own-use consumption of various fuels during the conversion and transportation of fuels.

Table 3-13. 2005 Global energy balance

EJ	Coal	Crude Oil	Petro-leum	Nat Gas	Nuclear	Hydro-power	Renew-able	Biomass	Electr	Heat	TOTAL
Production	125.2	167.6		101.4	30.4	10.3	0.9	47.2			483.0
TPES	125.2	167.6	0.0	101.4	30.4	10.3	0.9	47.2	0.0	0.0	483.0
Discrepancy from IEA TPES Data	*4.1*	*(3.0)*	*3.1*	*2.5*	*0.2*	*(0.2)*	*(1.6)*	*(0.8)*	*0.1*	*(0.0)*	*4.3*
Electricity Generation	(77.7)		(13.0)	(32.7)	(30.6)	(10.3)	(0.1)	(3.9)	52.5		(115.8)
District Heat	(3.5)		(1.1)	(8.1)	0.0		0.0	(0.9)		12.2	(1.5)
Oil Refining		(162.1)	154.0								
Alcohol Prod			0.4					(0.8)			
Losses & Own Use	(0.1)	(0.3)	(0.3)	(7.8)	0.0	0.0	(0.0)	0.0	(11.9)	(1.4)	(21.9)
TFD	43.9	5.3	139.9	52.8	(0.2)	0.0	0.7	41.6	40.7	10.7	335.4
Discrepancy from IEA TFD Data	*16.2*	*4.8*	*(3.2)*	*1.2*	*(0.2)*	*0.0*	*0.4*	*(1.1)*	*(13.4)*	*(0.6)*	*4.1*
Households	3.7	0.0	10.8	18.6	0.0	0.0	0.3	33.6	15.4	5.4	87.8
Services	0.7	0.0	5.2	6.7	0.0	0.0	0.0	0.3	12.5	0.9	26.3
Transportation	0.0	0.0	83.1	0.1	0.0	0.0	0.0	0.0	0.3	0.0	83.6
Industry	23.9	0.7	35.6	27.9	0.0	0.0	0.0	6.9	21.5	4.2	120.6
Agriculture	0.7	0.0	5.0	0.3	0.0	0.0	0.0	0.3	1.5	0.2	7.9
Final Discrepancy	14.8	4.5	0.2	(0.8)	(0.2)	0.0	0.4	0.5	(10.5)	0.1	9.1

Note: Numbers may not sum due to rounding. Discrepancies reflect statistical discrepancies within data sets (TPES and TFD) and stock changes (between TPES and TFD). Source: IEA (2006a-b). Definitions: TPES: total primary energy supply; TFD: Total final demand; Negatives shown in parentheses.

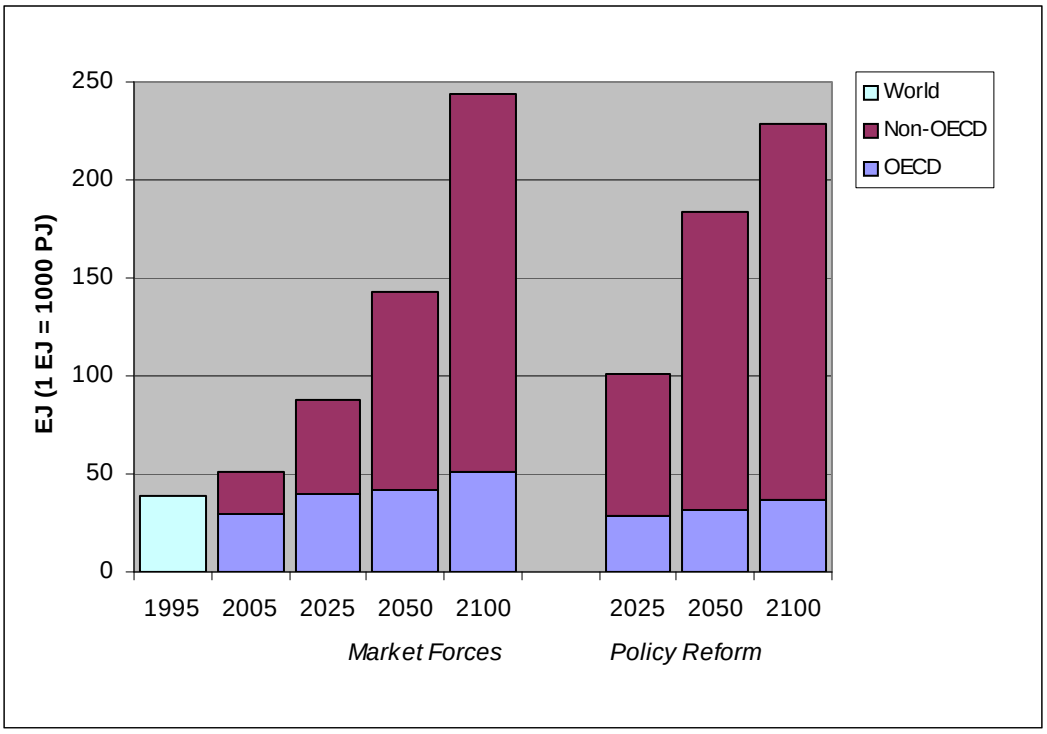
Scenarios

Methodology

Global electricity requirements are shown in Figure 3-43. For each time period, these are calculated by adding total electricity demands across all final demand sectors to an estimate of electricity losses and own-use. Losses and own-use of electricity and other

fuels are expected to converge towards current OECD practices in the *Market Forces* scenario. Currently, losses of electricity in many developing countries are inflated due to the theft of electricity from the grid by consumers. The *Policy Reform* scenario assumes concerted action to reduce losses in all regions, particularly in the developing regions.

Figure 3-43. Global electricity requirements for all sectors



Globally, in the *Market Forces* scenario, annual electricity requirements expand rapidly from 51 EJ (14 PWh) in 2005 to 244 EJ (68 PWh) in 2050 for an increase in the electricity requirements by a factor of 4.7. This represents a 5.7% per year growth rate. Global requirements for electricity in the *Policy Reform* scenario are higher than *Market Forces* in 2050, reaching 184 EJ (51 PWh) in 2050, compared to 143 EJ (40 PWh) in *Market Forces*. However by 2100, the *Policy Reform* efficiency and loss-reduction policies have compensated for the increased reliance on clean electricity, and the requirements of 228 EJ (63 PWh) are slightly lower than the *Market Forces* requirements in that year. In the *Policy Reform* scenario, the combined effect of changing economic activities, increased demand side efficiency, and adjustments in the final fuel mix towards renewable electricity for many end-uses, lead to reduced electricity requirements in the OECD compared to the *Market Forces* scenario. The demand for electricity in the non-OECD regions is approximately equal between the two scenarios. However aggressive efficiency improvements in the *Policy Reform* scenario balance the increased use of electricity due to the rising personal incomes, industrialization, and the larger GDP growth relative to the *Market Forces* scenario, and energy policies guide final

consumption away from the use of the carbon-intensive fuels, and towards electricity and natural gas, increase electricity demands.

Fuel Shares for Electricity Generation

In developing each scenario, electricity generation from solid waste and hydroelectric production are determined first, as these are constrained by waste generation rates and the hydroelectric potential in each region, respectively. The remaining requirements are met by a combination of fossil, nuclear and renewable fuels.

Electricity generation from solid waste incineration is a small part of the total, increasing from roughly 100 PJ (petajoules) in 2005 to 890 PJ in 2100 in the *Market Forces* scenario. As the share of landfilled waste drops dramatically and incineration of non-recyclable waste increases in the *Policy Reform* scenario, electricity generation from solid waste increases to around 1500 PJ in 2100.

Hydropower development in the *Market Forces* scenario is based on national estimates of economically exploitable hydropower capability after aggregation into regions. (WEC, 2007). Also see Box 3-1, below. In this scenario it is assumed that hydro production expands as demand increases, but at a gradually slower rate as the economically exploitable limit is reached. In this approach, when production is well below the maximum exploitable limit, production increases roughly in linear proportion to demand. As the maximum production is approached, production continues to increase, but at a gradually slowing rate. Denoting hydroelectric production by P_H and total electricity demand by E, the general expression for the change in hydroelectric production as a function of electricity demand can be written mathematically as

$$P_H = P_{H,\max} - \left(P_{H,\max} - P_{H,2005}\right) \cdot \exp\left[-a\left(\frac{E - E_{2005}}{P_{H,\max}}\right)\right]. \qquad (3\text{-}1)$$

For all regions except FSU and Latin America the values of the parameter a that appears in Equation (3-1) (the "hydro production parameter") are calculated by fitting to historical data (1975-1995) from IEA (2004a-b) on hydropower production and electricity demand. In Latin America, hydro production increased unusually rapidly over the historical period. In the *Market Forces* scenario hydro production continues to increase, but at a slower rate than in the past, reflecting a gradually declining value for the hydro production parameter a in Equation (3-1). Values for the production parameter adopted in the scenario are shown in Table 3-14.

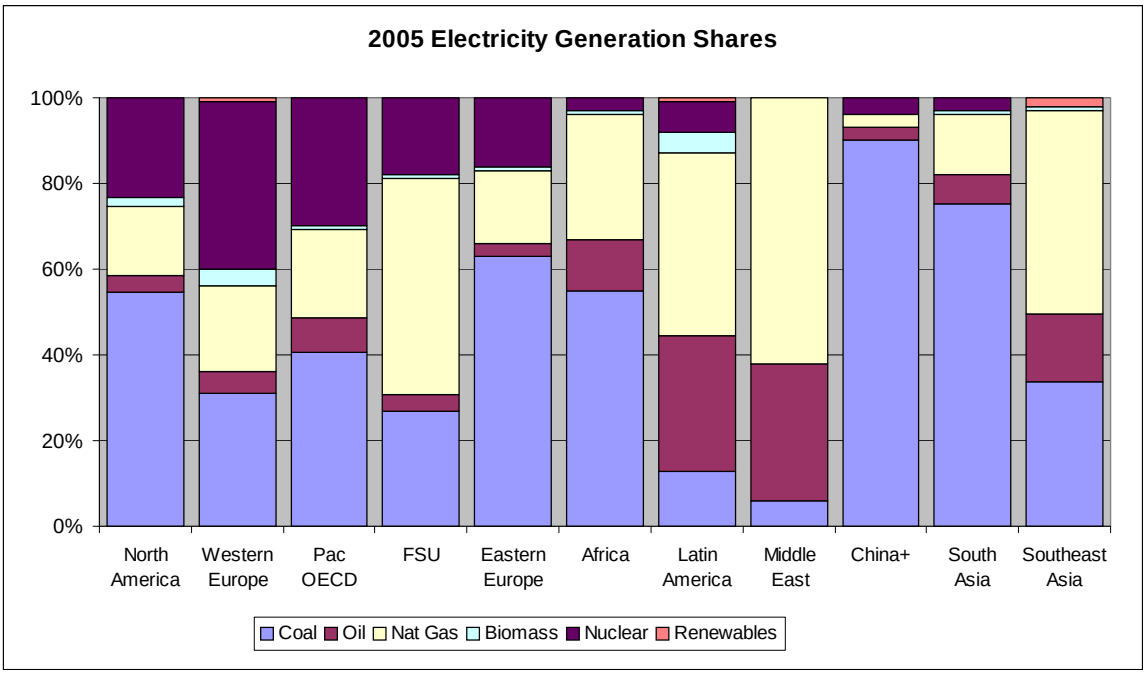
Table 3-14. Values for hydro production parameter

Hydro production parameter values						
	Market Forces			Policy Reform		
	2025	2050	2100	2025	2050	2100
North America	0.100	0.103	0.103	0.120	0.125	0.125
Western Europe	0.147	0.147	0.147	0.147	0.182	0.182
Pac OECD	0.035	0.035	0.035	0.035	0.035	0.035
FSU	0.147	0.250	0.250	0.120	0.120	0.120
Eastern Europe	0.069	0.069	0.069	0.045	0.070	0.070
Africa	0.086	0.086	0.086	0.051	0.040	0.040
Latin America	0.350	0.200	0.200	0.250	0.200	0.200
Middle East	0.047	0.047	0.047	0.040	0.045	0.045
China+	0.192	0.192	0.192	0.090	0.150	0.150
South Asia	0.188	0.188	0.188	0.125	0.090	0.090
Southeast Asia	0.066	0.066	0.066	0.030	0.040	0.040

The calculated hydro production parameter values for each region are used for the *Market Forces* scenario inputs, while the hydro production parameter values for the *Policy Reform* scenario are adjusted so that hydro electricity production in the *Policy Reform* case does not exceed what is developed in the *Market Forces* case (to meet one of the constraints of the scenario, described in item (a) below in the description of the *Policy Reform* scenario development of the electricity shares).

Fuel shares for the remaining requirements in the base year and in the scenarios in 2050 are shown below in Figure 3-44. By 2100, electricity generation for the remaining requirements in the *Policy Reform* scenario is made by 80-90% renewables, and the remainder is biomass with cabon-sequestration enough to reach the negative carbon targets set for the scenario. (See Chapter 7 for discussion of setting the carbon targets in each sector, and how the targets are achieved through the process for adjusting the fuel shares). Carbon sequestration of biomass electricity generation is assumed to develop only after 2050, and thus there is a large jump in the amount of biomass fuel required between the 2050 and 2100 scenario years. This jump corresponds with a large increase in the demand for biomass fuel from the forestry sector, and has large implications for land-use.

Figure 3-44. Regional electricity generation shares 2005 and 2050



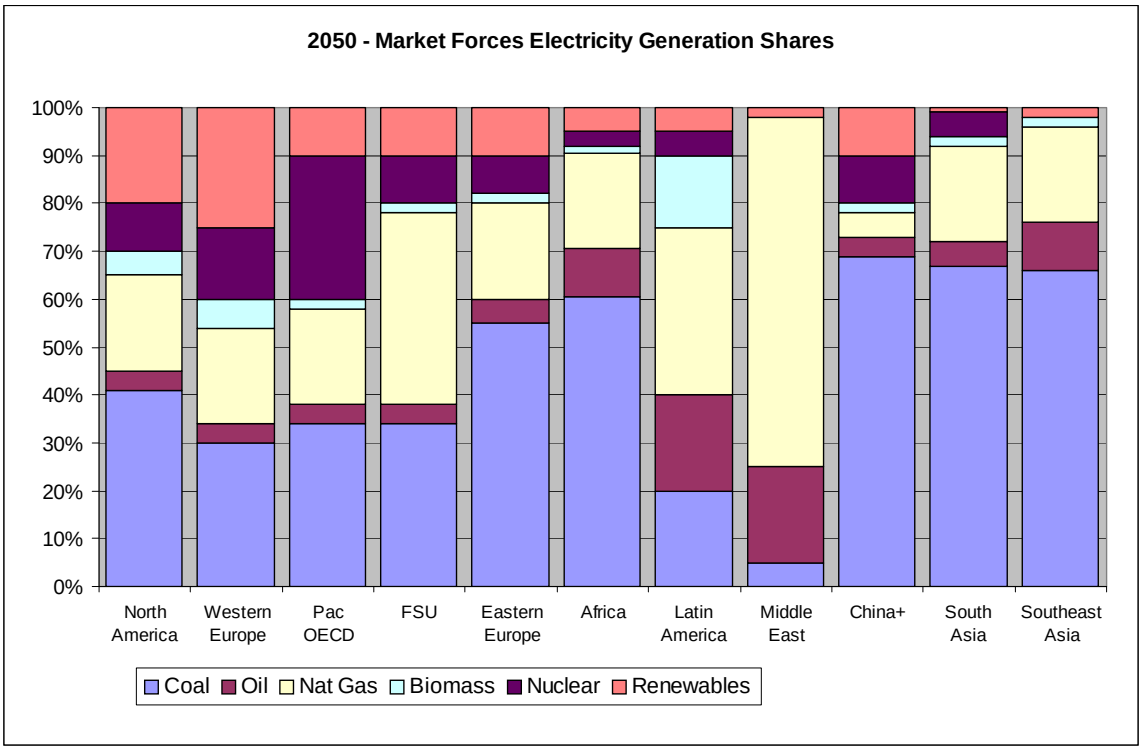
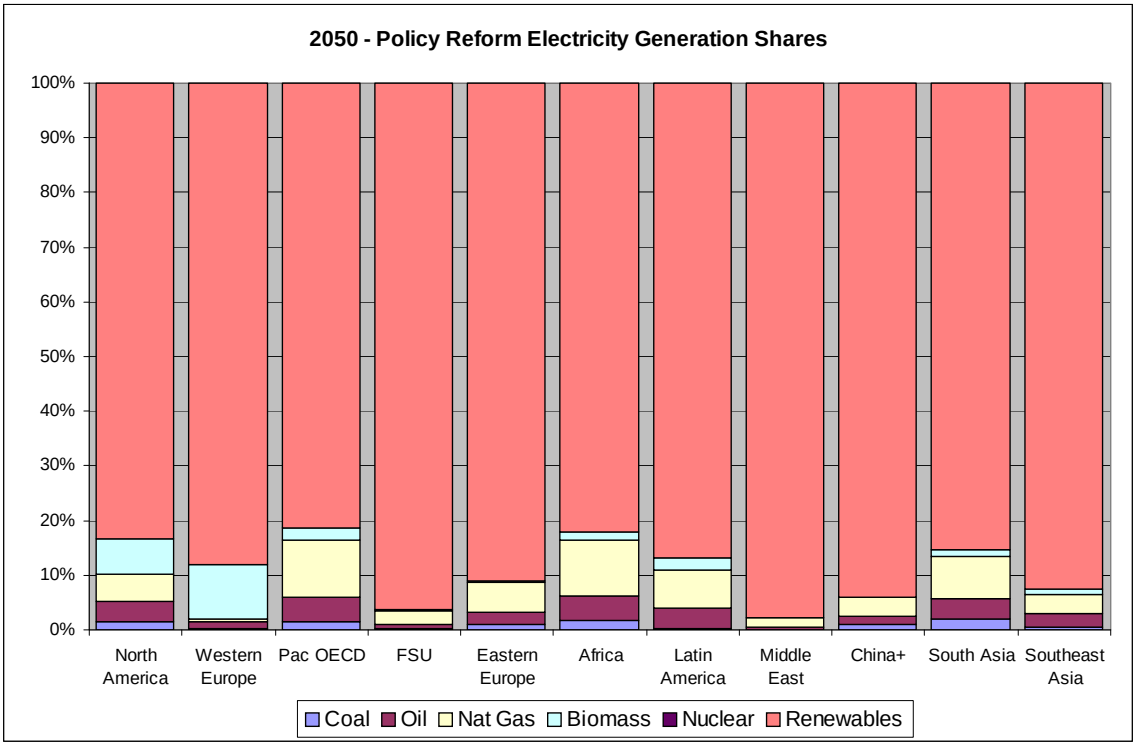


Figure 3-44 Continued. Regional electricity generation shares 2005 and 2050



For this remainder electricity generation, *Market Forces* scenario generation shares are based on a review of a variety of other reports and expert judgment, especially the *Reference* scenario of the Greenpeace Energy [R]evolution study (Greenpeace 2007). Changes in shares reflect both fuel switching within energy conversion sub-sectors (for example, from coal-fired to natural gas plants), and changes in technology. New technologies, with higher efficiencies than those in the base year, are represented by the "New" and "Next Generation" conversion processes for electricity.

In the *Policy Reform* scenario, future electricity generation fuel shares for 2025 and 2050 are governed by a much larger number of assumptions and constraining factors, especially the overall requirement to substantially reduce greenhouse gas emissions relative to the *Market Forces* scenario in order to meet the CO_2 emissions targets input for the *Policy Reform* scenario.

a) First, hydro electric generation is constrained to not exceed the *Market Forces* scenario (for the reasons discussed in Box 3-1). This tends to increase the future share of hydro in the *Policy Reform* scenario in the OECD regions, but to decrease its share in most of the developing countries where overall electricity demand substantially increases.

b) Second, nuclear power is assumed to be completely phased out by the year 2050 in all regions, for reasons related to cost, safety, radioactive waste disposal and

security issues. *Market Forces* scenario trends are assumed to continue at first, with new nuclear plants being added until the year 2010. Thereafter, no new nuclear plants are assumed to be added. For a more detailed review of issues related to the development of nuclear power, see Raskin and Margolis (1995).

c) Third, the market penetration of biomass and other non-hydro renewable electricity forms (solar, wind, municipal solid waste, geothermal, wave and tidal) is assumed to increase dramatically. Assumptions are guided by a review of a number of global and regional scenarios, especially the Greenpeace Energy [R]evolution study (Greenpeace 2007). The penetration of intermittent (non-biomass) renewables in 2050 is substantial, reaching from a minimum of well over 60%, and up to 95%, of electricity generation in all regions.

d) Finally, electric generation shares for the three major fossil fuels (coal, oil and natural gas) are developed. Future fuel shares reflect the increasing scarcity of oil over the study period; the availability of fossil resources in each region; a continuation of the current trend away from coal-fired and oil-fired electricity generation and towards natural gas-fired thermal plants; and the overall requirement to constrain CO_2 emissions in each region to within the portion of the target regional carbon budgets allocated to energy conversion.

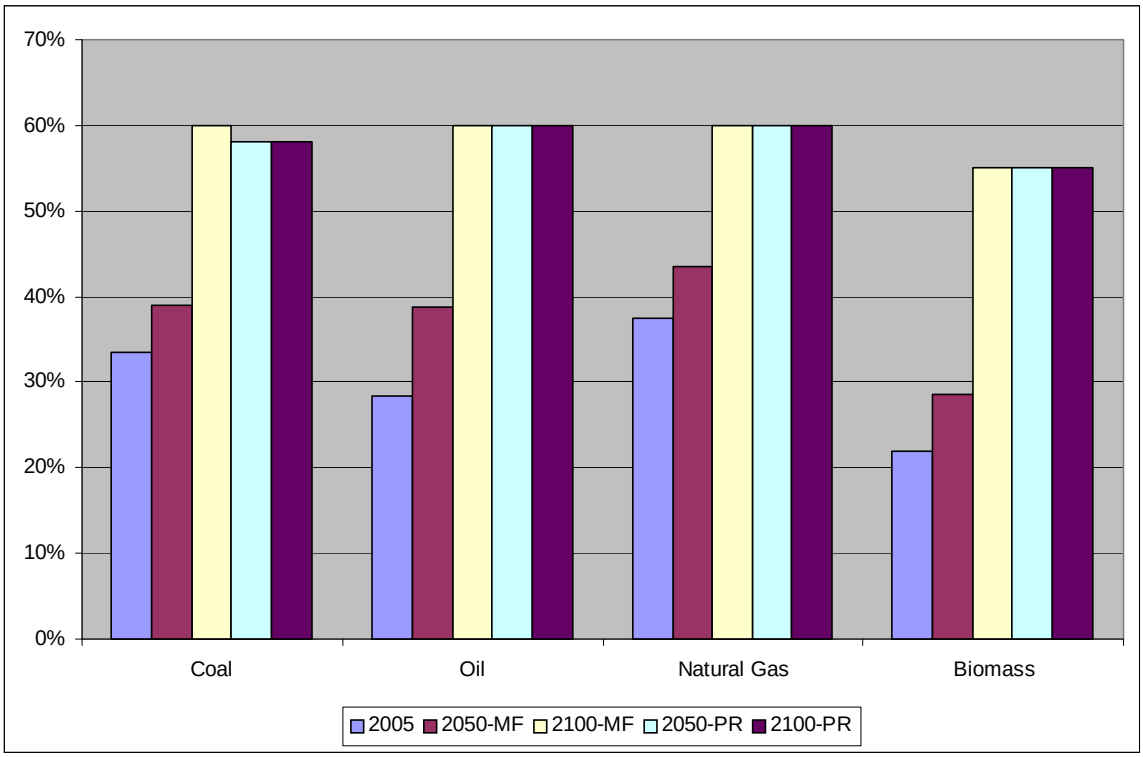
Some amount (5-20%) of electric generation was assumed to be natural gas or oil (#2 oil) fired in each region in order to allow for load following needs of the generation system.

Box 3-1. Hydropower

As an indigenous and renewable energy resource, hydropower offers the benefits of reducing fuel import dependency and air pollution relative to fossil fuel-fired generating options. These benefits are conditional, however. The renewability of hydropower is only approximately correct, since reservoir siltification gradually erodes the resource potential, and the contribution of hydropower to self-reliant development is compromised insofar as the financing and construction of these capital-intensive facilities depend on external hard currency loans and foreign contractors. Beyond issues of engineering feasibility and cost-competitiveness, the construction of large-scale hydroelectric facilities can significantly disrupt local communities and ecosystems. The environmental and social impacts of hydroelectric plants include: the disturbance of the spawning grounds of migratory fish; the flooding of natural habitats, farmlands, and communities; the displacement of populations; the alteration of local hydrological patterns; and risks of catastrophic flooding from dam failure. In recent years, sensitivity to the environmental and social repercussions of large-area flooding for reservoirs has increased amongst energy system planners. Political and social opposition has challenged new dam construction, while international donors have begun to take a tougher look at the full costs of hydropower development (Lenssen, 1992). With many of the best sites already exploited, it seems likely that opposition will increase as new facilities are proposed that carry increased costs - economic, environmental and social. Meanwhile, the expansion of settled areas and farmland as populations and economies grow will encroach on potential hydroelectric sites and raise the stakes and possibility for conflict. These frictions will delimit the expansion of feasible hydroelectric resources to well below the ultimate potential. In this regard, smaller scale hydro facilities may be an attractive alternative to large-scale projects, although there is some indication that the environmental impact per unit of generation does not diminish with decreasing size (Gleick, 1992).

Trends in power plant efficiencies are summarized in Figure 3-45. In the *Market Forces* scenario, the average efficiency of generation plants in all regions reaches values typical of current prototype plants. In the OECD regions, these efficiencies are reached by 2025 as existing plants are retired and new plants are phased in. In other regions, which are lagging in the development of these technologies, it is assumed that these efficiencies are reached by 2050. Thus, the *Policy Reform* scenario assumes a concerted drive to develop and deploy more advanced electric generation technologies, with average electric efficiencies reaching between 55 and 60% in all regions by 2050. Existing technologies, such as combined-cycle thermal plants and integrated coal and biomass gasification are capable of meeting the goals set for the period to 2025 in the *Policy Reform* scenario, while in the longer term, fuel cell technologies may provide even greater improvements by overcoming the inherent thermodynamic limitations of thermal power generation. A similar effect would result from the greatly expanded use of conventional technologies implemented as combined heat and power systems. Such systems are already capable of combined electric and heat efficiencies in excess of 60%. However, this assumes that district heating is capable of being developed much more widely than its current status, a possibility not explicitly modeled in this study. Achieving the high efficiencies of district heating is only possible where there is a demand for a large amount of heat (or steam) near the generating units.

Figure 3-45. Average electric power plant efficiencies



Heat

For district heating and cogeneration, the *Market Forces* scenario assumes the continued dominance of fossil fuels, with little change in overall fuel mixes and efficiencies. The *Policy Reform* scenario assumes efficiency improvements and gradual fuel switching away from coal and oil towards natural gas and biomass, in accordance with the overall decarbonization trends of the scenario.

Primary Energy Production

Primary energy supplies in a given year include the key natural resources in a given region (fossil fuels, uranium, hydropower, biomass, geothermal, wind and solar), the trade in energy commodities, and net changes in energy stocks. The energy systems of each region are linked through trade in fuel commodities and the interconnection of distribution systems. Primary energy supply in a given region is equal to primary resource production, plus net imports (defined as imports minus exports) plus stock changes. As such, it is a measure of the total primary energy forms needed for all activities in each region (including imports of final energy forms such as electricity). Thus, the primary production includes both non-renewable natural resources (e.g., oil and

gas extraction, coal mining, uranium mining) and renewable, or potentially renewable, resources (e.g., direct solar, wind, hydropower, and biomass). Summing over regions, in principle, net imports should add to zero (since each unit of export from one region corresponds to an import in another).

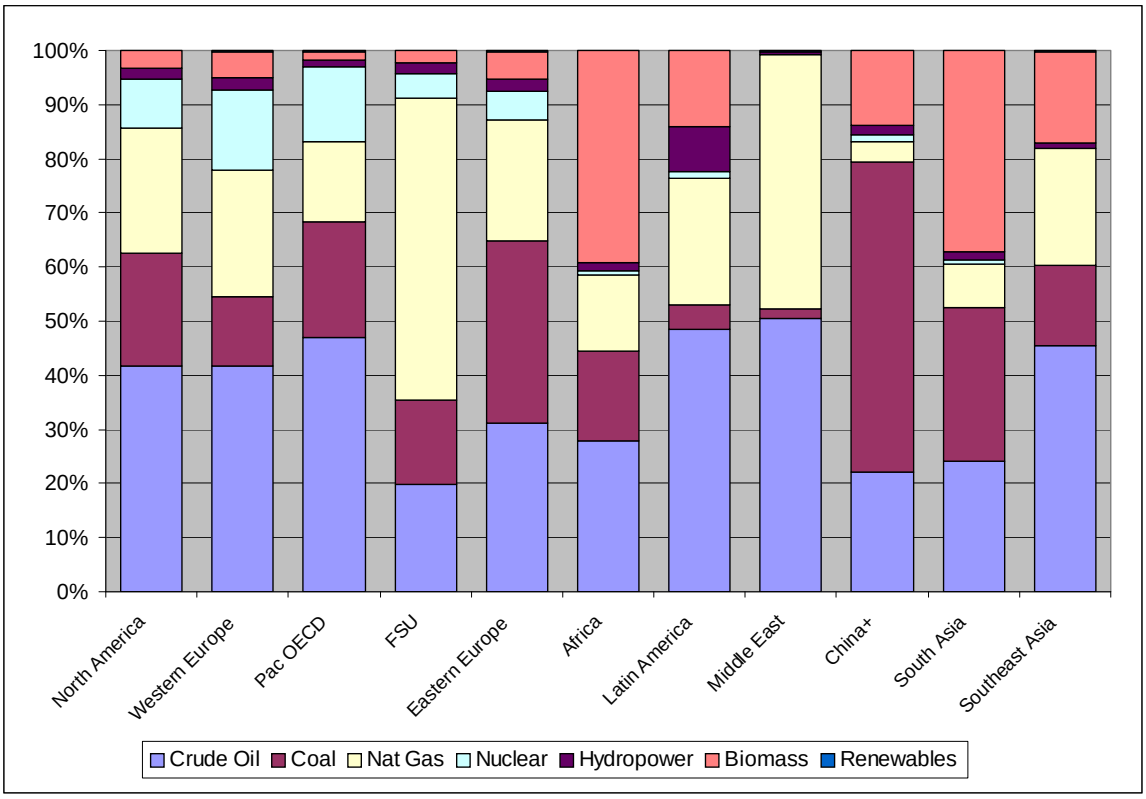
Current Accounts

Current global primary energy use is about 390 EJ per year. The energy mix is dominated by fossil fuels which account for 81% of global primary energy supplies. Fossil fuels include crude oil (38%), coal (22%) and natural gas (20%), which along with uranium (6%) and hydropower (2%) comprise the major *modern* energy sources. The other major primary energy source is biomass, which contributes 10% of global energy requirements. Biomass sources are dominated by the so-called *traditional* energy sources used in developing countries, such as wood for cooking, wood for charcoal kilns, dung and agricultural waste. Biomass statistics are quite uncertain, since the trade in these sources lies largely outside formal markets, where more reliable transaction statistics are available.

There are substantial differences across regions in the mix of primary energy sources, as shown in Figure 3-46. For example, coal provides the largest share of primary energy in Eastern Europe and China+, while crude oil is dominant in Latin America and the Middle East. It is also worth underscoring the significant role played by biomass in Africa, Latin America, South and Southeast Asia and China+, accounting for between 18% and 46% of total primary energy.

Since energy supplies are derived from either indigenous resources, or from imports from other regions, the natural resource endowment is a critical factor defining a region's potential economic development potential. Energy-dependent countries must devote foreign exchange earnings to cover essential energy imports for development and are vulnerable to the price fluctuations and interruptions in international energy markets. By contrast, those areas with substantial energy resources, such as the Middle East, command considerable geopolitical influence, but as exporters are also vulnerable to price fluctuations in the global market for oil. Currently, we have not implemented the flows of imports and exports by region in the model; we only model net imports between the collective set of importing regions and exporting regions.

Figure 3-46. Primary energy supply shares by region – 2005



Note: Excludes electricity imports and exports

Trade patterns correspond directly to the availability of exploited reserves. Mineral statistics are generally organized into the categories of *resources*, which are estimates of all physical deposits, and *reserves*, that proportion of resources which is considered economically exploitable. The latter is in turn composed of proven reserves, which can be commercially exploited under today's technological and economic conditions, and estimated additional reserves recoverable, which are estimated to be recoverable (with reasonable certainty) given current geological and engineering information. Fossil fuel and nuclear reserves, including both proven and additional, are gathered in Table 3-15.

Table 3-15. Proven reserves

Energy Content in EJ	Coal	Crude Oil	Nat Gas	Uranium
North America	7470	243	300	232
Western Europe	369	88	184	17
Pac OECD	2331	10	33	252
FSU	6780	687	2316	265
Eastern Europe	618	13	13	7
Africa	1491	704	564	225
Latin America	525	687	296	57
Middle East	44	4060	2872	10
China+	3450	110	112	30
South Asia	1755	35	94	13
Southeast Asia	180	49	276	0
World	25013	6686	7060	1109
OECD	10170	341	518	501
Transitional	7398	700	2329	272
Developing	7445	5646	4213	336

Source: Survey of Energy Resources (WEC, 2007). Data for uranium are converted from mass to energy units assuming 1 tonne of uranium = 336 TJ, a figure appropriate for conventional open-cycle reactors. If fast-breeder reactors are assumed, the resource estimate increases by a factor of about 60.

A crude measure of the sufficiency of global energy reserves is obtained by dividing world reserves by the current annual consumption – about 112 EJ for coal, 171 EJ for crude oil, 105 EJ for natural gas, and 31 EJ for uranium. If current patterns were to continue, the reserves reported in Table 3-15 would satisfy several decades of requirements for oil, natural gas and uranium, and more than two centuries of coal use. However, growing energy demands, environmental pressures and geopolitical concerns would constrain the abundance of these resources substantially, as we shall discuss in the next section, implying the maximum or peak year of production for any given fuel is probably more significant than the total numbers of years of current consumption that might be available. In particular, most oil industry analysts now believe that peak oil production will occur within the next few years under a *Market Forces* type scenario.

Scenarios

Methodology

Global primary energy requirements by macro-region are shown in Figure 3-47. In the *Market Forces* scenario they grow at an annual average rate of about 1% per year from 480 EJ in 2005 to over 1200 EJ in 2100. A particularly rapid expansion is seen in the non-OECD regions, where primary energy use more than triples from 253 EJ in 2005 (just over half the global total) to 956 EJ in 2100 – accounting for nearly 80% of the global total. By 2100, China+ followed closely by South Asia greatly surpass North America as the largest users of primary energy by more than 70 EJ. Fossil fuels continue to dominate, accounting for 86% of global primary energy supply in 2050 compared to 82% in 2005. Nevertheless, over the same period there is significant absolute expansion in all fuels, particularly natural gas and renewable energy forms (which increase by a factor of nearly 50 albeit from a very low base of only 0.4 EJ in 2005). Figure 3-48 below shows total global primary energy requirements by fuel type.

In the *Policy Reform* scenario, the annual average rate of growth in global primary energy requirements is only 0.26% per year from 2005 to 2100, with global primary energy requirements reaching about 600 EJ in 2050. Fossil fuels no longer dominate, with their share falling to only about 28% of global primary energy supply in 2050, and their elimination completely by 2100. Primary energy requirements fall in the OECD regions to 47% of their 2005 values, while demand in the non-OECD regions doubles, reaching about 500 EJ – 82% of the total energy supply in 2100. The changing mix of primary energy requirements is also noteworthy. By 2050, the total requirements for coal decrease to about 18% of the 2005 value – reflecting the desperate need to find less carbon-intensive fuels to help meet greenhouse gas mitigation targets. However, because of its dominance in the transport sector, reducing oil consumption proves more difficult. Nevertheless, by 2050, global oil consumption declines to less than 35% of the 2005 value. By 2050, natural gas consumption declines to less than 65% of the 2005 value. However, all carbon-emitting fuels are phased out completely by 2100. In contrast, carbon-neutral forms of energy grow rapidly, with hydropower resources more than doubling, and biomass resources more than tripling by 2100. Renewable energy forms grow extremely rapidly in the *Policy Reform* scenario to nearly 700% of the 2005 value by 2050, representing 443 EJ, compared to the 0.4 EJ in 2005 (See Figure 3-48).

Figure 3-47. Global primary energy requirements by macro-region (includes renewables)

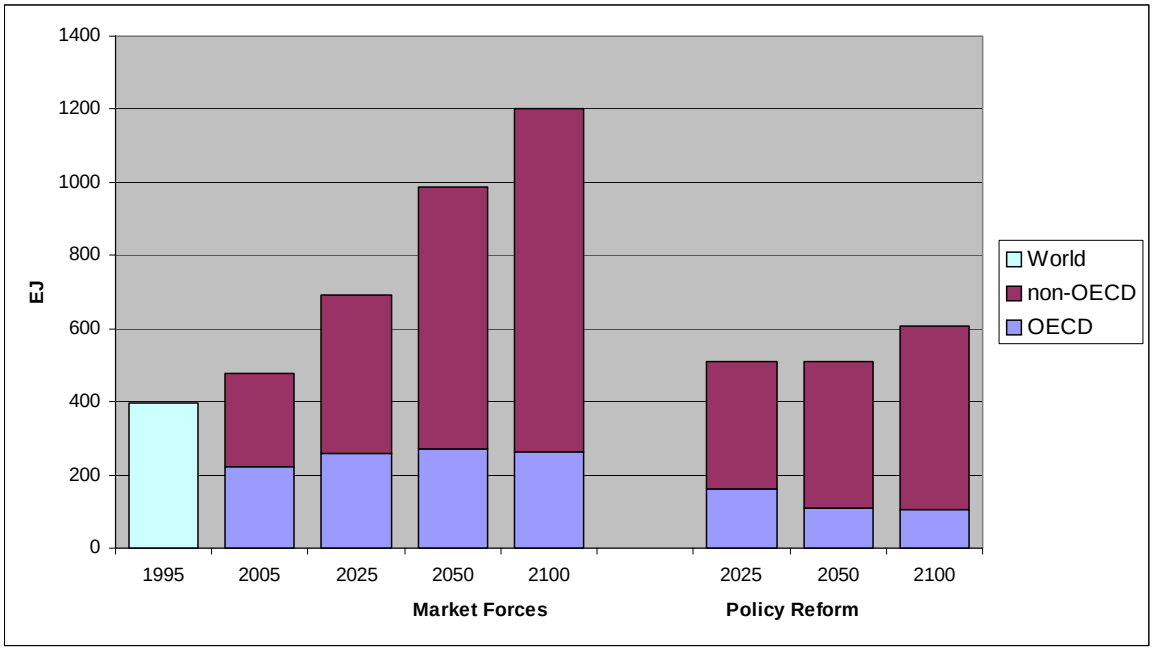
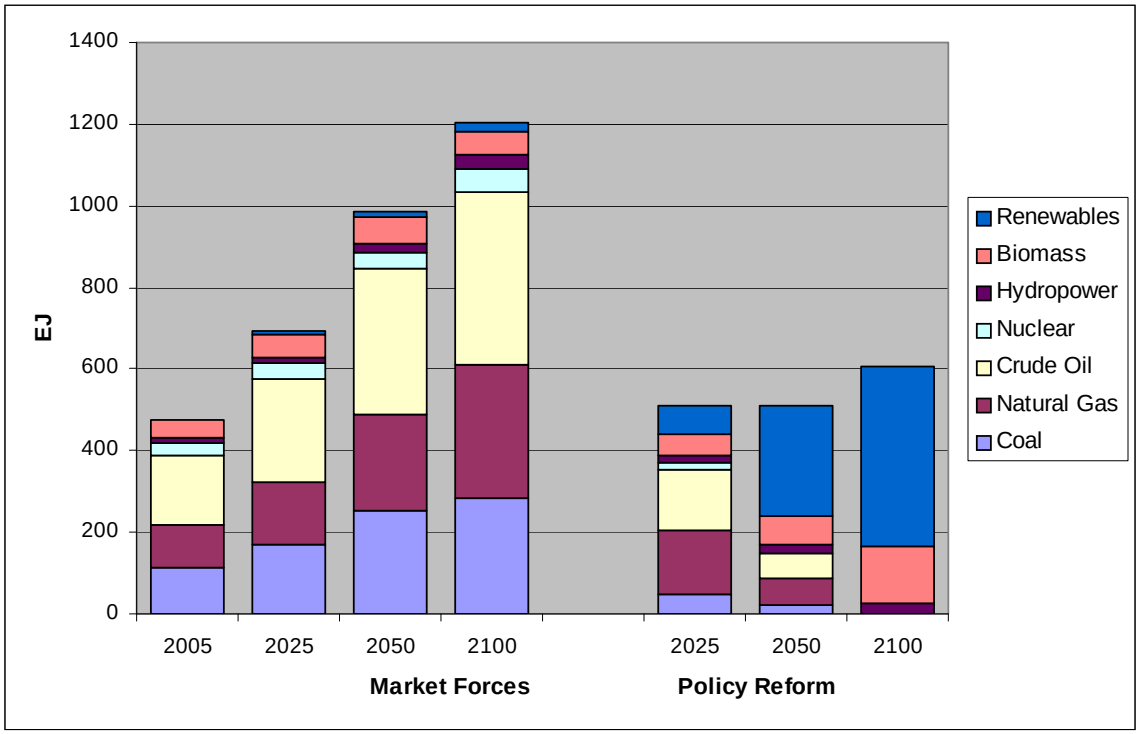


Figure 3-48. Global primary energy requirements by primary fuel



Energy Resources

Additions to proven reserves of crude oil no longer continue to keep pace with increases in demand. Thus, the long-term outlook for conventional crude oil resources is less comforting than it was in recent decades. Estimates of ultimately recoverable reserves – the total of previously extracted, proven and undiscovered recoverable reserves– have not increased greatly since the 1960s (Masters et al., 1990). Rather, estimated additional reserves have been gradually reclassified as *proven* reserves.

Remaining proven oil reserves are approximately 1200 billion barrels (WEC, 2007; BP, 2007). Our scenarios do not currently account for unproven reserves. As the demand for oil grows in both scenarios, these reserves would be depleted around 2039 (Figure 3-49). However, according to standard theories of oil exploitation, production decreases may occur much sooner, perhaps as early as 2010 when *half* of the global resource will have been extracted. There are many studies stating that we have already reached "peak oil", or are about to within the next few years. These theories were first exploited in 1956 by M. King Hubbert to correctly predict that oil production from the lower 48 American states would peak around 1970 (Hubbert, 1956). According to the theory, adding the output of fields in a large region usually produces a bell-shaped curve that predicts crude oil production over time. While this simple production-based model does not take economic or political factors affecting consumption into account, its empirical approach does embody long-run technical improvements in extraction technologies (Mackenzie, 1996).

Table 3-16. Year when resource will be depleted

	Approximate year in which resource will run out	
Fuel	*Market Forces*	*Policy Reform**
Coal	2099	3933
Natural Gas	2053	2070
Crude Oil	2039	2055
Uranium	2046	2135

* All values are approximate. In *Policy Reform*, coal, natural gas and crude oil use is eliminated by 2100, but the annual requirements from the 2050 and 2100 scenario years are used to estimate the cumulative production over that time period to estimate the year resource will theoretically run out. For uranium, the resource is phased out by 2050, so the year shown reflects the annual demand from 2025. Theoretically, if the resource is not being used, it will last indefinitely.

Table 3-16 shows the scenario estimates of when resources will be depleted, based on the annual requirements in the last year the resource is consumed. This does not take into

account the rate at which the resources, particularly the crude oil, will be able to be accessed and extracted out of the ground.

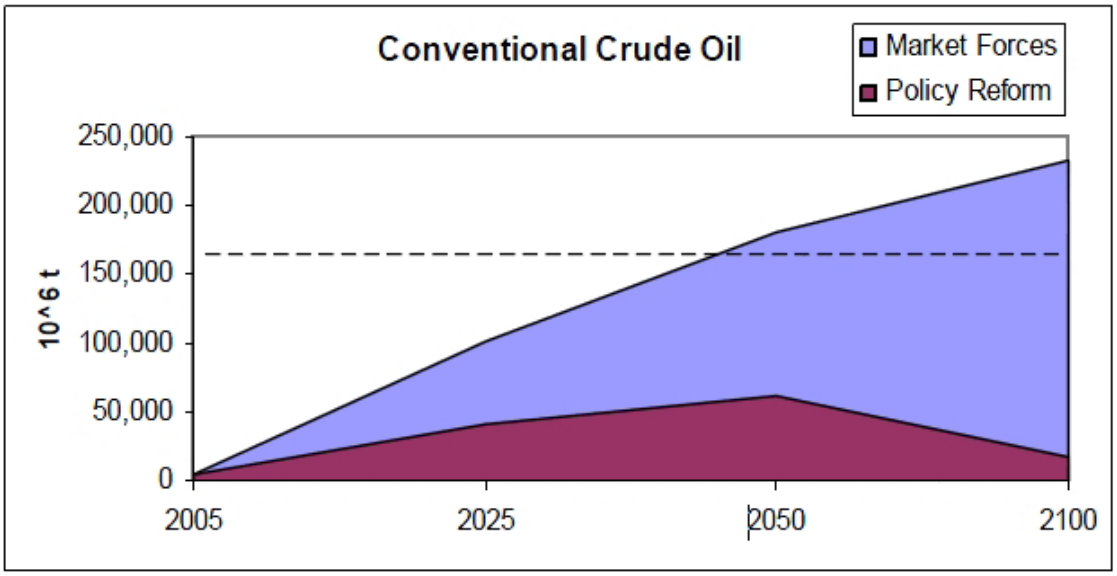
Figure 3-49 compares the global fossil fuel and uranium reserves to the requirements in both *Conventional Worlds* scenarios. (Note the dotted line represents the proven reserves of each resource). Recall that in the *Market Forces* scenario, annual crude oil requirements continue to grow enormously over the whole study period – increasing by nearly a factor of 1.2 by 2100. In the *Policy Reform* scenario, annual requirements begin to decline by 2025, being phased out by 2100.

In practice, the gap between oil supply and demand is likely to be closed in a number of ways: supply might be increased by more discoveries of conventional sources than currently anticipated, though this is not likely, or by unconventional options such as tar sands and oil shale. However, exploitation of these unconventional resources is likely to pose severe environmental problems and to be much more costly than conventional crude. On the demand side, the pressure on oil resources could be curtailed through fuel switching and efficiency improvements – options taken up in the *Policy Reform* scenario. Similarly, renewable and biomass-based substitutes for oil (e.g., hydrogen and ethanol) may gain acceptance more quickly than is assumed in either the *Market Forces* or *Policy Reform* scenario. The evolution of the transport sector will be especially important in this regard. Overall though, in the *Market Forces* scenario, the heightened risk of economic vulnerability and international conflict challenges the continuity and growth assumptions of the scenario.

To a lesser extent, natural gas requirements in the scenario also push against conventional resource constraints. Global proven natural gas reserves, including those that have already been developed, are estimated at about 11 EJ (WEC, 2007; BP, 2007) – roughly 72 trillion cubic meters. In *Market Forces*, proven global reserves are depleted around 2053. In the *Policy Reform* scenario, because of declining use of the resource, natural gas resources would last until 2070. Coal reserves remain abundant, but with increasing demands in the *Market Forces* scenario, are expected to run out in 2099. Environmental concerns restrict the use of coal in the *Policy Reform* scenario until it is completely phased out in 2100, allowing reserves to theoretically last indefinitely.

Beyond global supply and demand relationships, the geopolitics of oil seems set to become a resurgent theme in the *Market Forces* scenario as industrialized regions increasingly depend on imports from the Middle East and Latin America (Swart, 1996). As shown in Figure 3-50, remaining oil reserves are heavily concentrated in the Middle East, Africa, Latin America and FSU. The rest of the world, including all OECD regions, accounts for only about 4.5% of proven and additional oil reserves. Natural gas reserves are heavily concentrated in the FSU and the Middle East, with significant reserves also in Africa, Latin America, Southeast Asia, and North America. Coal reserves are more spread out, but most are found in the regions of North America, FSU, and China+, with a significant amount in Pacific OECD, South Asia, and Africa.

Figure 3-49. Global fossil and uranium reserves compared to requirements



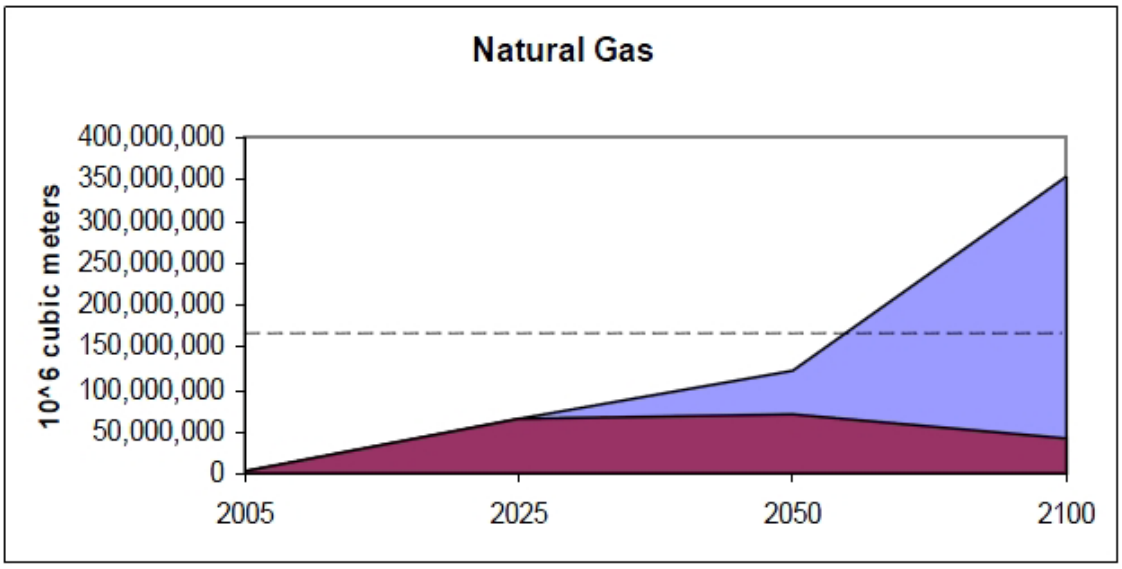


Figure 3-49 Continued. Global fossil and uranium reserves compared to requirements

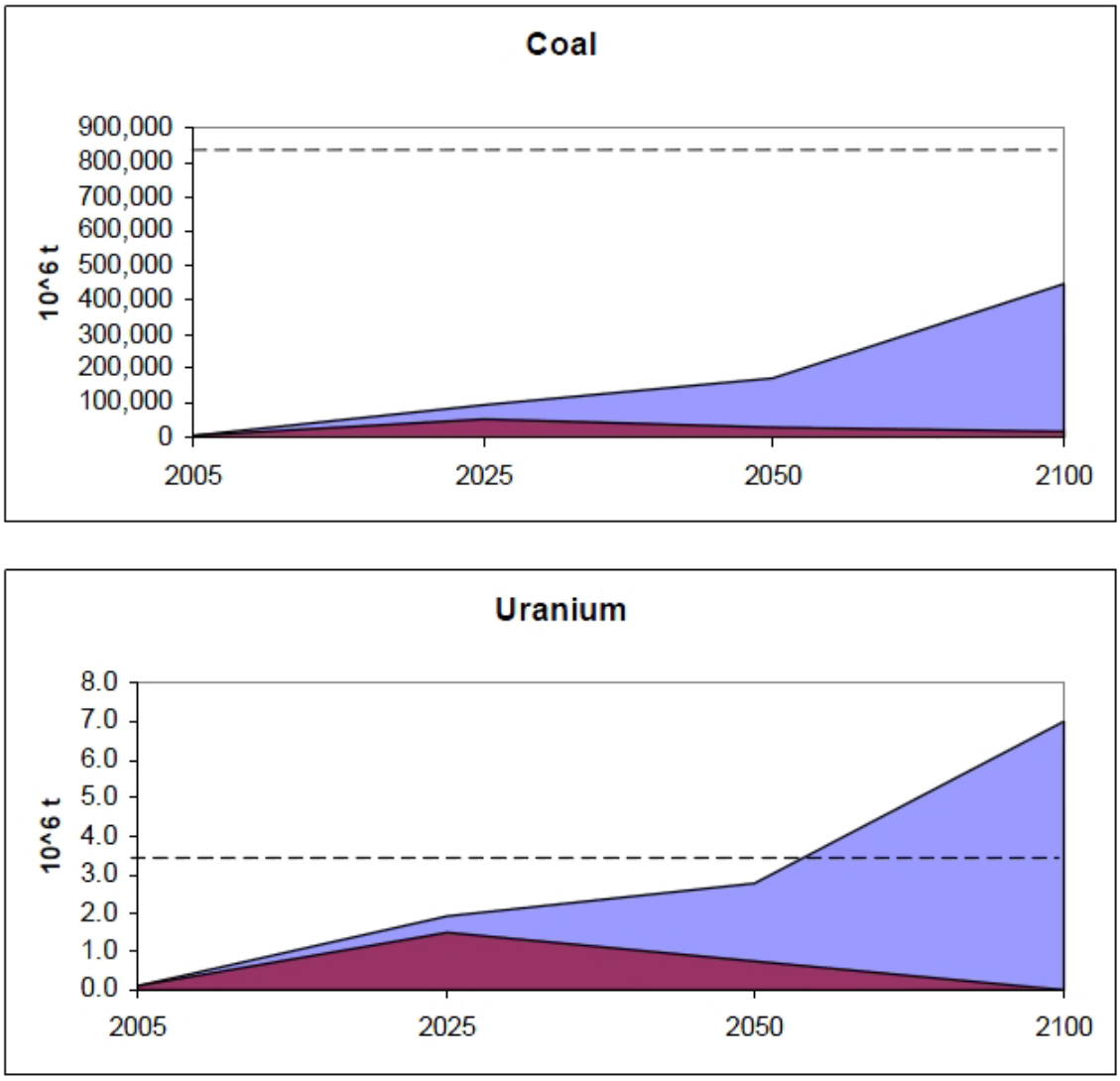
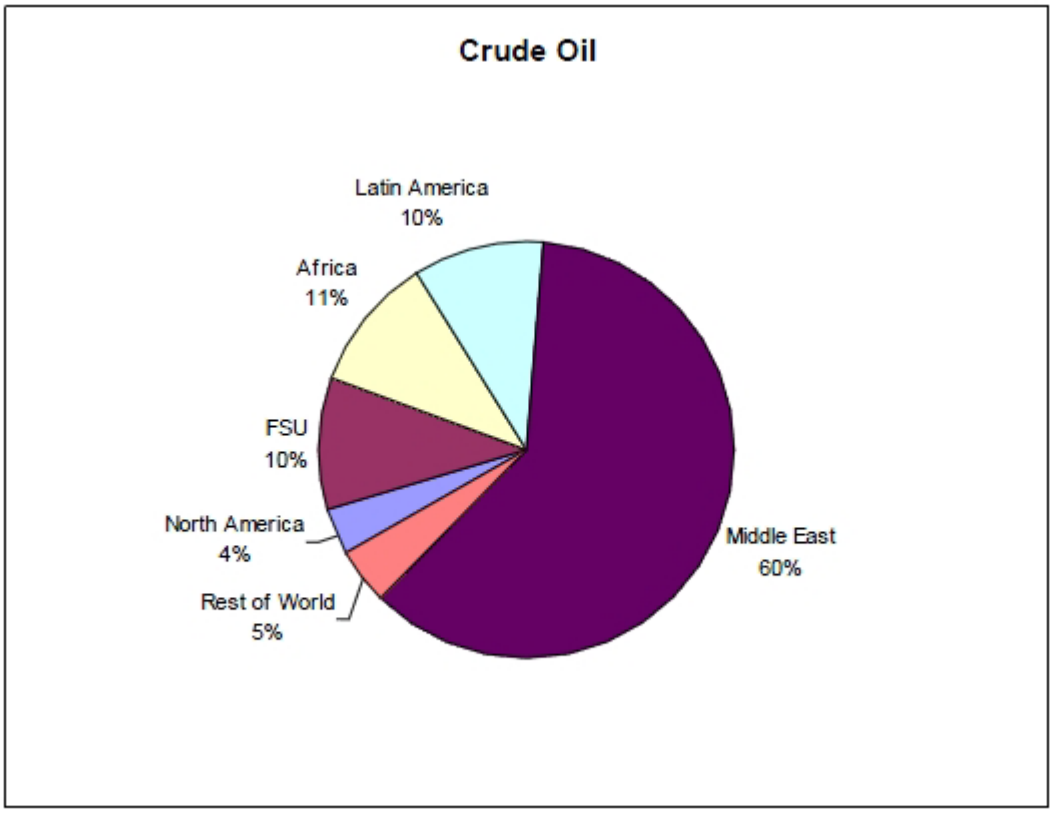


Figure 3-50. Unrecovered reserves of Fossil fuels – 2005


Crude Oil
Latin America
10%
Africa
11%
FSU
10%
North America
4%
Rest of World
5%
Middle East
60%

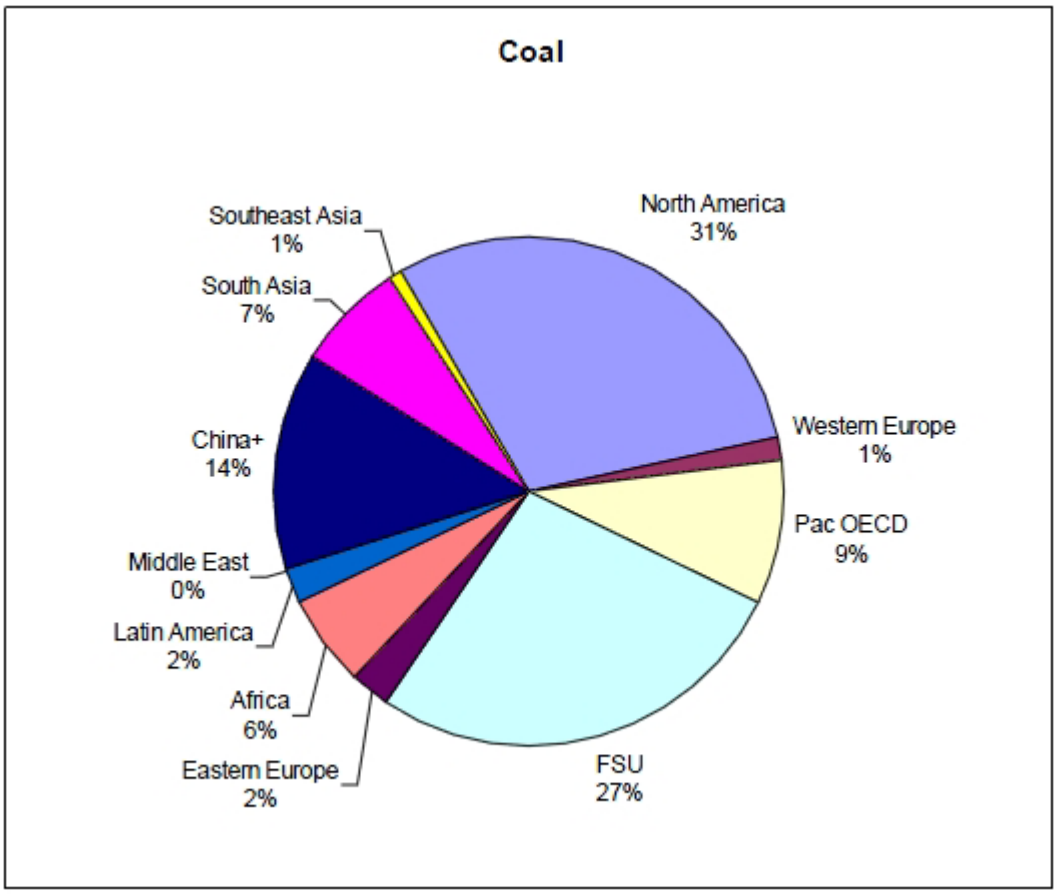
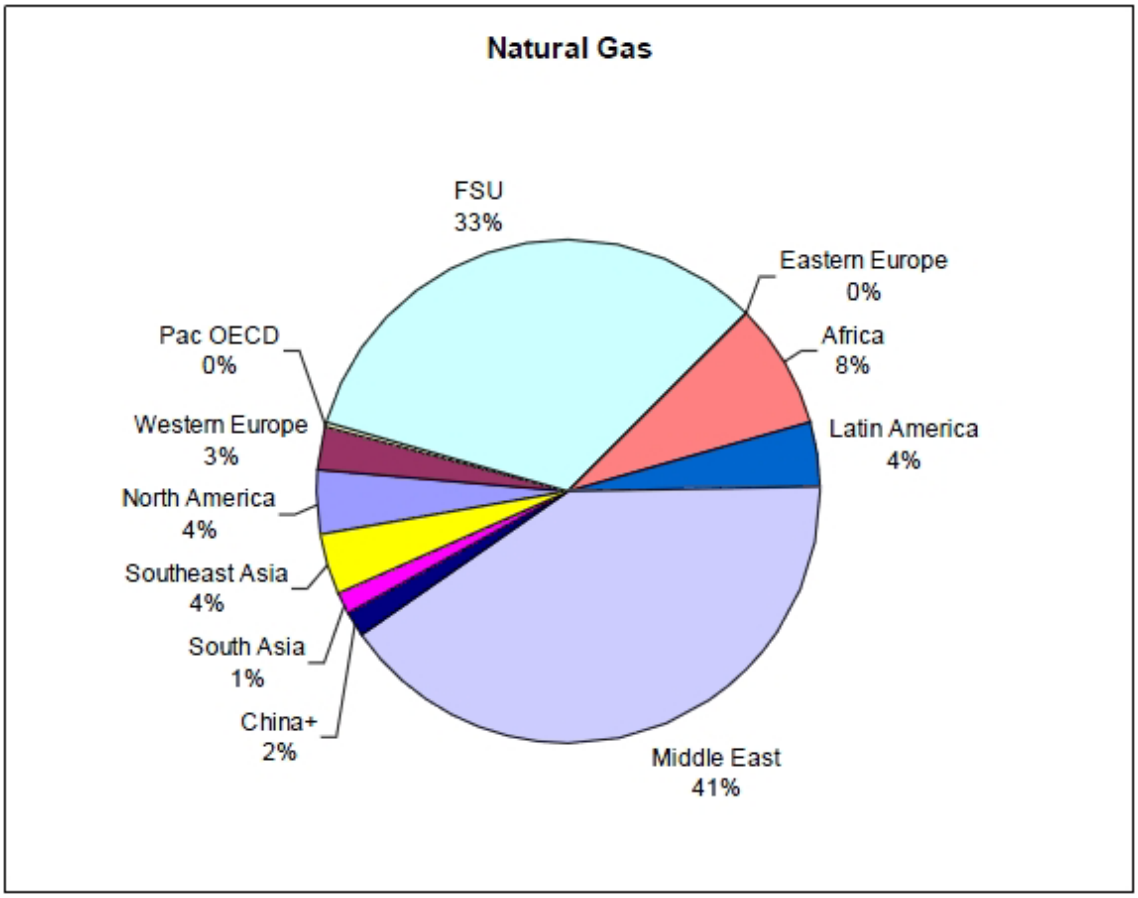

Coal
Southeast Asia
1%
North America
31%
South Asia
7%
Western Europe
1%
China+
14%
Pac OECD
9%
Middle East
0%
Latin America
2%
Africa
6%
Eastern Europe
2%
FSU
27%

Figure 3-50 Continued. Unrecovered reserves of Fossil fuels – 2005

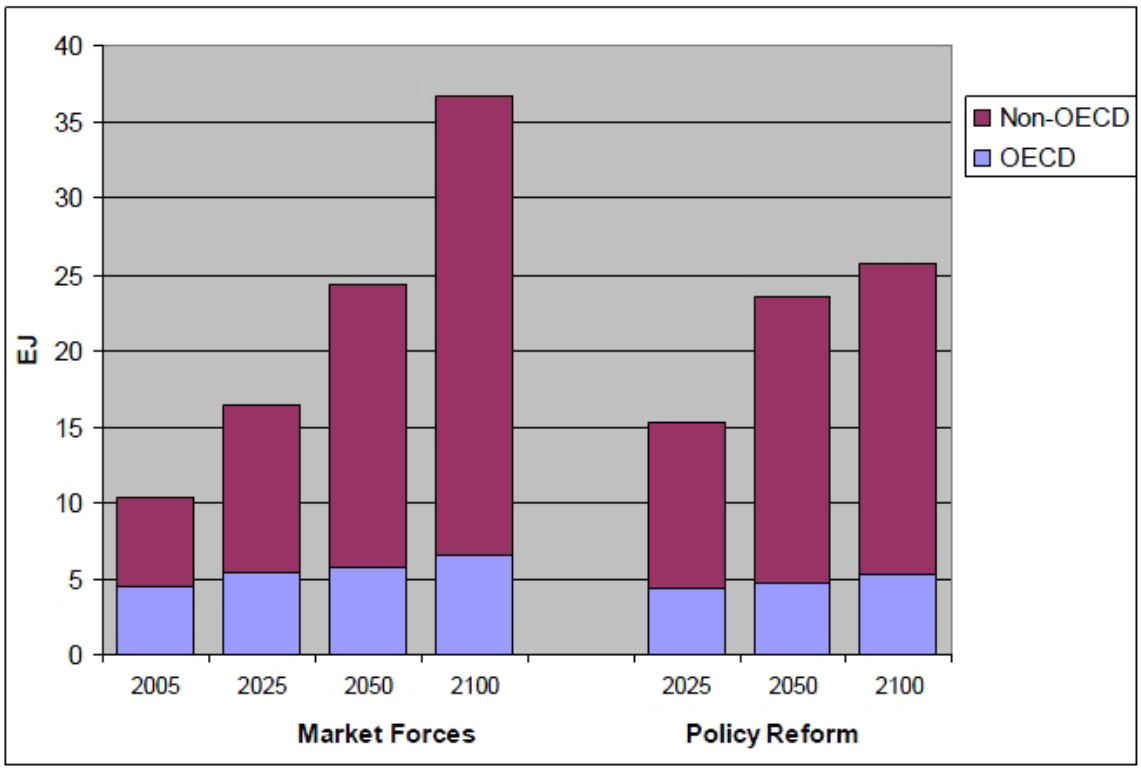


Note: Includes regional shares of proven reserves only. Shares based on physical units (tonnes of coal, barrels of oil, m^3 of natural gas) rather than energy content.

Hydropower

Annual hydroelectric power production increases globally from about 10 EJ in 2005 to over to 36 EJ in 2100, in *Market Forces*, and to about 26 EJ in *Policy Reform*. This level of output is well below the gross theoretical capability, which is estimated to be 145 EJ/year (WEC, 2007). In both scenarios, hydropower development has been explicitly limited to reflect at least partial avoidance of more environmentally and socially detrimental hydro projects. This stipulation strongly limits hydropower development in the OECD, where hydropower generation increases by 0.9% per year over the period 2005 to 2100 in the *Market Forces* scenario, and by 0.7% per year in the *Policy Reform* scenario. In the non-OECD regions, hydropower generation is able to expand by a factor of over 5 in the *Market Forces* scenario and by a factor of 3.5 in the *Policy Reform* scenario, compared to the 2005 value (See Figure 3-51).

Figure 3-51. Hydropower production by macro-region



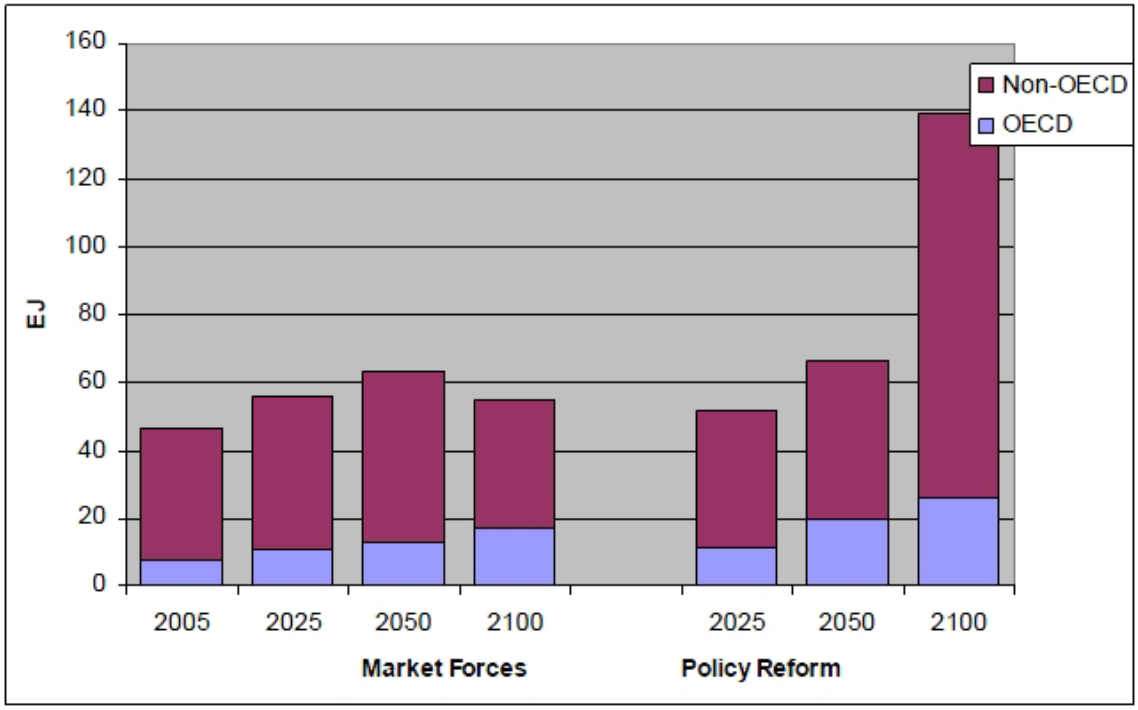
Traditional Biomass Fuels

The debate about the "woodfuel crisis" has progressed since the early 1980s when woodfuel consumption was thought to be leading to large-scale deforestation in Africa and other regions. Since then, most experts have come to agree that traditional woodfuel consumption is not the major cause of deforestation in most parts of the world. Land clearing for agriculture and logging are now seen as the most common culprits of deforestation (see, for example, O'Keefe et al., 1984; Leach and Mearns, 1988; Munslow et al., 1988; Heaps et al., 1993). Nevertheless, issues of resource sufficiency, rural economic development and environmental stress remain important when considering traditional fuel scenarios.

While a lack of good data on consumption, collection, and resources makes the issue hard to quantify, there are known to be many areas of woodfuel shortage today. Indicators of shortage are increasing wood collection distances by rural householders (generally women and children), the substitution of animal dung and agricultural waste for woodfuel, and actions by rural people to either use wood more efficiently or plant trees. In the *Market Forces* scenario, there is a gradual transition away from traditional biomass fuels as incomes improve and people move up the "energy ladder" to cleaner and more convenient fuels. However, this effect is counteracted by the high rate of population growth so that actual levels of biomass demand goes from 46 EJ in 2005 to 50 EJ in 2050, then down to 38 EJ in 2100. In the *Policy Reform* scenario, focused actions to

reduce poverty also tend to reduce traditional household biomass consumption. These declines in traditional biomass consumption are more than offset by the large increases in biomass consumption and production for "modern" uses such as electricity generation and production of transportation fuels. These "modern" forms of biomass are assumed to be grown sustainably, however they do contribute to pressures on agricultural and forestry lands. In *Policy Reform*, biomass is used increasingly as an industrial feedstock (as an alternative to petroleum based feedstocks), as well as for the production of ethanol (via sugarcane and cellulose) so that the total rises to 140 EJ in 2100. (See Figure 3-52).

Figure 3-52. Global requirements for all biomass for fuel and feedstocks



4 Agriculture and Food

A recurrent question about the future is whether increases in food production will be able to keep pace with the growing requirements of an expanding population consistent with constraints on land use. Addressing this question is complex, as it involves both technical issues regarding the potential for raising agricultural productivity, and social issues regarding diets and competing land uses.

The historical record of increases in agricultural output holds many positive developments. To take one recent example, the remarkable growth in yields accomplished by the "Green Revolution" was realized in part because of surprising and fortuitous interactions between what had originally seemed to be unrelated agricultural advances (Evans, 1998). However, the Green Revolution offers sobering lessons as well. Some of these concern the strategies pursued for raising crop yields. Much of the growth in crop production in the Green Revolution resulted from a shift in the distribution of biomass in the crops – more growth in the seeds in cereals, for example, rather than growth in leaves and stems – while overall production of plant matter changed little. Thus, there are limits to the ability of the Green Revolution strategies to continue raising crop yields. Perhaps as a result, recently growth in production has shown signs of slowing for some crops and some regions (Conway, 1997; Brown et al., 1997; Pinstrup-Anderson et al., 1997). Moreover, the strong response of Green Revolution crops to inputs of irrigation water, fertilizer and pesticides have led to large increases in the use of those inputs, often with negative environmental implications.

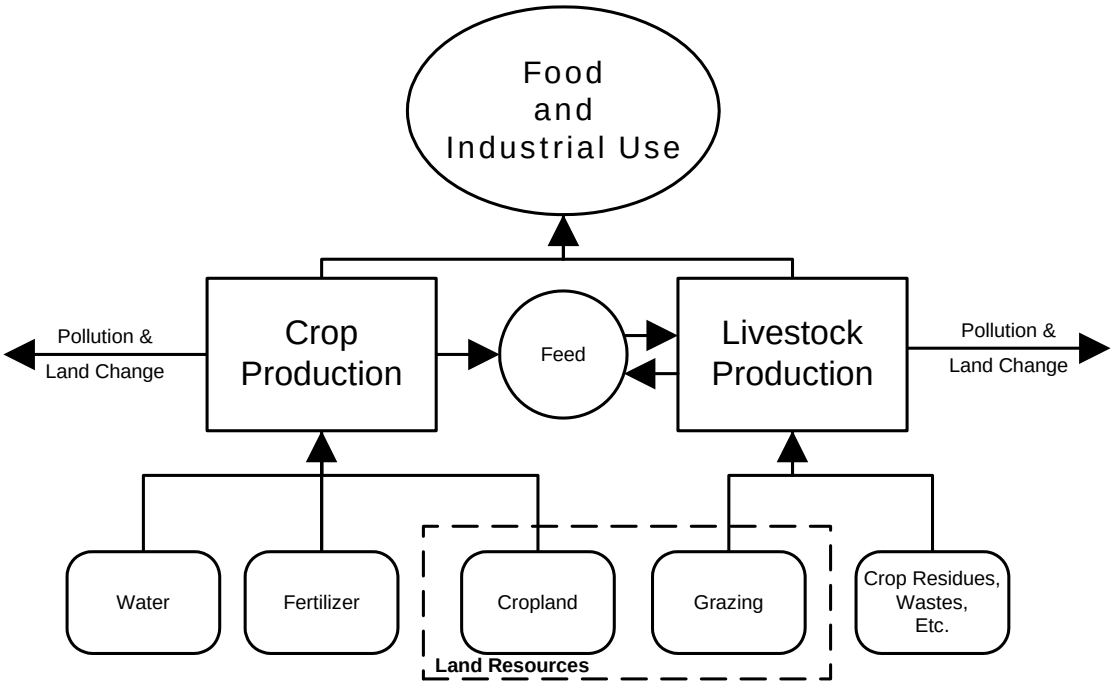
Also of concern is the geographic distribution of the benefits of the new crop varieties. While the Green Revolution efforts undoubtedly enabled the world to avoid severe food shortages in developing countries – with the percentage of the population that was hungry dropping from 35% in 1970 to 20% by 1991, and to about 14% in 2005,[4] despite a 76% increase in population between 1970 and 2005 (UN, 2006a) – nevertheless, the general improvement masks considerable differences between regions. In the effort to increase global production, agricultural research initially focused on improving yields on the best land (Conway, 1997). As a result of both the research focus and regionally distinct agricultural policies, gains were concentrated in the "Green Revolution Lands" of South and East Asia, West Asia, North Africa and Latin America. People in less well-endowed countries, especially in Sub-Saharan Africa, and poorer people in better-endowed countries working poor and marginal lands, experienced much smaller productivity increases. Moreover, problems of food distribution remain, and in 2005 nearly 900 million people were hungry (discussed in Chapter 2, page 29).

[4] Base year hunger results for 2005.

Faced with a likely 30% to 40% increase in world population between 2005 and 2100, invoking past experience alone will not lay to rest the crucial question of whether agricultural production will be sufficient to feed the world. A detailed analysis of these issues is required.

Our analysis of agricultural production starts with human dietary and industrial demands for agricultural products, and then it translates these demands into requirements for land, seed, water and nutrient (nitrogen) inputs. The conceptual connections between agricultural production systems and human dietary requirements as represented in this analysis are illustrated in Figure 4-1 below. Agricultural products are separated into crops and animal products. Both crops and animal products are consumed for food and feed; in addition, some agricultural products are used as fuel, or as industrial feedstocks. As illustrated by the input of water to crop production in the figure, crops can be grown on irrigated, as well as rainfed, land. Livestock can be grazed, fed on grain or fodder, or fed crop residues, wastes and other informal sources.

Figure 4-1. Structure of agricultural production system

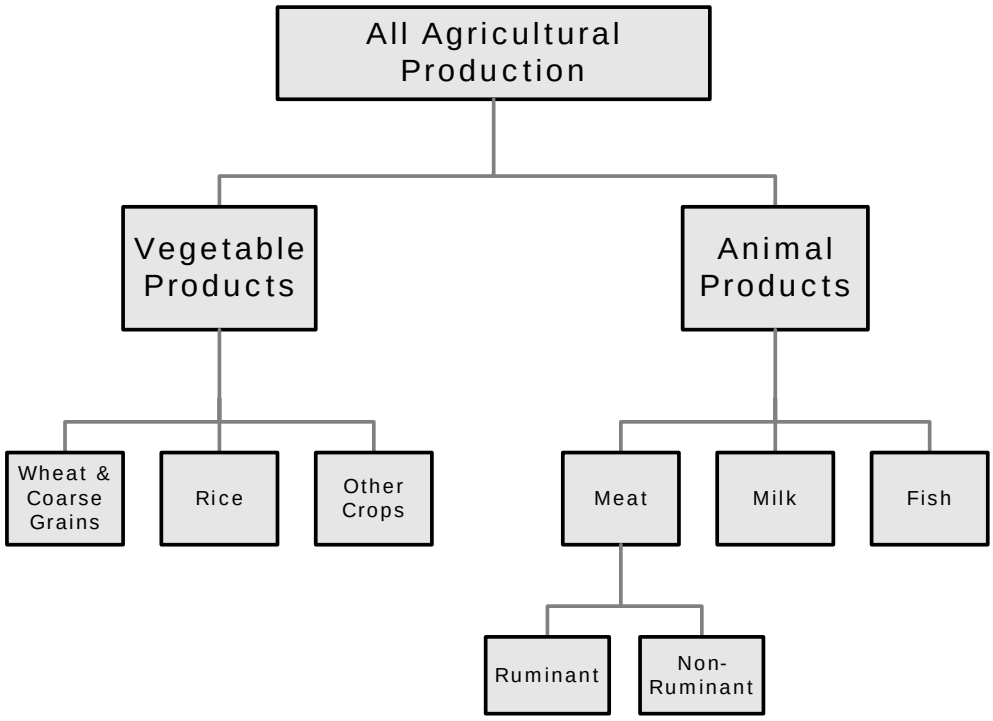


The data and scenarios presented in this section draw on several sources, notably the FAOSTAT database (FAO, 2007a); the FAO scenarios from two reports, *Agriculture Toward 2015/2030* (FAO, 2000a) and World Agriculture Towards 2030/2050 (FAO 2006). These major sources are supplemented by additional data collections and studies, as noted in the text.

Demand for Agricultural Products

Agricultural products are grouped into seven aggregate categories – three plant crop products and four animal products – as shown in Figure 4-2. Data for 2005 on agricultural production, consumption and trade are drawn from the FAOSTAT database (FAO, 2007a). However, care should be exercised when comparing figures from this report with figures in the FAOSTAT database. In FAOSTAT, data for similar commodities are sometimes expressed in incompatible terms. For example, in some cases weights of rice may be given with the hull on the grain or removed, and oils, alcoholic beverages and other processed foods may be expressed in terms of the final product or in terms of the primary raw material. Here, commodity weights are reported in "primary equivalent" terms – that is, they are expressed in terms of the raw material. For example, trade in processed vegetable oils is put in terms of the equivalent amount of the oil crop from which the oil was produced.

Figure 4-2. Commodity groupings used for the scenario analysis



Crop Commodities

The crop groupings emphasize the importance of the cereal crops, represented by the commodity groupings "wheat & coarse grains" and "rice." The cereal staples form the basis for the food and feed supply in nearly every region of the world. While in some areas in Latin America and Sub-Saharan Africa root crops are the staple source of starch, even in those regions the cereals play an important role in diets and agricultural production. Among cereals, rice is considered separately here, because of the unique importance of the crop in some parts of the world, especially in Asia.

Non-cereal crops are grouped into an aggregate "other crop" category. This is a very inhomogeneous group, including root crops and tubers, sugar crops, oilcrops, fruits and vegetables, coffee, etc. Yields and energy contents per kilogram vary considerably within this group, much more than between different types of grain. The differences arise largely because of the different characteristics of the harvested part of the plant. For example, the water stored in vegetables and root crops substantially increases the weight of the harvested material, without adding to the caloric content. As a consequence, while the weight of "other crops" harvested per hectare often exceeds that of cereals, the food energy per hectare is often less than that of cereals.

Livestock Commodities

Again, the livestock commodities are grouped into four categories, as shown in Figure 4-2. The first is ruminant livestock raised for meat. Ruminant animals are those that can digest grasses, such as cattle, goats and sheep. The second category is non-ruminant (monogastric) livestock, such as pigs and poultry, which are typically fed grain or food waste. The third and fourth categories are milk and fish.

Both the limitations of the FAOSTAT data, and the limitations of an aggregate analysis, require some simplification in the composition of these categories. Consequently, the "Fish" category includes all seafood, "Milk" also includes milk products, such as butter, cheese, and ghee, and production from non-ruminant livestock also includes some livestock products that are not associated in the FAOSTAT database with a particular animal, such as animal fats.

Non-Food Uses of Agricultural Products

With the important exception of energy crops, the focus of this analysis of agriculture is on the use of agricultural products as food and feed. In addition to these dominant uses, crop and livestock products are used as industrial feedstocks, such as latex for rubber, cotton for fabric, animal hide and hair for leather and wool, etc. Also, in many cases some of the agricultural product is used for the next growing cycle. For example, some of the harvest from crops must be retained as seed for the next season's planting (unless seeds are purchased, as they must be for some hybrid varieties: see Conway, 1997; Krishnamoorthy, 1983), and some eggs are retained for hatching. Added to all of the requirements are the inevitable losses between the farm and market, and from market to mouth. Each of the uses – industrial consumption, seed requirements and losses – are typically less than 10% of total requirements in the base year. In the analysis, these uses increase in proportion to overall production.

Requirements for sugarcane for fuel are derived from the demand for fuel alcohol calculated as part of the energy scenarios (see Chapter 3, page 33). In the base year 2005, Latin America is the only region with a significant use of sugarcane as an energy crop, and this is assumed to be true in the scenarios as well. Other energy crops that may become important for alcohol production in the future are perennial grasses and tree crops. These alternative sources are discussed in Chapter 3.

Current Accounts

The major demand for agricultural commodities is for food. Per capita food consumption varies widely across the world, a variation that is ultimately reflected in disparities in hunger levels between regions. Food provides people with a source of energy, biological building material, and crucial chemicals used in biological processes within the body. In this analysis, the focus is on food energy supply, measured in calories or kcalories (thousands of calories). The food energy supply is the energy in the food that is available to drive metabolic processes – that is, it is the energy in the digestible portion of the food.

Average regional calorie consumption is shown in Figure 4-3. Values range from 2,437 kcal/cap/day in Africa to over 3,400 kcal/cap/day in Europe and North America. These values can be compared to estimated per capita food requirements, to get an idea of their adequacy. Average food requirements at a national level generally depend upon three factors: the distribution of metabolic requirements in the population, the amount of waste, and the distribution of food availability. Metabolic requirements vary with level of activity – e.g., plowing a field vs. sitting at a desk – gender, age, physical size and condition. The age distribution and typical level of activity in a population, and the number of women who are pregnant, can significantly affect the average energy requirements. Moreover, for these requirements to be met, it is first necessary that food reaches people, so losses and the distribution of food availability must be taken into account when evaluating average intake. Assuming a reasonably egalitarian food distribution, and taking population-specific factors into account, the FAO has estimated a range of 2,700-2,860 kcal/cap/day as a minimum average level of consumption to achieve food adequacy in developing countries (FAO, 1996). The average consumption levels for South Asia and Africa clearly fall short of the bottom of this range by 8 to 9%, consistent with the high levels of hunger in the regions. The FAO's estimated range is for developing countries, and may not apply to industrialized countries, where food requirements are different. However, the very high values in Europe and North America are due at least in part to high levels of waste (Bender, 1997).

Some general features of dietary patterns across regions can be seen in Figure 4-3. First, as a general trend, as caloric intake increases, a greater proportion of total calories is derived from animal products (See Figure 4-4). Both high caloric consumption and high meat consumption are associated with high per capita income: the highest average consumption is in the European and Northern American regions, which also have some of the highest incomes among the eleven regions, while the lowest average consumption is in South Asia and Africa, which have the lowest average incomes of all the regions. Second, in general, as incomes (and average food intake) increase, the amount of calories derived from crops remains relatively steady. However, the amount derived from cereals tends to decrease, while that from non-cereal crops (labeled "Othercrops" in the figure) increases. This is a reflection of a general pattern that with increasing incomes, people, countries and regions diversify their diets away from staple crops (mainly cereals) to other foods, including meat and non-staple crops, such as fruits. Among the cereals, wheat and the coarse grains dominate in most regions, but in Asia rice is by far the most important cereal grain consumed.

Some exceptions to these patterns should also be noted. The large contribution of the "Othercrop" category to diets in Africa and Latin America (over 40%) reflects the importance of root crops as staples in many African regions, and of root crops and fruits in Latin America. The relatively large contribution of meat in China+ (20%) is supplied by pigs, which are low-maintenance animals that can scavenge food and crop wastes.

Figure 4-3. Regional daily calorie intake per capita (2005)

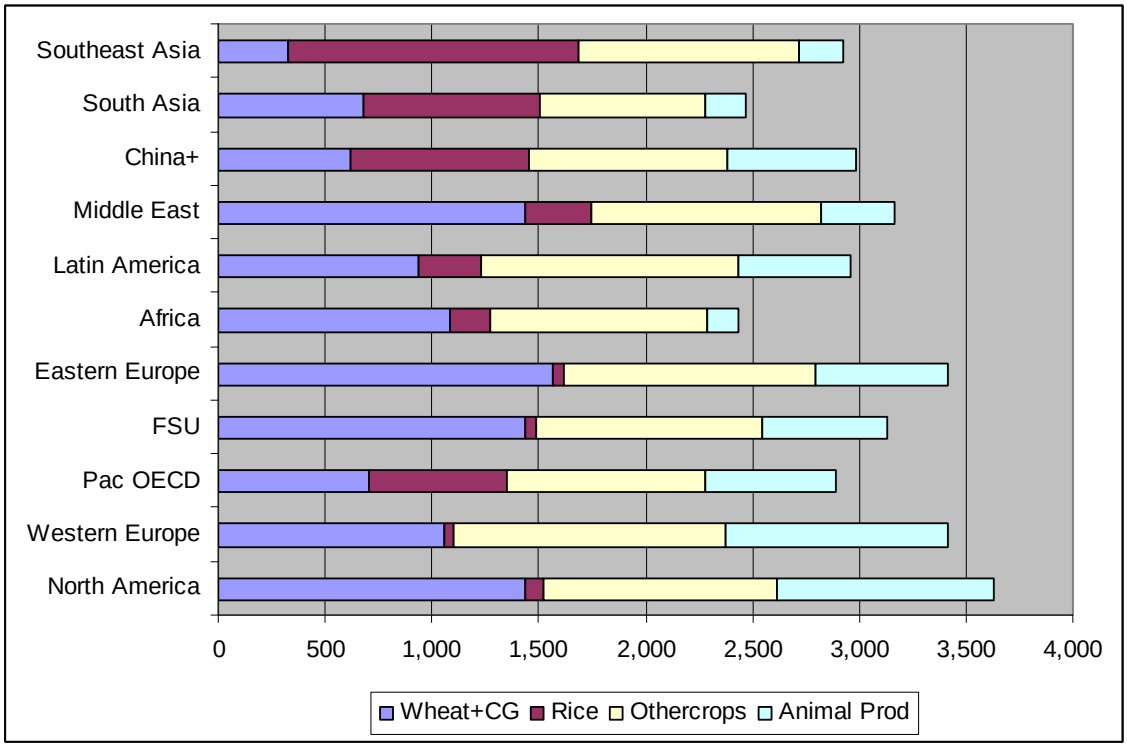
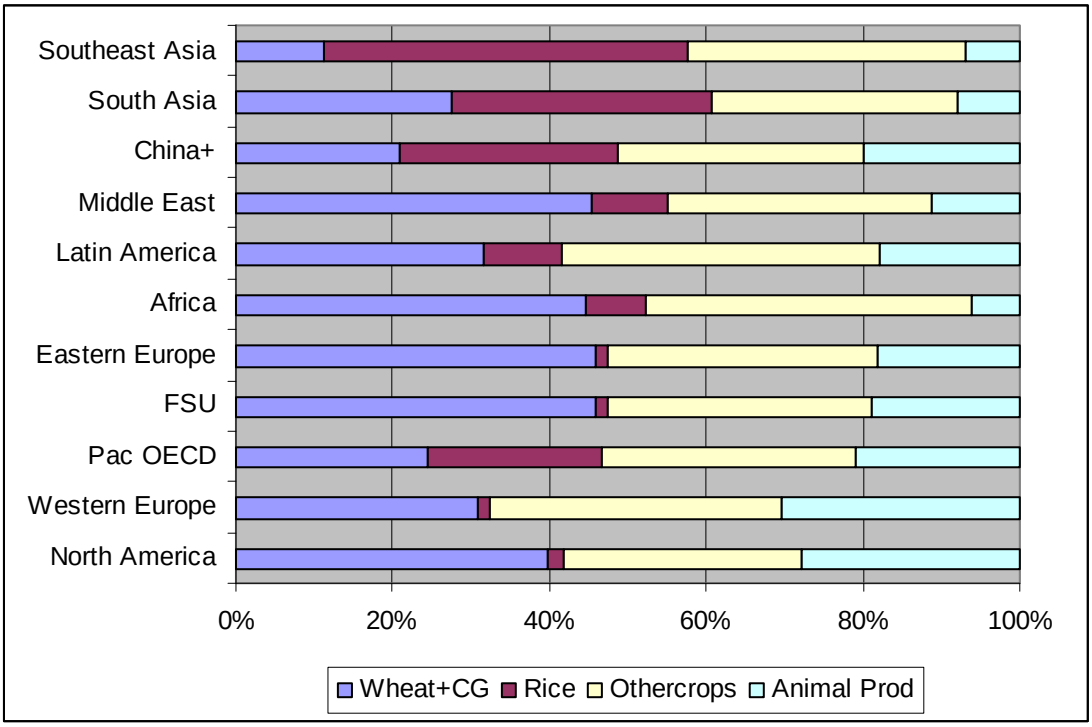


Figure 4-4. Regional calorie intake/capita as a share of total consumption (2005)

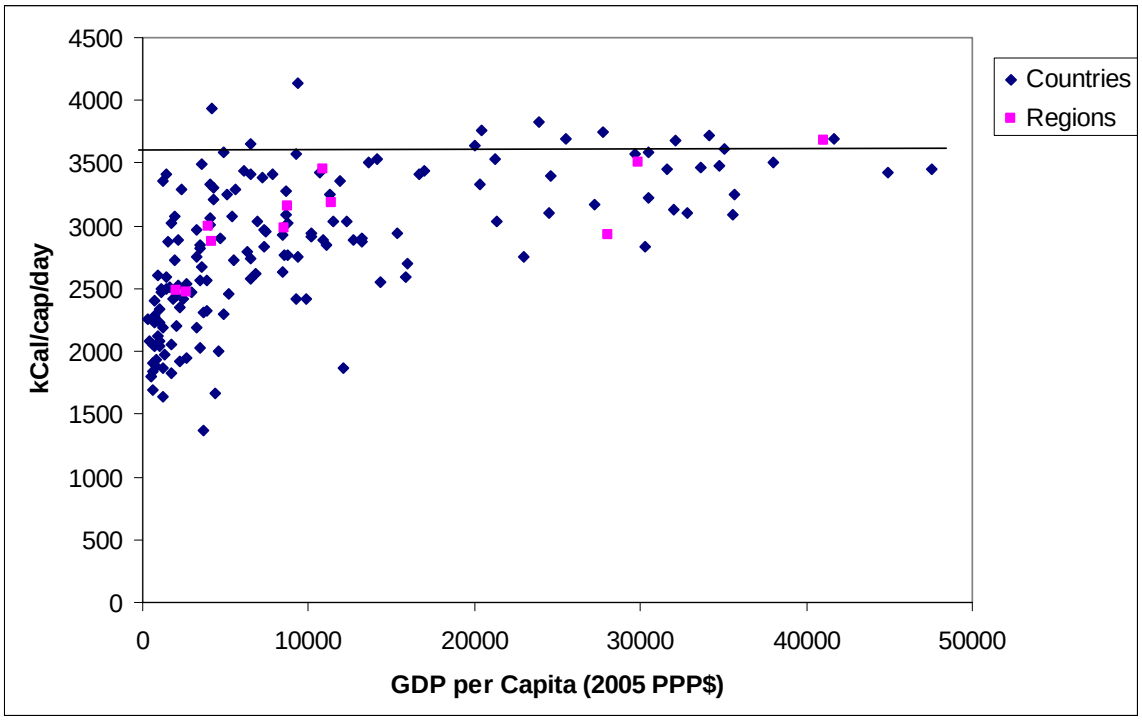


Scenarios

In the scenarios, the general patterns seen in the base year data persist (See Figure 4-3). As incomes increase, average caloric intake generally increases as well, with a greater proportion of calories derived from meat, while the contribution from staple cereal crops declines relative to non-cereal crops.

As incomes rise, it can be expected that caloric intake will eventually saturate, because there are physiological limits to the number of calories that can be absorbed. Current data show evidence of saturation, when looking across countries at different income levels (Figure 4-5). However, average caloric intake can be significantly higher than would be expected from physiological requirements alone, a pattern evident in high-income countries. This occurs both because of overeating and because considerable losses due to plate waste and other factors enter the total (FAO, 2007a; W. H. Bender, 1994; 1997). The expected pattern of saturation at relatively high per capita levels of intake is incorporated in the scenarios.

Figure 4-5. Caloric intake vs. income (2005)



Sources: GDP per capita, World Bank (2008a); caloric intake, FAO (2007a)

In the *Market Forces* case, for the OECD regions, where the average caloric intake is currently high, the intake per capita in 2100 is set to stay at its high base year level of 3,636 kcal/cap/day in North America, and 3,432 kcal/cap/day in Western Europe. This is roughly consistent with the FAO scenario report, World Agriculture Toward 2030/2050

(FAO, 2006a), where it was projected that the average caloric intake by 2050 would reach about 3,540 kCal/cap/day in industrialized countries. In the Pacific OECD region, intake is much lower in 2005 than might be expected given the high average income of the region. The discrepancy can be attributed to differences in dietary preferences, and comparatively low levels of food waste, between Japan and the other industrialized countries (Bender, 1997). In the scenarios, we assume that intake in the Pacific OECD increases slightly to 3200 kcal/cap/day by 2100, while still remaining significantly below European and North American levels, reflecting the persistence of historical dietary preferences despite continued global cultural convergence.

In the *Policy Reform* case, the daily caloric intake for OECD regions is lowered by 2100 to represent policy changes to reduce wasted food in the system, so that in North America and Western Europe the average per capita daily consumption is 3,200 kcal. In the Pacific OECD, there is still an increase in daily consumption, however to a lower level of 3,100 kcal/capita/day by 2050.

In the non-OECD regions, caloric intake is assumed to follow an s-shaped (logistic) curve with increasing income, asymptotically approaching a maximum daily caloric intake of 3,500 kcalories/capita in the *Market Forces* and *Policy Reform* scenarios, a value set based on levels seen today in industrialized countries, and close to the value indicated by the horizontal line in Figure 4-5. In the calculation of caloric intake in non-OECD regions, the income elasticity (the percent change in intake with each percent change in income) decreases with increasing levels of intake, in the following way:

$$\text{Elasticity} = \frac{\text{Income}}{\text{Cal Intake}} \times \frac{\Delta\,\text{Cal Intake}}{\Delta\,\text{Income}} = \text{Max Elasticity} \times \left(1 - \frac{\text{Cal Intake}}{\text{Max Cal Intake}}\right) \quad (4\text{-}1)$$

The elasticity is zero when intake is at the maximum level of 3,500 kcal/cap/day, so that intake will remain at that level, no matter how high income may rise. The elasticity approaches its maximum value at very low levels of intake, indicating that at low intake, an increase in income is accompanied by a relatively rapid increase in average caloric intake. For all non-OECD regions, the maximum elasticities are set to 0.6 in the scenarios. This value for the maximum elasticity is chosen to give changes in caloric intake that are similar to those projected in the FAO scenario (2006).

The contribution to diets from animal products increases more rapidly in the scenarios than from crop products, consistent with historical patterns. All animal product consumption, as a fraction of total calories consumed, is assumed to increase with income, asymptotically approaching 30% of caloric intake. In Western Europe, where 30% of calories come from animal products in 2005, meat consumption stays level at the respective base-year level through 2100.

Within animal products, shares of meat, milk and fish remain relatively steady over the scenario period. For the OECD regions which already consume high levels of meat products, the absolute number of calories supplied by the categories of ruminant animal meat (beef, etc) and seafood is set to remain constant, resulting in a slight decline in the shares of these categories within calories coming from animal products. The share of

animal product calories coming from dairy products is kept constant at the base year level.

In non-OECD regions, the shares of animal products remain the same for ruminant animals and dairy products, while the absolute calories supplied by seafood remains constant from the base year, resulting in a significant decline in share over the scenarios as non-OECD regions increase their total caloric intake. However, increasing pressures on fishery resources are assumed to drive up prices and depress demand somewhat over the scenario period. As a result, fish consumption declines slightly as a share of total calories from animals. The remaining share of animal product consumption goes to an increased share of other non-ruminant meat, such as poultry and pork.

Of the calories coming from vegetable commodities, all regions maintain the base-year average number of calories coming from wheat/coarse grains and rice, and any increase in overall caloric intake over the scenario results in an increased share of "other crops", including vegetables, fruits and spices.

The results for the *Market Forces* scenario are shown in Figure 4-6. The results for the *Policy Reform* scenario are very similar, as shown in Figure 4-7. However, caloric intake in developing regions is higher in the *Policy Reform* scenario than in the *Market Forces* scenario, as shown in Figure 4-8, with the exception of Eastern Europe, which is assumed to converge to Western Europe caloric intake levels. The OECD regions have a lower daily caloric intake in the *Policy Reform* compared to *Market Forces* scenario, as a result of various policies meant to reduce food waste and improve health.

Figure 4-6. Dietary Changes in the *Market Forces* scenario

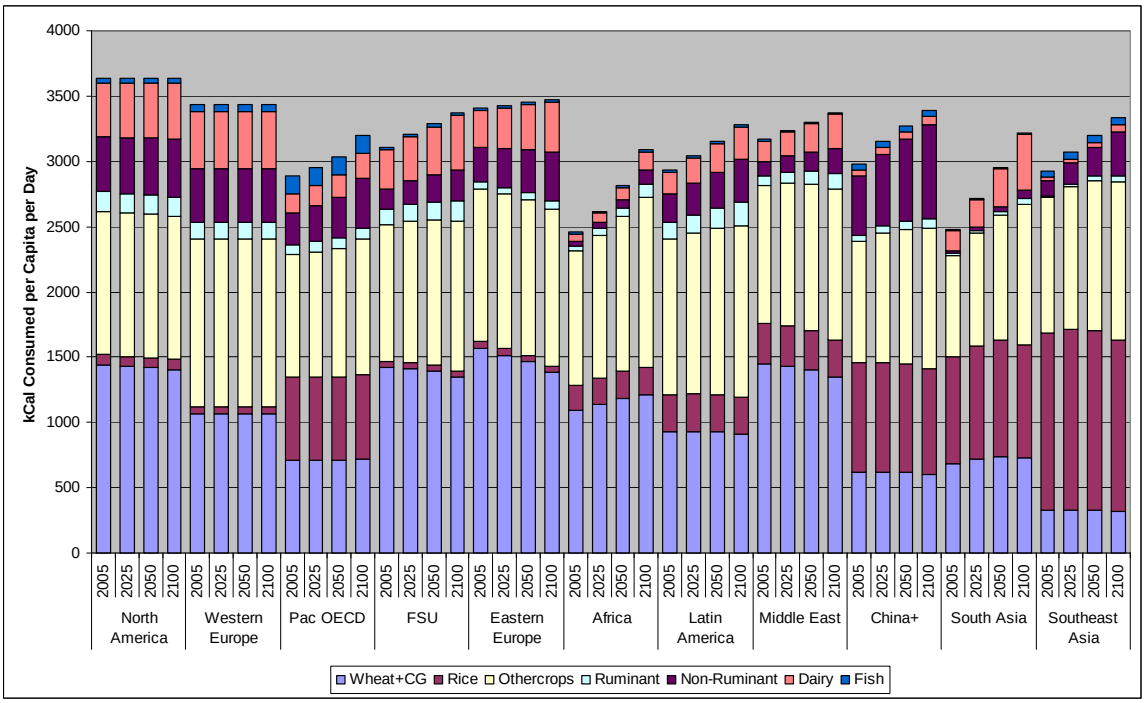


Figure 4-7. Dietary Changes in the *Policy Reform* scenario

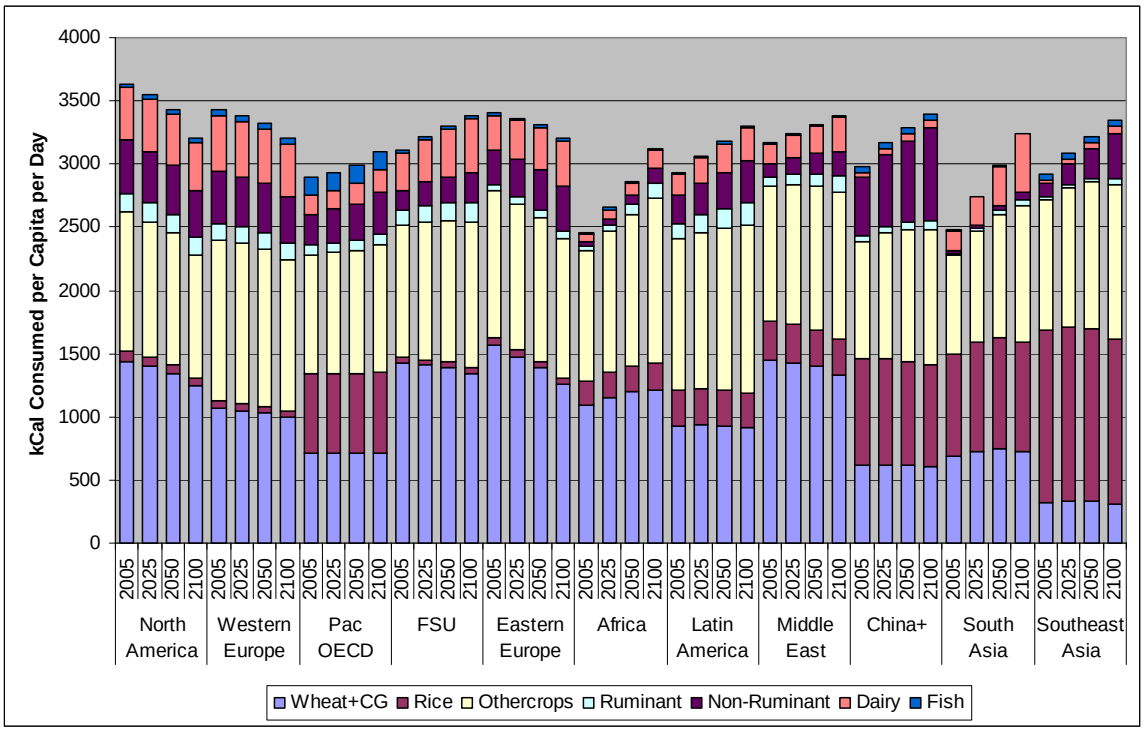
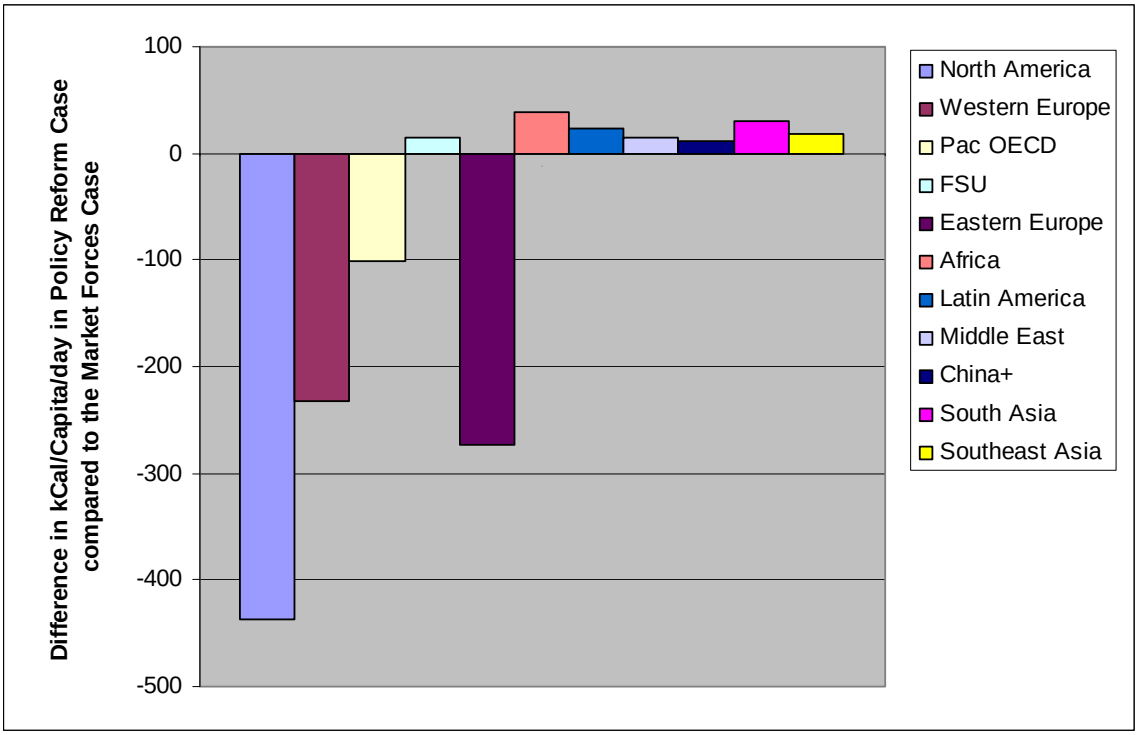


Figure 4-8. Difference in daily calorie intake between *Policy Reform* and *Market Forces* scenarios in 2100



Trade and Regional Food Supplies

The requirements for agricultural products in a given region can be met either through domestic production, or through trade. In this analysis, agricultural trade patterns in the scenarios are based on current patterns, while taking into account future limits to production from land and water resources encountered in the course of the scenarios.[5] Specific assumptions for the key crop and livestock commodity groupings used in this study are reported below.

[5] Note that in both developing and industrialized countries today, agricultural producers receive government support, which strongly influences trade. In part, this support is offered in order to offset some risks inherent in agricultural production – sensitivity to fluctuating weather conditions and long time lags between planting and harvest. However, in part it is the result of complex political and social constraints, the goals of national trade strategies, and competing demands from agricultural producers, consumers and trading partners. Despite recent changes in international agricultural trade agreements, this difficult policy environment, which helps to shape the patterns of trade today, can be expected to persist in the future.

Domestic Demand

As noted above, domestic requirements for agricultural products are the total of demand for food, feed, industrial, and other uses, as well as any losses that might occur. These requirements may be met either through domestic production or through trade. That is,

$$\text{Production} = \text{Requirements} + \text{Net Exports}, \qquad (4\text{-}2)$$

where

$$\text{Requirements} = \text{Food} + \text{Feed} + \text{Losses \& Other}. \qquad (4\text{-}3)$$

Note that "Net Exports" will be negative in importing countries. Production, requirements and trade are reported in the FAOSTAT database in mass terms. The same convention is followed in this analysis, in which each of the terms in Equations (4-2) and (4-3) are expressed in metric tonnes.

Trade and Production

Net exports are reported in this section both in absolute terms and in terms of a self-sufficiency ratio (SSR). The SSR is defined as the amount of food (in tonnes) available from domestic sources, divided by total requirements.[6] The SSR is given by:

$$\text{SSR} = \frac{\text{Production}}{\text{Requirements}} = 1 + \frac{\text{Net Exports}}{\text{Requirements}}. \qquad (4\text{-}4)$$

In scenarios, the term "Losses & Other" that appears in Equation (4-3) is assumed to increase proportional to overall production within each agricultural commodity group. That is,

$$\text{Losses \& Other} \equiv s_{\text{L\&O}} \times \text{Production}, \qquad (4\text{-}5)$$

where $s_{\text{L\&O}}$ is the share of production that is lost or diverted to industrial and other uses. With "Losses & Other" changing with production as in Equation (4-5), and defining the self-sufficiency ratio as in Equation (4-4), production changes in the following way with the self-sufficiency ratio:

$$\text{Production} = \left(\frac{\text{SSR}}{1 - s_{\text{L\&O}} \cdot \text{SSR}} \right) \cdot (\text{Food} + \text{Feed}). \qquad (4\text{-}6)$$

Given requirements for food and feed, and trade, as specified by the self-sufficiency ratio, Equation (4-6) determines production in the scenarios.

[6] In the FAOSTAT statistics, domestic production and changes in stocks are recorded for each country. For this report, in developing base-year data, both production and stock changes are considered as domestic sources when computing the SSR, while in the scenarios, stock changes are set to zero, in the expectation that they will average to zero in the long run.

Animal Products

Current Accounts

According to FAOSTAT figures (2007a), in 2005 about 32 million tonnes of fish and around 45 million tonnes of all other kinds of meat (from both ruminant and non-ruminant animals) were shipped across national borders. These are gross national (not regional) trade flows. In this analysis, we consider net regional flows, that is, total regional exports less total regional imports. These regional flows, which are computed by aggregating from the national to the regional level, and across commodities, are much smaller than national flows, since some national exchanges are internal to regions, and countries may both export and import items from a given commodity group.

Trade in animal products is shown in Table 4-1. Note that global net exports are not exactly zero: this is a reflection of statistical errors in the reported data. For meat and milk trade, the SSRs for most regions are quite close to one. The small variation in the SSRs indicates that there is little trade compared to domestic production, reflecting the difficulty of shipping livestock products.

Table 4-1. Net trade in animal products in 2005

Mtonnes	Fish & Seafood		Ruminant Meat		Other Meat		Milk	
	Net Exports	SSR	Net Exports	SSR	Net Exports	SSR	Net Exports	SSR
North America	-2.2	0.76	0.9	1.07	6.1	1.18	2.1	1.01
Western Europe	-1.9	0.86	0.1	1.01	2.8	1.06	12.2	1.06
Pac OECD	-4.4	0.69	2.2	1.81	-2.4	0.77	13.7	1.57
FSU	0.2	1.04	-0.7	0.87	-2.5	0.77	-1.0	0.97
Eastern Europe	-0.4	0.69	0.1	1.09	-0.2	0.99	2.3	1.08
Africa	-0.5	0.94	-0.7	0.91	-0.9	0.90	-6.2	0.82
Latin America	2.4	1.17	1.1	1.07	1.9	1.09	-3.2	0.95
Middle East	-0.3	0.70	-0.2	0.85	-0.7	0.61	-4.3	0.53
China+	3.3	1.06	-1.4	0.9	-0.8	0.97	-3.3	0.90
South Asia	0.5	1.06	0.2	1.04	0.0	1.07	-0.6	1.02
Southeast Asia	2.1	1.14	-0.2	0.84	0.5	1.08	-5.1	0.35
World	-1.3	1	1.5	1	3.6	1	6.6	1

Note: For the Fish (Seafood) and Ruminant Meat categories, the SSR was calculated based on its reported Net Exports (SSR = 1 + Net Exports/(Production – Net Exports)), rather than based on the production compared to the total demand for the specified products (SSR = Production/Total Required). This was done to correct for the discrepancies in the data between demand (total required) and production which produced incorrect SSRs. The discrepancies were then added to the production.

It is easier to ship fish and seafood than to ship milk, beef and other meat products, and levels of trade in seafood are correspondingly higher than for other animal products. For this category, exports are dominated by the regions of China+ and Latin America, and Southeast Asia, within which several countries are major seafood exporters today.

Scenarios

In the scenarios, the trade patterns in animal products are based on those for the base year. Specifically, it is assumed that regions that are net importers in the base year continue to import. However, they meet most additional demand through expanded domestic production and a small proportion through increased trade, consistent with patterns seen in the FAO's scenarios found in World Agriculture Towards 2030/2050 (FAO, 2006a) and Agriculture Toward 2015/30 (FAO, 2000a). Self-sufficiency ratios for net exporters are kept as close to the base-year value as possible while ensuring that trade balances at the global level.

Crop Products

Current Accounts

In 2005 some 300 million tonnes of cereals and 116 million tonnes of fruit were shipped across national borders. Most of the exchanges were commercial transactions: cereal food aid shipments were only about 6.5 million tonnes in 2005/2006 (FAO, 2008a), or about 2% of total cereal exports. As with trade in livestock products, net regional exports are reported both in absolute terms and as self-sufficiency ratios.

Patterns of trade for crop products are shown in Table 4-2 for the crop commodity groupings used in this study. For wheat and coarse grains, the industrialized regions taken as a whole are net exporters, with most exports originating in North America. All of the developing regions are net importers. The volume of trade in rice is much smaller than that for wheat and coarse grains. The major rice-consuming regions are largely self-sufficient in the aggregate, while the regions with the lowest levels of self-sufficiency consume very little rice. For non-cereal crops, the industrialized regions are net importers. The exports from the developing regions are entirely from Latin America and Southeast Asia. A variety of crops are exported from Southeast Asia, while fruit dominates exports from Latin America.

Table 4-2. Net trade in crop commodities in 2005

Mtonnes	Wheat+CG		Rice		Othercrops	
	Net Exports	SSR	Net Exports	SSR	Net Exports	SSR
North America	94.6	1.3	5.1	1.9	(25)	0.9
Western Europe	5.6	1.0	(0.9)	1.0	(76)	0.8
Pac OECD	(20.0)	0.7	(2.0)	0.9	(34)	0.7
FSU	23.0	1.2	(0.9)	0.5	(47)	0.8
Eastern Europe	11.0	1.1	(1.0)	0.4	1	0.9
Africa	(48.0)	0.7	(10.0)	0.6	(39)	0.8
Latin America	(13.0)	0.9	(1.5)	0.9	261	1.5
Middle East	(24.0)	0.6	(4.6)	0.3	(37)	0.5
China+	(5.0)	1.0	3.3	1.0	(76)	0.9
South Asia	(2.5)	1.0	8.1	1.0	(63)	0.9
Southeast Asia	(14.0)	0.6	8.6	1.0	136	1.4
World	7.7	1	4.2	1	1.5	1

Scenarios

In the scenarios, requirements for crop products increase rapidly, driven by demand for both food and feed. Global demand for wheat and coarse grains grows by close to 2% per year on average between 2005 and 2050 in both scenarios, nearly three times the rate of population growth. Continuing the pattern seen in the second half of the 20th Century, most of the required increase in production is met through increasing productivity, achieved in part through increased irrigation. Nevertheless, some of the increase is met by expansion of the cropped area. Constraints on land and water availability largely determine the changing trade patterns in the scenarios.

The general strategy followed in this analysis is to first specify increases in yields and cropping intensity, which is the average number of harvests on a single piece of land in a given year. Next, self-sufficiency ratios are set, maintaining them as close to base-year values as possible while ensuring that global production equals global demand, and constrained by the condition that land requirements do not exceed the available potentially arable land area. Yield and cropping intensity assumptions, and the area of potentially arable land, are discussed in later subsections.

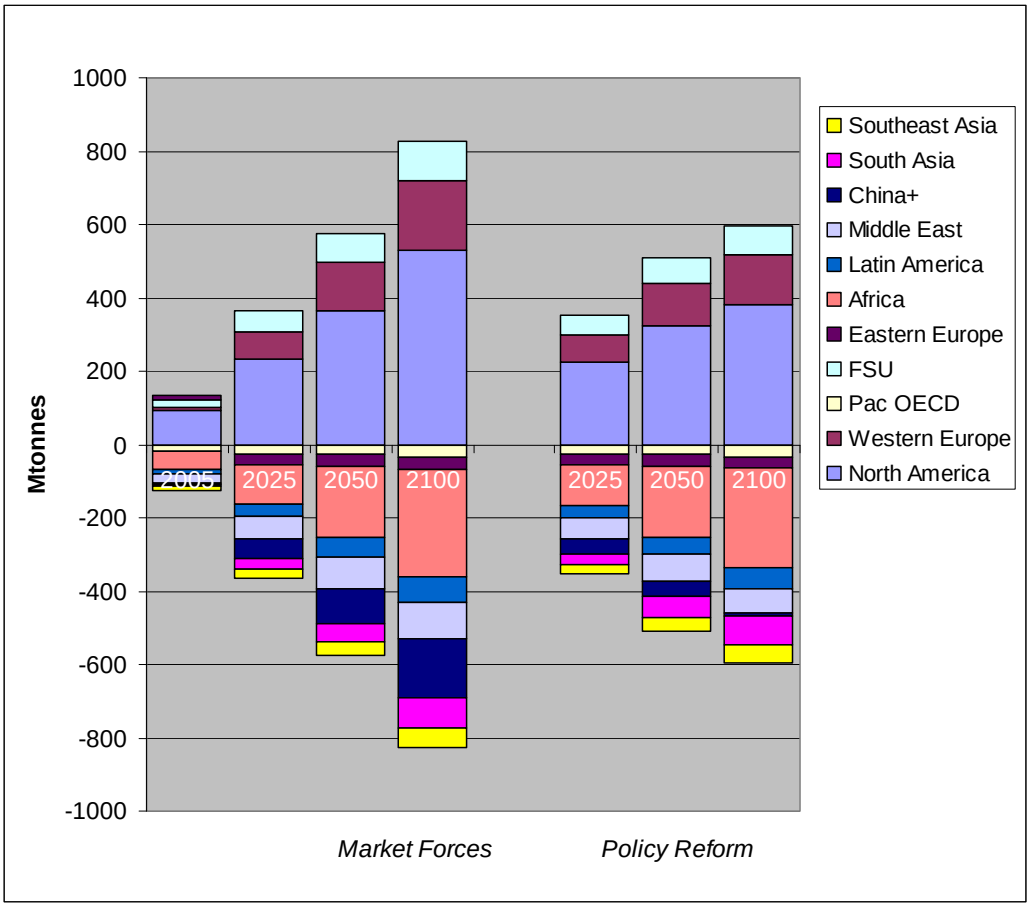
There are important exceptions to this general approach. First, Eastern Europe is expected to decrease its production of cereals and other crops substantially in all scenarios, going from a net exporter to a net importer. This is done to reduce the pressure of various land constraints that arise throughout the scenarios. Second, Africa increases its dependence on imports, despite large increases in the area of cultivated land, as population growth drives large increases in food demand.

In the *Policy Reform* scenario, importing regions generally rely to a greater extent on trade than in the *Market Forces* scenario. Regional production levels are also constrained by the sustainability targets. The target of halting, and then reversing, deforestation, and the requirement to minimize the growth in water stress, strongly restrict the expansion of cropland and irrigation in some regions. The resulting scenario values for the self-sufficiency ratios for cereals are shown in Table 4-3. With the exception of Eastern Europe, the Non-OECD regions are cereal importers in the base year, and they continue to be net importers in both scenarios. In the *Market Forces* scenario the regional pattern and total imports of cereals for developing regions in 2025 are comparable to the projections to 2020 by the International Food Policy Research Institute (IFPRI, 2001), and to the projections for developing country imports in the FAO scenario Agriculture Toward 2015/2030 (FAO, 2000a) and World Agriculture toward 2030/2050 (FAO, 2006a), in which developing country net imports increase by around 2.7 times between 1995/97 and 2030, and 2.2 times between 1999/01 and 2050. While the results differ in detail, imports in developing countries generally increase over the scenarios, which is consistent in the *Market Forces* case, which starts at about 70 Mtonnes of cereals (including rice) in 2005, going to 328 Mtonnes in 2025, and reaching 768 Mtonnes by 2100. Figure 4-9 and Figure 4-10 show the scenario imports and exports by region for wheat and coarse grains (excluding rice), and all grains (including rice).

In the base year, North America , Western Europe, FSU, Eastern Europe, and South Asia are the only net cereal exporters In the *Market Forces* scenario, Eastern Europe and the FSU become significant exporters, as they recover from a post-Soviet drops in production and as yields in the FSU, which today are still well below those of Western Europe and North America, increase. South Asia becomes a net importer by 2025 and remains so through 2100. The *Market Forces* scenario values in 2025 are again broadly comparable to those of IFPRI. In particular, the transitional regions become net exporters in the IFPRI scenario, and South Asia shifting to become a large importer of cereal grains. Table 4-3 shows the self-sufficiency ratios for cereal crops (excluding rice) in the scenarios.

The self-sufficiency ratios for non-cereal crops are shown in Table 4-4. In the *Market Forces* scenario, OECD regions, along with FSU, maintain their base-year self-sufficiency ratios, while Eastern Europe, Latin America, and Southeast Asia increase their level of exports by 2100. However, Africa, the Middle East, China+, and South Asia, due to population growth and land constraints, import an even higher percentage of their requirements by the end of the scenario. In the *Policy Reform* scenario the pattern is substantially the same. However, Latin America exports remain at somewhat more moderate levels than in the *Market Forces* scenario.

Figure 4-9. "Wheat and Coarse Grains" imports (negative) and exports (positive)



Note: These results are for Wheat and Coarse Grains, not including Rice.

Figure 4-10. All cereal imports (negative) and exports (positive), including “Wheat and Coarse Grains” and “Rice”

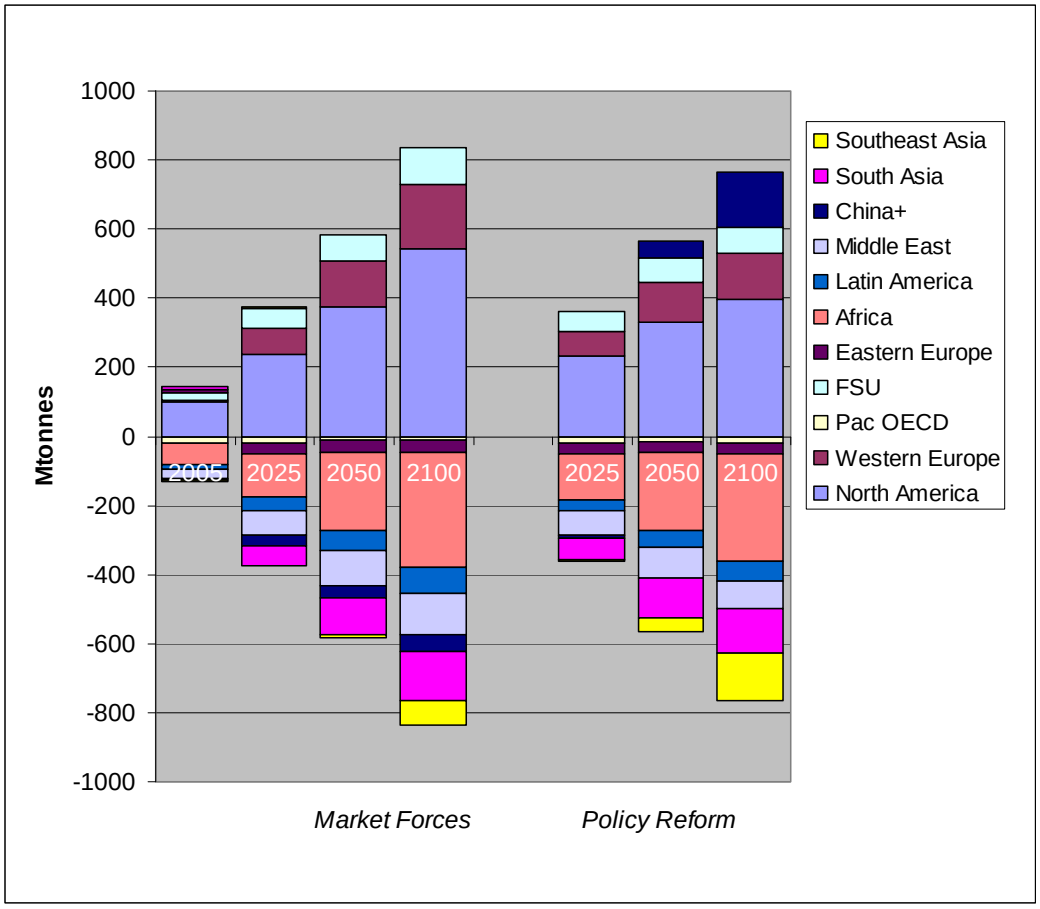


Table 4-3. Self-sufficiency ratios for cereal crops in the scenarios

		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	1.30	1.60	1.80	2.02	1.59	1.74	1.81
Western Europe	1.03	1.32	1.52	1.73	1.31	1.46	1.53
Pac OECD	0.68	0.68	0.68	0.68	0.68	0.68	0.68
FSU	1.18	1.43	1.59	1.75	1.42	1.54	1.60
Eastern Europe	1.10	0.80	0.80	0.80	0.80	0.80	0.80
Africa	0.71	0.67	0.64	0.62	0.66	0.63	0.61
Latin America	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Middle East	0.55	0.40	0.37	0.39	0.41	0.42	0.53
China+	0.98	0.84	0.75	0.55	0.88	0.89	0.98
South Asia	0.98	0.85	0.80	0.72	0.84	0.77	0.72
Southeast Asia	0.62	0.62	0.62	0.62	0.62	0.62	0.62

Table 4-4. Self-sufficiency ratios for non-cereal crops in the scenarios

		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Western Europe	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Pac OECD	0.74	0.74	0.74	0.74	0.74	0.74	0.74
FSU	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Eastern Europe	1.01	0.80	0.80	0.80	0.80	0.80	0.80
Africa	0.92	0.88	0.84	0.81	0.87	0.84	0.81
Latin America	1.30	1.63	1.77	2.01	1.62	1.70	1.76
Middle East	0.65	0.39	0.33	0.28	0.41	0.40	0.60
China+	0.92	0.79	0.72	0.60	0.83	0.84	0.92
South Asia	0.90	0.75	0.68	0.58	0.73	0.66	0.62
Southeast Asia	1.51	1.85	2.00	2.25	1.83	1.93	1.99

Livestock Production and Feed

The nutritional requirements of livestock place significant pressures on land resources. They can do so directly, when the animals are grazed, or indirectly, when they are fed grain or other crops grown on cropland. The increasing consumption of animal products that occurs in the scenarios leads to large increases in feed demand.

In all parts of the world, livestock are fed from diverse sources. The ability of ruminant animals, in particular, to digest cellulosic material enables them to extract energy from varieties and parts of plants that are indigestible to humans and non-ruminant livestock, such as grasses and crop residues. Grasses, in turn, can be obtained from a range of sources – grazing land of varying quality, fodder or roadside verges. Animals may be fed household wastes, and are also fed on grain, hay or other crops, fish meal, or offals. Understandably, with so many alternative sources of feed and so much latitude in the use of informal feed sources, reliable statistics on feeding regimes are hard to come by. The difficulty is compounded by considerable uncertainty in the use of land. It is often not known whether grazing land is actually used to raise livestock, and even when the land is used for that purpose, it may be used solely for livestock or it may also support wildlife. However, while these uncertainties bedevil attempts to assign feed to livestock for the purposes of scenario analysis, it is possible to construct an approximate allocation that takes into account available information regarding feeding regimes in different regions. Such an allocation is used as the basis for this analysis. To the extent that the general pattern of feeding systems are captured in the allocation, the scenarios reflect the implications of modifying livestock production systems within physically reasonable bounds.

The approach followed is to use available data on feed use and livestock production to construct an approximate feed energy balance, which exploits the equality between estimated feed energy requirements and supply to deduce an estimate of the feed energy supplied from unrecorded sources.[7] Variables that affect the feed energy balance are then adjusted in scenarios to explore the implications of different possible developments in the livestock sector.

Feed Requirements

Current Accounts

Feed requirements can vary considerably between different kinds of livestock, between different animals of the same species, and between different animals in the same herd (for

[7] The structure of the feed energy balance used in this report is based on the FAO's Livestock Development Planning System (Lalonde and Sukigara, 1997), but has been considerably simplified. Feed energy balances have been used in other studies as well (e.g., Wirsenius, 2000).

example, young vs. mature, draft vs. meat-producing). In order to aggregate feed requirements over different kinds of livestock, it is often helpful to express them in terms of the requirements of a "standard animal" – in conventional terminology, a livestock unit (LSU). Adopting a commonly-used definition, for this analysis a livestock unit may be thought of as a unit of energy, equivalent to about 35,600 MJ, or 8.5 million kcalories of metabolizable feed energy per year (Lalonde and Sukigara, 1997).

Detailed methodologies for estimating energy requirements are described in the IPCC guidelines for estimating greenhouse gas emissions (IPCC/OECD/IEA, 1996; IPCC, 2006). The IPCC also provides default values for estimating energy requirements of livestock in different regions of the world. Table 4-5 provides feed energy estimates in terms of livestock units per head per year based on the IPCC data, used for this analysis.

Table 4-5. Estimated feed energy requirements

LSU/head/year	Cattle		Sheep	Pigs	Poultry
	Dairy	*Non-Dairy*			
North America	1.63	0.68	0.21	0.39	0.014
Western Europe	1.28	0.58	0.21	0.39	0.014
Pac OECD	0.88	0.55	0.21	0.39	0.014
FSU	1.04	0.6	0.21	0.39	0.014
Eastern Europe	1.04	0.6	0.21	0.39	0.014
Africa	0.47	0.28	0.13	0.13	0.007
Latin America	0.65	0.49	0.13	0.13	0.007
Middle East	0.47	0.28	0.13	0.13	0.007
China+	0.72	0.48	0.13	0.13	0.007
South Asia	0.54	0.23	0.13	0.13	0.007
Southeast Asia	0.54	0.23	0.13	0.13	0.007

Notes**:** Based on IPCC/OECD/IEA (1996), assuming 1 LSU = 35,600 MJ; values for poultry based on Lalonde and Sukigara (1997). The estimates for cattle take into account the age composition of the herd and the use of animals for draft.

In the analysis, estimated feed energy requirements per head are multiplied by animal populations reported in FAOSTAT (FAO, 2007a), to obtain an estimate of total feed energy requirements for the national herd. For this analysis, disaggregated FAO data on livestock populations are used. The totals are then grouped into the aggregate categories used for this study – ruminant meat-producing animals, non-ruminant animals, and dairy animals.

Scenarios

In the scenarios, feed requirements are driven by the production of livestock products. Feed requirements are estimated using feed-to-production ratios, expressed as the ratio of the number of LSUs of feed energy required to produce a tonne of meat or milk. Feed-to-

production ratios decrease over the course of the scenarios, based on historical patterns seen in the FAOSTAT data (FAO, 2007a). Some considerations to bear in mind when interpreting feed-to-production ratios are discussed below in Box 4-1.

In analyzing historical changes in feed-to-production ratios, the feed-to-production ratio is split into three factors: the feed requirements per head (the average feed requirements for the herd) divided by the carcass weight multiplied by the offtake rate (the ratio of the number of animals slaughtered each year to the number of animals in the herd). That is,

$$\text{feed - to - production ratio} = \frac{\text{LSU per head}}{\text{carcass weight} \times \text{offtake rate}} \quad . \quad (4\text{-}7)$$

A commonly-used approximation is that LSU per head increases with animal liveweight to the power 0.75 (NRC, 1996). The ratio of liveweight to carcass weight shows relatively little variation over time, so for this analysis it is assumed that the ratio of average liveweight to the average carcass weight of slaughtered animals does not change over the scenario period. Applying these assumptions to Equation (4-7) gives an expression for changes in feed-to-production ratios over time, expressed as an index:

$$\text{feed - to - production ratio index} = \frac{1}{(\text{carcass weight index})^{0.25} \times \text{offtake rate index}} \quad . \quad (4\text{-}8)$$

Both carcass weight and offtake rate can be estimated from FAOSTAT data (FAO, 2007a), and historical indices constructed. At a regional level, changes in feed-to-production ratios estimated using Equation (4-8) are generally well-correlated with changes in meat production, consistent with a picture in which rising demand induces changes in practice that lead to productivity improvements. Values for the "productivity response" for beef – the percent decline in the feed-to-production ratio associated with a percent increase in beef production – are shown for developing regions in Table 4-6.

Table 4-6. Productivity response for beef in developing regions

FAOSTAT Region	Productivity Response	R^2
Latin America		
Central America and Caribbean	0.3	0.8
South America	0.1	0.2
Africa		
Central Africa	0.1	0.4
East Africa	0.3	0.9
Northwest Africa	0.6	0.8
West Africa	0.4	0.6
Southern Africa, excl. South Africa	0.7	0.8
South Africa	0.5	0.7
Asia		
Near East	0.4	0.8
South Asia	0.5	1.0
East & Southeast Asia	0.2	0.7

Note: Based on data spanning the period 1961-1998 (FAO, 1999a).

Values for productivity response assumed for beef in the *Market Forces* and *Policy Reform* scenarios are shown in Table 4-7.

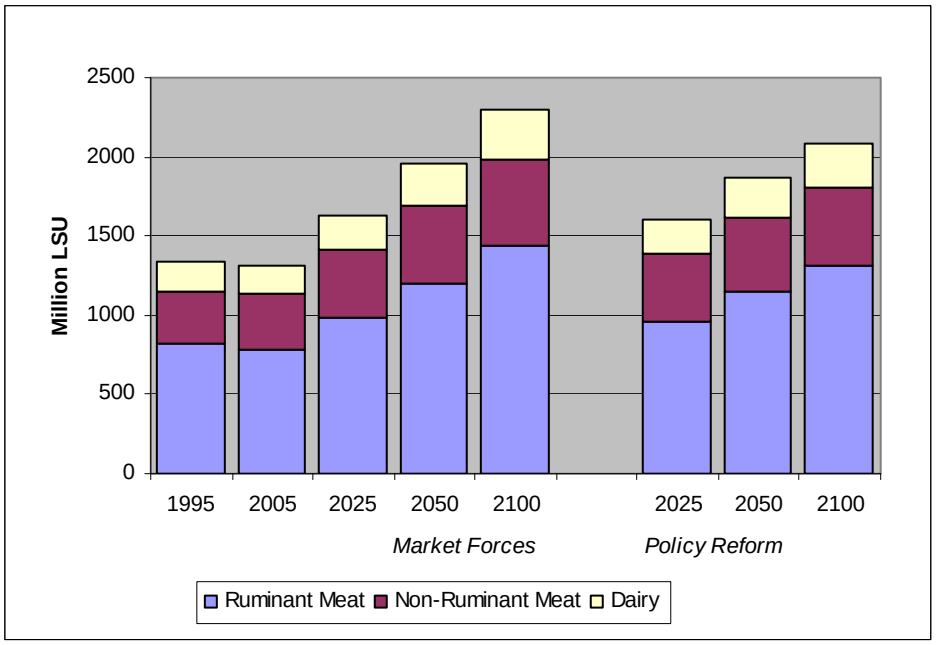
Table 4-7. Productivity response for beef in the scenarios

	Market Forces	**Policy Reform***
North America	0.5	
Western Europe	0.0	
Pac OECD	0.3	
FSU	0.1	
Eastern Europe	0.1	
Africa	0.4	0.5
Latin America	0.1	0.2
Middle East	0.4	0.5
China+	0.3	
South Asia	0.5	
Southeast Asia	0.2	

* Values shown when they differ from *Market Forces*

Given regional production and the feed-to-production ratios, feed requirements are determined in scenarios. Total global feed requirements are similar in the *Market Forces* and *Policy Reform* scenarios, as shown in Figure 4-11. Feed requirements are slightly lower in *Policy Reform* compared to *Market Forces*, despite higher livestock production, due to lower feed-to-production ratios.

Figure 4-11. Feed requirements in scenarios



Box 4-1. Feed-to-production ratios

Many factors can influence the values of feed-to-production ratios. Because of this range of influences, they are not related in a simple way to the efficiency of livestock production systems.

First, the ratio of food production to feed requirements only reflects the use of animals for producing food, which may not be the sole purpose of the livestock system. Livestock are raised for many purposes other than the production of food; for example, they may be raised for draft, manure, prestige (e.g., to use as gifts or dowry) or financial security (Galaty and Johnson, 1990; Conway, 1997; Hudson, 1992; Durning and Brough, 1991). Animals raised for these purposes compete for feed with animals raised for food, increasing the ratio of feed input to food production.

A second consideration is that a relatively high feed-to-production ratio can reflect the influence of disease, such as animal trypanosomiasis (Plucknett et al., 1990). One-third of Africa is affected by trypanosomiasis (sleeping sickness), which limits cattle densities to as little as 30% of their potential in humid areas, and to 63% of their potential in sub-humid areas (Swallow, 1999). Trypanotolerant animals are less productive than they would be in the absence of the disease, but are more productive, given the presence of the disease, than are disease-intolerant animals. In both scenarios the impact of trypanosomiasis and other diseases is expected to decline as a result of focused programs. Also, in the case of trypanosomiasis, the decrease will occur as a side-effect of clearing land (Crosson and Anderson, 1992).

Finally, the availability of markets, veterinary services, wells, dip tanks and other resources affects feed-to-production ratios. In areas where these are scarce, a hardy but low-yielding animal is preferable to a higher-yielding but susceptible one (Homewood and Rogers, 1991). In the scenarios, the supporting infrastructure is expected to expand in developing regions.

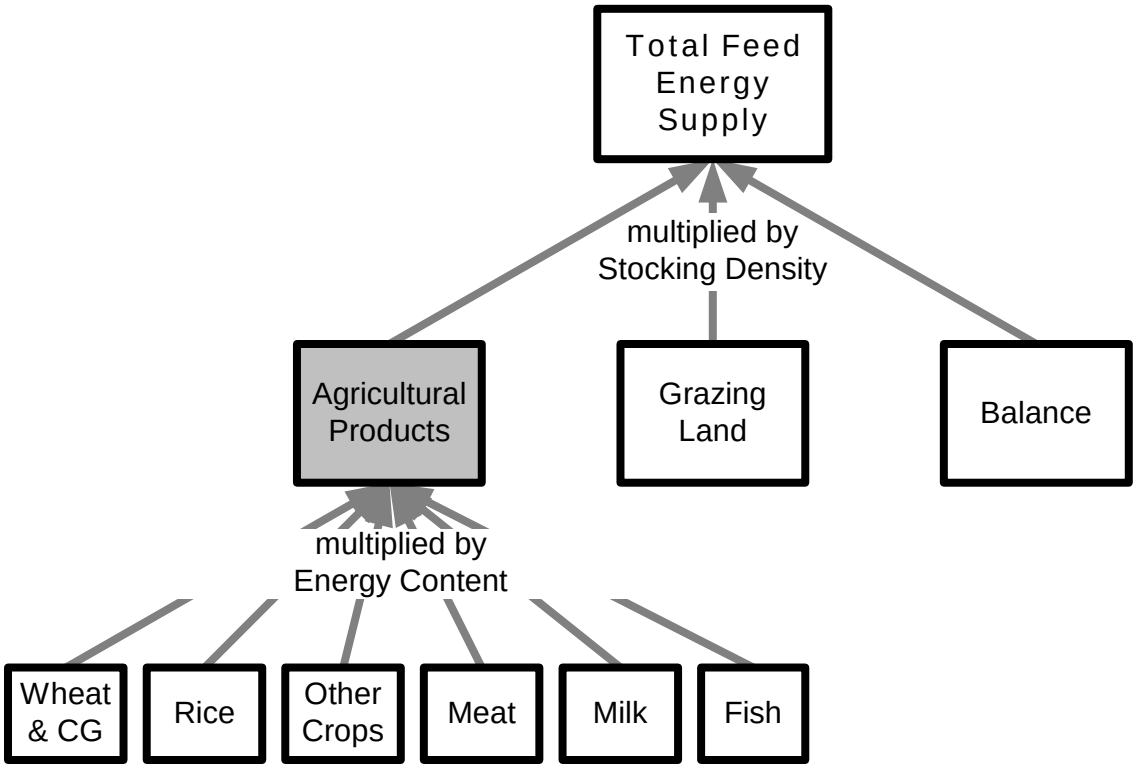
Feed Supply

Current Accounts

Of the many possible sources of feed, only two are reported in FAOSTAT: the area of “permanent meadows and pastures” and the use of crops and livestock products as feed. For this analysis, another category is added to the to the two categories recorded in FAOSTAT. This additional category, a residual “Balance” category, implicitly includes both the feed energy supplied from unrecorded sources, as well as any discrepancies arising from statistical errors or assumptions used to generate the feed energy balance.

The components of the supply side of the feed energy balance are shown in Figure 4-12. As shown in the figure, the energy contents are used to convert the supply of crops and livestock products used for feed as recorded in the FAOSTAT database to a feed energy equivalent. To convert grazing and pasture land to feed energy terms, the land area is multiplied by the stocking density, or the average number of livestock units per hectare.

Figure 4-12. Components of feed energy supply



Both the use of agricultural products for feed and the area of grazing land are recorded in FAOSTAT statistics. Of these two recorded feed sources, the most straightforward is feed from crops and livestock products. While in practice energy contents can vary over a significant range, for large-scale analyses such as this one it is sufficient to use average values of feed energy contents, which are available in standard tabulations. The energy contents used for the current accounts are constructed by averaging over representative values from Lalonde and Sukigara (1997) and FAO (2007c), shown in Table 4-8.

Table 4-8. Energy contents of different feed sources - 2005

kcal/kg	Energy Content
Wheat+CG	3,217
Rice	3,215
Oilcrops	2,310
Pulses	2,875
Sugarcrops	2,689
Roots+Tubers	2,940
Fruit & Veg	2,827
Meat	4,110
Milk	4,135
Fish	2,850

More problematical is the estimation of feed provided by either grazing land or unrecorded sources. For any given country, "permanent meadows and pastures" may, despite the name, also include unimproved rangelands – or it may not. Difficulties in identifying where animals are actually grazed may lead to grazing and pasture areas being defined by land cover, rather than by use – for example, by assigning all grasslands to the category. Alternatively, it may reflect legal status, such as land held under grazing permits, but not actively grazed. The permanent meadows and pastures category should include land permanently planted to fodder crops, but will not include fodder crops grown in rotation with food crops. Moreover, fodder crops are not recorded in FAOSTAT crop production statistics (FAO, 2007a). As a consequence, when land is used both for fodder and for other crops, the fodder production may not be recorded under any category, which in some countries, including industrialized ones, is a substantial omission.[8] Aside from the qualifications regarding statistics on "permanent meadows and pastures," the productivity of grazing land – which can vary by a large factor – is not reported in FAOSTAT. Bearing these limitations in mind, for developing the current accounts, the following procedure is followed.

First, feed requirements are estimated for the three categories of livestock (excluding fish) used in this study: meat-producing ruminant animals, dairy animals and meat-producing non-ruminant livestock.[9] Second, concentrate feeds – the sort of feed reported

[8] Differences in definition may explain some variation in the reported totals for permanent pasture. For example, in the United States, the USDA gives an area of 51 Mha for pastureland and 212 Mha for rangeland in 1992 (USDA, 1994), while the FAOSTAT total for the same year is 239 Mha. In contrast, Maheshwari (1995) reports that in India 4% of total land area is pastures (which agrees with the FAOSTAT figure), while 40% of the total area is available under rangelands.

[9] Feed requirements for fish are not considered explicitly in the analysis, as most of the feed demand for grain today is from cattle, pigs, sheep and poultry, with only about 5% being fed to fish. Based on figures from Brown et al. (1998), aquaculture production was 23.1 million tonnes in 1996, of which 85% was from non-carnivorous species. These require about 2 tonnes of grain per tonne of fish produced, which implies feed requirements of about 40 million tonnes,

in FAOSTAT – are allocated across livestock categories, guided by regional estimates reported in de Haan et al. (1996). As the third and final step, for grazing animals (ruminant meat and, in some regions, dairy), the fractions of feed supplied from unrecorded sources and grazing land are estimated, based on values for the fraction of meat and milk production from mixed farming systems compared to grazing systems from de Haan et al. (1996).

This procedure assigns values to all of the contributions to feed energy shown in Figure 4-12. The stocking rates, for which data are unavailable, are calculated as an output from this procedure, yielding the estimates shown in Table 4-9. The extensive semiarid rangelands of North America, the former Soviet Union, China+, Latin America and Pacific OECD (Australia) appear to be reflected in the estimated stocking rates.[10] Also, the relatively better-watered pastures of Western and Eastern Europe are represented by higher stocking rates and the arid rangelands of the Middle East in comparatively low stocking rates. Trypanosomiasis severely restricts use of livestock in humid regions of Africa, so most of the livestock are in semiarid areas, consistent with the estimated stocking density. The figure for South Asia stands out as the highest. While this may be a result of overstocking (Misri, 1999), it may likely be that some land used for grazing is not recorded in the FAOSTAT "Permanent Meadows and Pastures" category.[11]

Table 4-9. Estimated stocking rates - 2005

LSU/ha	Stocking Rate
North America	0.20
Western Europe	0.73
Pac OECD	0.11
FSU	0.07
Eastern Europe	0.40
Africa	0.09
Latin America	0.32
Middle East	0.01
China+	0.12
South Asia	0.80
Southeast Asia	0.19

compared to 865 million tonnes of crops used for feed in 1994. In 2006, global aquaculture produced 63.3 million tones in 2005, more than double the amount FAO reported for 1995 (FAO, 2008b).

[10] Estimates reported in Lalonde and Sukigara (1997) indicate that typical stocking rates in semiarid areas range from 0.1 to 0.3 LSU/ha, in subhumid areas from 0.3 to 1.0 LSU/ha and in humid areas from 1.0 to 2.5 LSU/ha.

[11] See Wirsenius (2000) for a discussion of problems with feed statistics for South and Central Asia

Scenarios

Methodology

In the scenarios, the demand side of the feed energy balance is estimated first, as described in the previous subsection. Feed supply is then set equal to the estimated feed requirements, and the total allocated to different feed sources. Grazing land and unrecorded sources (such as crop residues) are estimated first, with feed supplied by agricultural products calculated as the remainder.

Grazing Land

In the *Market Forces* scenario, areas of grazing and pasture land in most regions are assumed to increase or decline consistent with past trends, as recorded in FAOSTAT and discussed in the FAO's Country Pasture Profiles (FAO, 2007d), adjusted in light of land-use constraints.[12] Even with expanding trends in Latin America and China+, land-use constraints force pasture growth to be very moderate in China+, and actually reverse to a strong contraction in Latin America. Table 4-10 gives the growth rates for grazed pasture in both scenarios.

The growth or contraction of grazing land is adjusted to manage land constraints arising from agricultural or other land needs (for built environment and forestry). While pasturing animals may be considered desirable, the *Policy Reform* requirement for more meat in the relatively better off non-OECD regions (compared to *Market Forces*), along with the increased amount of reserved (protected) land and other land-use constraints, increases the incentive for raising crops with feed rather than on pasture land. This is why we end up with larger reductions in pasture growth rates in *Policy Reform* scenario.

[12] Historical changes in pasture area recorded in FAOSTAT for most regions show small changes over time. Unfortunately, as discussed above, the reported areas may not correspond to land actually grazed. Rather, it may show land categorized as grazing land by land cover, such as grassland areas, or by legal status, such as land held under grazing permits but not actively grazed. While these limitations must be acknowledged, at present there does not appear to be an alternative data source preferable to the FAOSTAT database.

Table 4-10. Pasture growth rates in scenario years

Average annual growth in pasture area since previous scenario year (%/yr)						
	Market Forces			Policy Reform		
Region	2025	2050	2100	2025	2050	2100
North America	-0.05	-0.05	-0.05	-0.05	-0.05	0.00
Western Europe	-0.05	-0.05	-0.05	-0.15	-0.15	-0.15
Pac OECD	-0.05	-0.05	-0.05	-0.15	-0.15	-0.15
FSU	0.10	0.10	0.10	0.00	0.00	0.00
Eastern Europe	0.00	0.00	0.00	-0.50	-0.80	-0.90
Africa	-1.50	-0.60	-0.60	-2.00	-1.00	-1.20
Latin America	0.00	0.00	0.00	0.00	0.00	0.00
Middle East	-0.10	-0.15	-0.15	-0.15	-0.20	-0.15
China+	0.05	0.05	0.05	-0.05	-0.20	-0.30
South Asia	-1.00	-1.00	-1.00	-1.00	-1.10	-1.30
Southeast Asia	0.10	0.10	0.10	-0.50	-0.60	-0.70

In Africa, FSU and Latin America it is assumed that there are intensive increases in productivity of grazing land, implemented in Polestar through increased stocking rates of animals on pastureland. Changes in a wide range of factors can lead to increased productivity. In Africa, an assumed reduction in the extent of tsetse infestation leads to greater production per animal, as discussed in Box 4-1, above, but also to increased grazing land productivity, as livestock are increasingly raised in more productive, better-watered environments. Taking into account the estimated impact of trypanosomiasis on stocking densities (Swallow, 1999), but assuming that the maximum stocking densities will not be achieved – for example, because the better-watered land is preferred for cropland rather than pasture – between 2005 and 2100 average stocking densities in Africa are assumed to increase from 0.09 LSU/ha to 0.15 LSU/ha.. In the former Soviet Union, in line with the general assumption of a recovery of agricultural productivity, it is assumed that stocking densities in the region nearly triple, from 0.07 to 0.2 LSU/ha between 2005 and 2100. Finally, in Latin America, increases in grazing land productivity arise from an increasing share of meat production on relatively more productive land, captured by an increase in average grazing land productivity from 0.32 to 0.38 LSU/ha (an 18% increase) between 2005 and 2100. All other regions maintain their base year stocking rates throughout the scenarios.

Crop Residues and Household Wastes

Unrecorded feed sources include a variety of different possible feeds, and are referred to in Polestar as the balance of feed. In developing regions, crop residues and household

wastes are particularly important, while in industrialized regions fodder is an important feed source that may go unrecorded in the FAO statistics.

Crop residues are considered as a feed source, and in both scenarios crop production increases, and with it, crop residue production. However, in general, the amount of crop residues available for feed can be expected to increase at a slower rate than crop production. In part, declining availability of residues might be expected because an important strategy for increasing yields in plant breeding programs is to breed crops with a greater "economic" portion of the crop (e.g., the grain) relative to the rest of the total biomass; since the rest of the above-ground biomass is the residue, this is expected to lead to a declining ratio of residue production to crop production.[13] Furthermore, if developing regions follow the pattern in some OECD countries of separating livestock and crop production, then it may not be economical to transport the residues to the animals. Finally, in developing countries today, use of crop residues as feed, fuel and bedding material for animals is diverting nutrients from the soil (Bumb and Baanante, 1996); if more residues are retained in the future to improve the soil, it will reduce the supply available for animals.

Other patterns in the scenarios would tend to increase the supply of residues. With total crop production rising dramatically especially in the developing countries, it can be expected that in some areas more crop residues will be available as feed. Moreover, in the *Policy Reform* scenario, especially, increased recycling of crop residues and wastes is expected as part of combined crop-livestock systems, in which a portion of the nutrients removed from the field with the residue returns in the form of manure (Conway, 1997; J. Bender, 1994).

Following the U.S. Council for Agricultural Science and Technology (CAST, 1999), which based its approach on considerations like those given above, in the scenarios it is assumed that in most regions the availability of non-recorded sources grows proportionally to population. This assumption captures in a rough way the increase in crop production and the production of household wastes. In Africa it is assumed that these sources increase faster than population, because the reduction of tsetse would facilitate the expansion of mixed crop-livestock systems in humid areas.

Livestock and Crop Products as Feed

In the scenarios, the supply of animal products for feed increases in proportion to total livestock production, although this remains a small part of the total amount of feed. This feed from animal products is added to the contribution of feed from unrecorded sources and from grazing land, as discussed above.

The contribution to feed coming from crops is calculated as a balance after the other feed sources discussed have been calculated. Feed energy contents, and the shares of different

[13] In regions where mixed crop-livestock farming systems are an important form of subsistence agriculture, this feature of high-yielding varieties has sometimes made farmers reluctant to adopt them (Humphreys, 1991).

crop commodities in feed supplied by crops (see Table 4-5) are left at their base-year values.

Feed Composition

Changes in use of feed from crops, grazing land and all other sources are shown by region in Figure 4-13 for the *Market Forces* scenario. Changes in the *Policy Reform* scenario are very similar. In most regions the share from the "balance," representing feed from unrecorded sources such as crop residues and animal products, declines. The share of feed from crops increases significantly in most regions. South Asia sees a large increase, as land constraints and current overstocking make expansion of grazing and pasture area unlikely. However, these may also be an artifact of poor base-year data, which are also a likely cause of the high estimated stocking density reported in Table 4-9. Figure 4-14 shows the actual amount of feed demand in all regions in the *Market Forces* scenario. There are dramatic increases in demand in Africa, Latin America, and China due to the huge increase in meat demand from the expanding populations and increased standard of living in these regions. Despite greater consumption and production of meat per capita in non-OECD regions in the *Policy Reform* scenario due to the increased incomes compared to the *Market Forces* scenario, lower populations in the *Policy Reform* scenario leads to similar levels of meat consumption, and in most developing regions feed shares differ little between the two scenarios. However, in China+, Africa and Latin America, ecosystem preservation goals are met in part through a lower expansion or contraction in grazing area, and a correspondingly greater use of feed.

Figure 4-13. Changes in feed composition in the *Market Forces* scenario

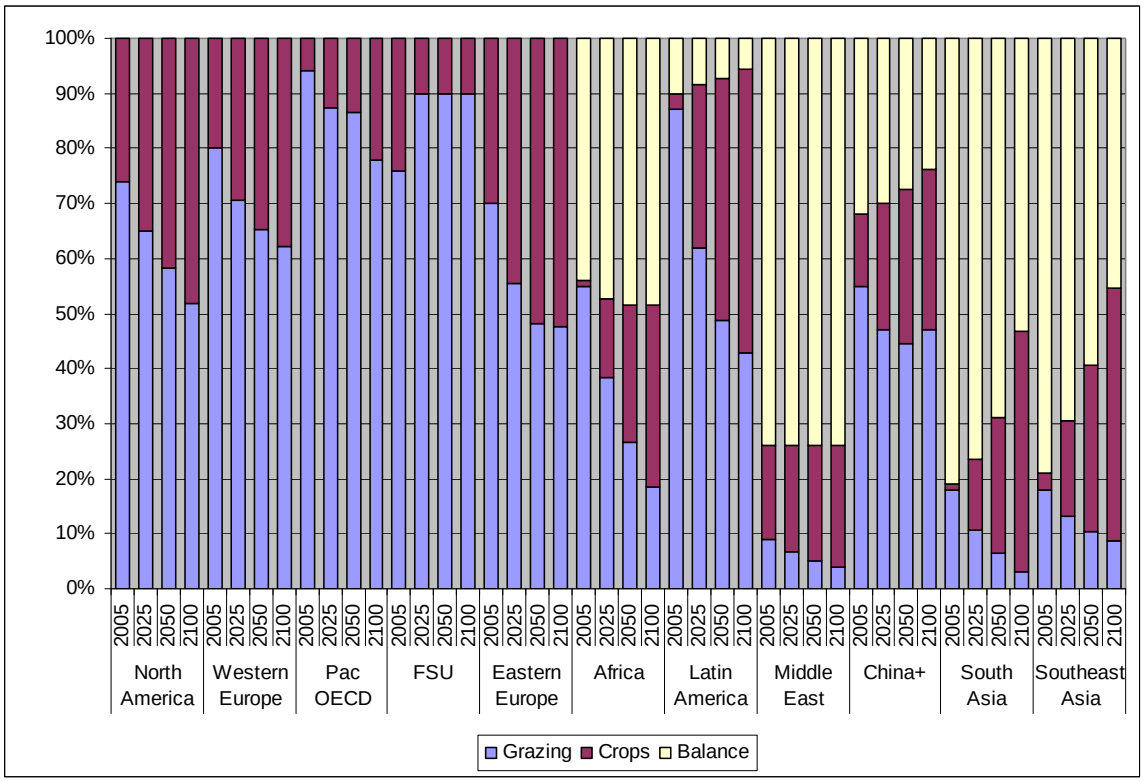


Figure 4-14. Feed growth and composition in the *Market Forces* scenario

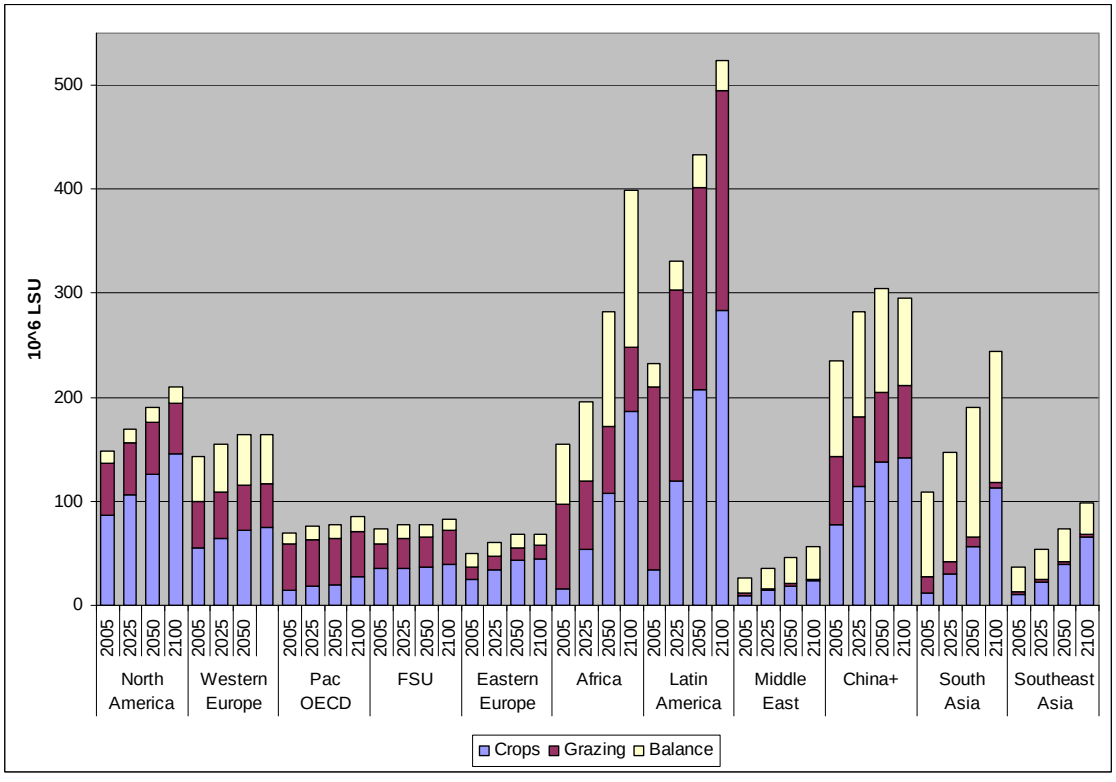


Figure 4-15. Global livestock production in *Market Forces* and *Policy Reform*

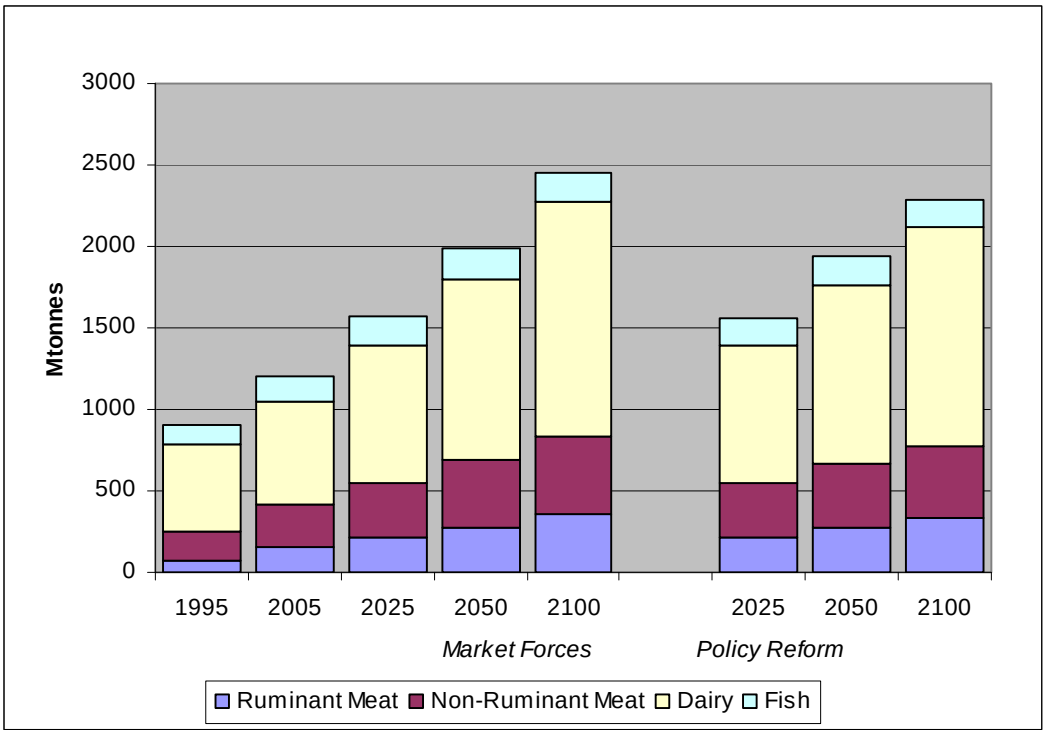
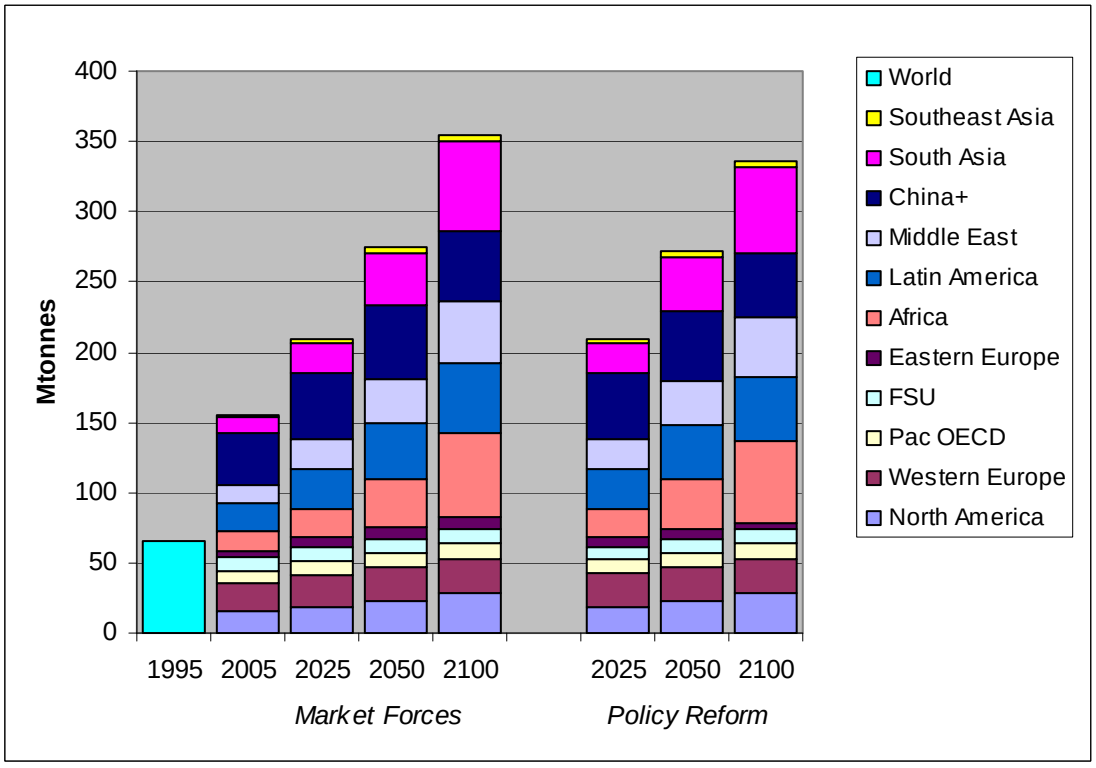


Figure 4-16. Global ruminant animal production by region



Fisheries and Aquaculture

In the base year, the demand for seafood is about 150 million tonnes. Captured seafood accounted for about 95.4 million tonnes in 2005, and global aquaculture produced 63.3 million tonnes in 2005 (FAO, 2008b). However, the fishery yield today is not optimal. Production can be increased in some areas, while in others, stocks are being over-fished. In many areas there is potential for increasing yields by reducing discarded "by-catch."

In the *Market Forces* scenario the demand for fish and other seafood increases between 2005 and 2050 from about 150 million tonnes per year to around 184 million tonnes, followed by a decline in demand by 2100 to 175 million tonnes. The decline is due to the demographic transition, as well as the assumption that the absolute calories per capita of seafood will remain constant, reflecting the decline in fisheries over time. The production from fisheries is assumed to stay at base-year levels, while aquaculture production increases from about 60-65 million tonnes to 90-95 million tonnes.

In the *Policy Reform* scenario the demand for seafood in 2050 is slightly less than that in the *Market Forces* scenario, about 176 million tonnes, followed by a decline in 2100 to 162 million tonnes. The main reason for the difference is the slightly smaller populations assumed in the *Policy Reform* scenario.

Crop Production

Whether supplied domestically or through trade, ultimately, the requirements for crops as food, feed and industrial feedstocks are supplied by the world's available arable land. The growth in crop requirements seen in the scenarios (Table 4-11) must be met either through extensive expansion of the cropped area or due to increases in cropland productivity. For nearly all of the roughly ten thousand years that settled agriculture has been practiced, most increases in production have been of the extensive variety. However, for most of that history, the number of people that were fed was relatively modest. Human populations reached one billion in the first quarter of the 19th Century, well over a million years after the appearance of modern humans. It took only another hundred years to add the next billion, another thirty years to add the third, and the rate of growth continued to accelerate. The world's population growth rate has now begun to slow, but not before population reached six billion, some time during the 1990s (Evans, 1998). The global population has begun to stress the available agricultural land resources. As this pressure has mounted, the growth in crop production has increasingly been of the intensive kind, and during the second half of the 20th Century, nearly all of the increase in crop production was achieved through productivity increases. Thus, in the thirty years between 1961 and 1991, as cereal production more than doubled, total cropland increased by only 11%. Thus, the potential to increase productivity further will probably play a determining role in expanding the world's supply of crops in the coming decades.

Cropland productivity is conventionally separated into two factors: yield per harvest and the number of harvests per year on a given piece of cropland, or cropping intensity. The average annual yield – the ratio of total annual production to total cropland area – is the product of the yield per harvest and the cropping intensity, and provides an overall measure of the productivity of cropland. Historically, there have been increases in both factors. Yields can be raised in a number of ways – by reducing the impact of pests and diseases, supplementing the soil with nutrients and water, adopting practices to retain soil and water, and introducing crop varieties that devote more of their biomass to the part of the plant that will be used, such as the grain, fruit or root, and less to the leaves and stems. The cropping intensity can be raised by, for example, shortening fallow periods (sometimes with detrimental impacts on cropland), through irrigation or water conservation, by breeding plant varieties with short growing periods, or by introducing practices to maintain soil fertility during intensive cropping.

Table 4-11. Demand for crops

Mtonnes	Wheat & Coarse Grains				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	312	446	507	426	459
Western Europe	193	237	238	237	236
Pac OECD	61	78	101	82	110
FSU	113	106	110	103	103
Eastern Europe	102	147	144	143	120
Africa	165	485	692	473	641
Latin America	138	543	706	466	550
Middle East	64	128	151	120	134
China+	248	354	339	346	332
South Asia	123	229	267	225	252
Southeast Asia	37	93	134	91	126
World	1,557	2,847	3,388	2,712	3,063

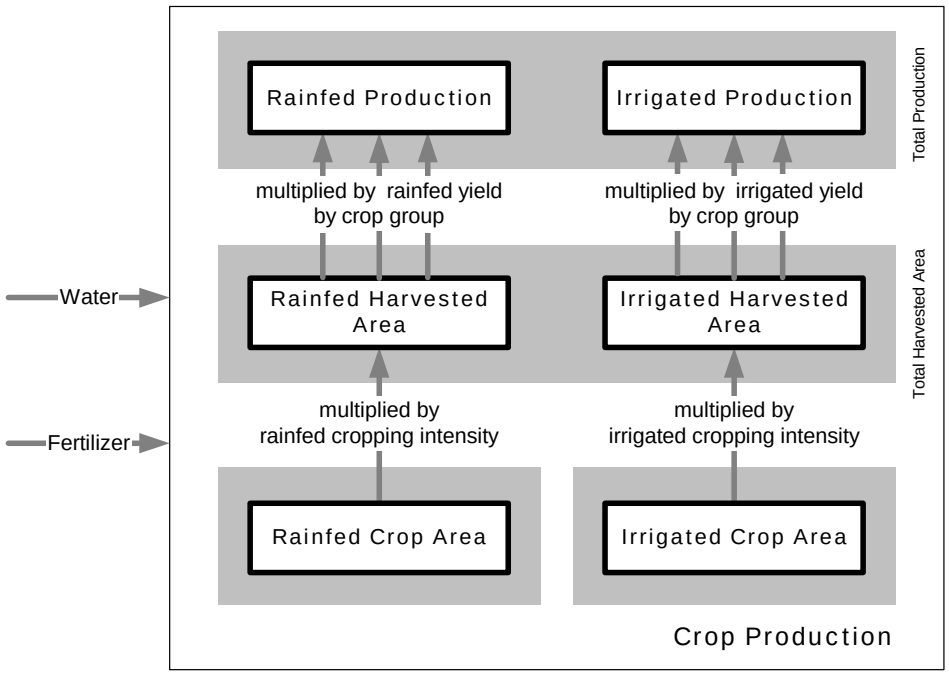
Mtonnes	Rice				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	4	6	6	5	5
Western Europe	3	3	3	3	3
Pac OECD	20	19	20	19	20
FSU	2	2	2	2	1
Eastern Europe	2	2	1	1	1
Africa	29	69	90	66	81
Latin America	28	44	44	41	38
Middle East	10	21	24	20	21
China+	212	230	191	218	172
South Asia	172	287	286	274	256
Southeast Asia	123	185	188	176	170
World	606	867	854	826	769

Table 4-11 Continued. Demand for crops

Mtonnes	Other Crops				
	2005	2050-MF	2100-MF	2050-PR	2100-PR
North America	280	373	397	352	351
Western Europe	370	377	338	366	317
Pac OECD	125	126	134	124	130
FSU	208	193	194	185	177
Eastern Europe	126	141	116	130	96
Africa	513	1,388	1,982	1,350	1,828
Latin America	666	1,175	1,253	1,095	1,086
Middle East	146	318	388	304	351
China+	965	1,218	1,095	1,170	1,011
South Asia	592	1,180	1,421	1,156	1,331
Southeast Asia	271	426	451	410	411
World	4,262	6,914	7,768	6,642	7,089

The structure of the crop production analysis adopted for this study is illustrated schematically in Figure 4-17. Both rainfed and irrigated cropland produce crops. In tropical regions, water is a major determining factor of the length and timing of the growing season, which can be extended with irrigation. Moreover, yields on irrigated land are generally much higher than on rainfed land. For these reasons, separate cropping intensities and yields are applied in the analysis to irrigated and rainfed land. For each hectare of harvested area, either rainfed or irrigated, there is a corresponding crop that is being harvested. Accordingly, total harvested area is allocated by crop commodity group. Multiplying the harvested area by yield per harvest gives total crop production. As indicated by the arrows pointing into the “crop production” box, changes in fertilizer and water inputs are associated with changes in irrigated area and yields over the course of the scenarios.

Figure 4-17. Structure of crop production analysis



Note: Items in gray boxes are reported together in FAO statistics (total rainfed and irrigated cropland, harvested area by crop and production by crop), and are disaggregated for the analysis using additional data and assumptions.

Figure 4-17 also illustrates some of the difficulties encountered in the construction of the base-year data set. The FAO statistics report total cropland and total irrigated cropland. Also, they report total harvested area by crop and total crop production. These categories are shown in the shaded boxes in Figure 4-17. However, for the analysis here it is important to capture the advantages of irrigation, which can increase both yields and cropping intensities. Consequently, the FAO base-year data must be disaggregated for the scenario analysis. Additional data and assumptions are introduced to disaggregate the FAO data, as described in this section.

Irrigation

Current Accounts

In areas where rainfall is insufficient to support crops, or where limited rainfall constrains the length of the growing season, cropland can be irrigated to make it productive. General data on irrigated agricultural area is taken from the EarthTrends database (WRI, 2007). Data on irrigated area by crop are scarce, with the exception of rice. Given the importance of irrigated rice production in some regions, for this analysis an effort has been made to estimate the amount of land area devoted to irrigated rice in major rice-producing countries. Irrigated land is assigned to rice using data from two sources, FAO's AQUASTAT program (FAO, 2007e), and the *Riceweb* database administered by

the International Rice Research Institute (IRRI, 1999). Regional estimates for the major rice-producing regions are shown in Table 4-12. The remaining irrigated land is assigned to the other two crop commodity groups – wheat and coarse grains, and all non-cereal crops – in proportion to harvested area.

Table 4-12. Irrigated rice area in major rice-producing regions

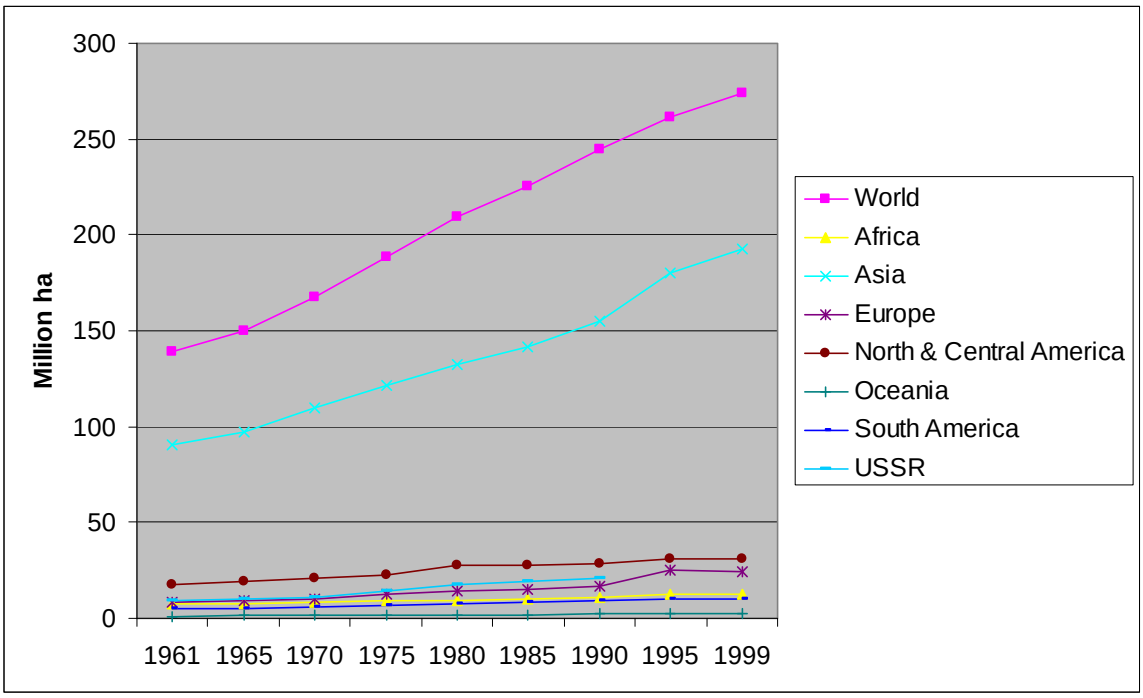
	Irrigated Area (%)
China+	77 *
South Asia	38
Southeast Asia	28
Latin America	16
Africa	10
Pac OECD	99
North America	100

* For China alone, the fraction is 92%

Source: IRRI, 1999

Historically, over the period 1961 to 1999, irrigated area increased in all regions, as shown in Figure 4-18 although it has recently declined in Eastern Europe and the FSU (a trend that is assumed to reverse in the scenarios). The expansion of irrigation has been one of the major factors underlying the growth in aggregate cropland productivity over the past half-century.

Figure 4-18. Irrigated area by region, 1961 to 1999



Source: Pacific Institute (2008). Note: After 1990, all irrigated area in the former USSR (FSU) is split among Europe and Asia.

Scenarios

Expansion of irrigated area in the future will be constrained by the amount of land suitable for irrigation, or the *irrigation potential*. However, estimates of irrigation potential are beset with difficulties. Beyond physical considerations – availability of water, nature of the soils, temperature – the potential for expansion of irrigation is influenced by economic and political considerations, especially when the water must be transported across country boundaries (Alexandratos, 1995). Bearing the uncertainties in mind, in general terms it seems likely that the potential for expansion of irrigated agriculture is much less than that of rainfed agriculture (Alexandratos, 1995; FAO, 1995; Leach, 1995; Seckler, 1996).

Changes in irrigated area in the scenarios, which reflect the limited potential for expansion, are based on the FAO scenario *Agriculture Toward 2015/2030* (FAO, 2000a) for developing countries and on the agricultural scenario of Leach (1995) for industrialized countries.

Irrigated areas in the *Market Forces* and the *Policy Reform* scenarios are shown in Table 4-13. For the *Policy Reform* case, the net increase in irrigated land area comes from less degradation of irrigated lands, and more policies to expand irrigation. Additionally, the efficiency of application of irrigation water improves through technology and policy improvements (see Chapter 6). Reduced production is made up partly through increased imports, a strategy often described as importing "virtual" water contained in the crops.

Table 4-13. Change in irrigated area in *Market Forces* and *Policy Reform*

	Market Forces				Policy Reform		
	Irrigated Area, Mha			Index	Irrigated Area, Mha		Index
	2005	2050	2100	2100/2005	2050	2100	2100/2005
North America	23	25	25	1.06	26	26	1.11
Western Europe	13	15	15	1.12	16	16	1.17
Pac OECD	6	6	6	1.00	7	7	1.06
FSU	21	23	23	1.12	27	28	1.32
Eastern Europe	10	11	11	1.12	12	13	1.33
Africa	13	17	17	1.31	13	11	0.85
Latin America	19	23	23	1.22	26	27	1.46
Middle East	18	17	17	0.93	17	17	0.94
China+	59	69	64	1.08	78	79	1.33
South Asia	81	98	84	1.04	89	77	0.95
Southeast Asia	14	18	18	1.31	15	12	0.89
World	277	323	302	1.09	324	312	1.13

Yield and Cropping Intensity

Current Accounts

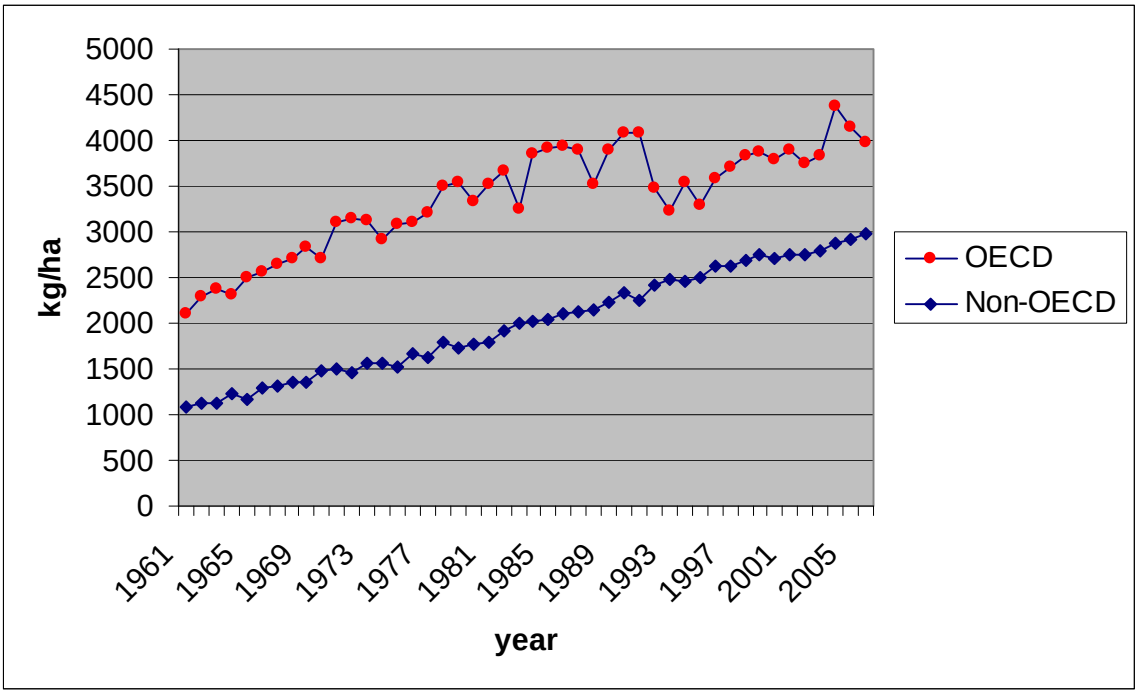
Total production and harvested area are available by crop from the FAOSTAT database (FAO, 2007a). The relationship between the FAO data and the data requirements for this analysis are shown schematically in the introduction to this section (Figure 4-17). As discussed above, in order to construct a data set at the level of detail required for the analysis, the FAO data are disaggregated further using additional assumptions. In particular, additional data and assumptions are introduced in order to estimate yields and cropping intensities separately for rainfed and irrigated land.

As shown in Figure 4-19 for cereals, average aggregate cropland productivity increased in all regions between 1961 and 2005. The indicator shown in the figures is *annual* yield averaged over both rainfed and irrigated cropland – that is, total annual production divided by crop area, equal to the product of the yield per harvest and the cropping intensity, averaged over rainfed and irrigated land. Both yields per harvest and cropping intensities have increased in past decades, but harvest yields have grown by greater factors. At the global level, between 1961 and 2005, cereal yields have increased by almost 2.5 times. At the regional level, and focusing on East and Southeast Asia, where multiple cropping increased considerably as a result of Green Revolution technologies,

aggregate crop intensities rose by just under 20% between 1961 and 1991. While this increase is substantially higher than the global average of 6%, cereal harvest yields grew by a greater amount, more than 80%, over the same period (FAO, 2007a).

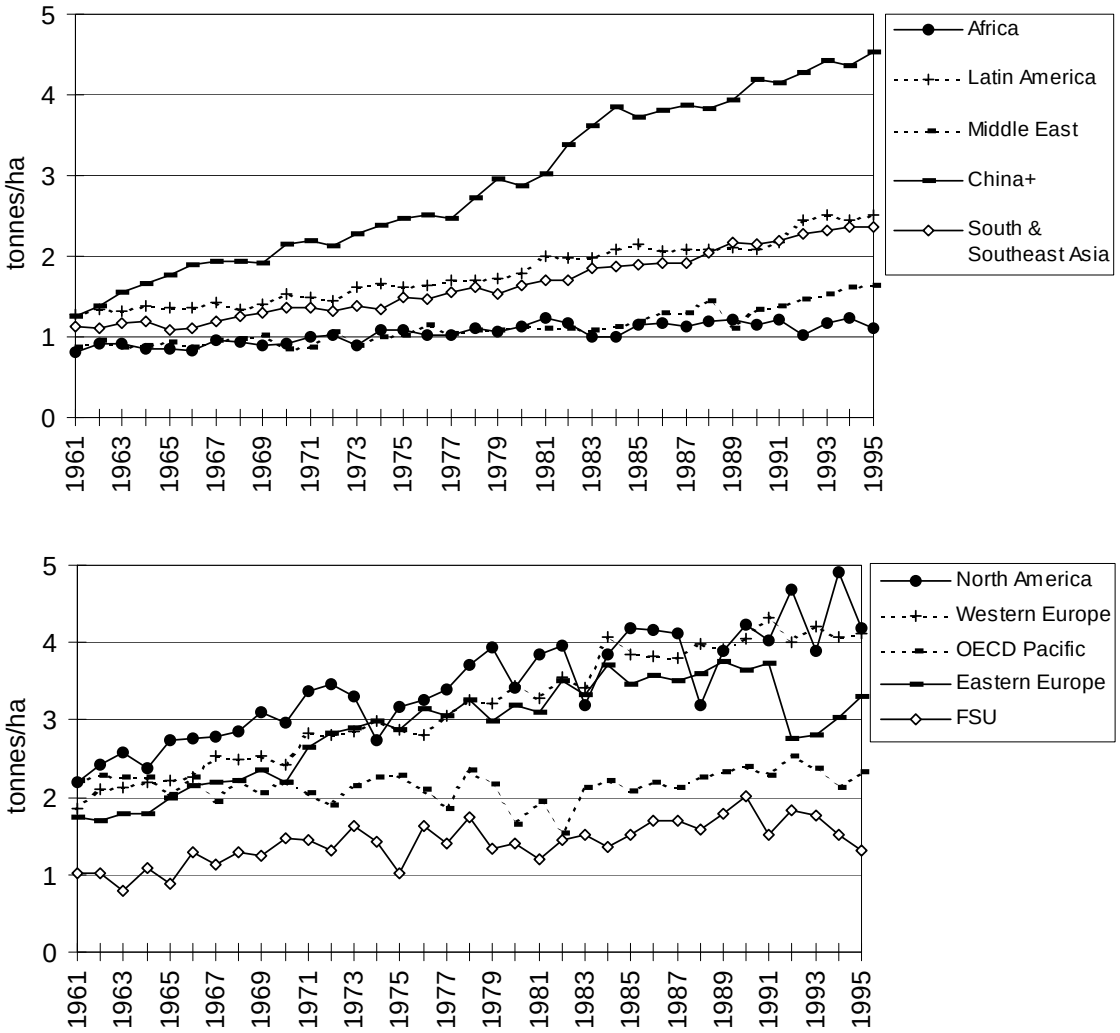
The yield trends in Figure 4-19 and Figure 4-20 exhibit a wide range of regional experiences. For example, cereal yields in China+ increased rapidly in the decades following 1961, while those in Africa remained almost unchanged. The OECD yield growth was strong and steady in Western Europe and North America. However, yield growth was slow in the former Soviet Union. Climate and soil constraints play a role in creating these divergences, but political and institutional settings also contribute. In particular, the strategies pursued in the Green Revolution tended to favor certain crops, climates and farming systems. These factors, in combination with institutional ones, led to greater yield gains in Asia and Latin America than in Africa or the Middle East.

Figure 4-19. Historical annual cereal yields by Macro-Region



Source: FAO (2008a)

Figure 4-20. Additional historical annual cereal yields by region



Source: FAO (1996b)

Disaggregating Base Year Data

In order to disaggregate the base-year figures at the level of rainfed versus irrigated production, ratios of yield and cropping intensity on irrigated land to those on rainfed land were estimated for each of the three main crop commodity groups. Given these ratios, as well as the area of irrigated land by crop and the FAOSTAT data, it is possible to assign yields and cropping intensities separately to irrigated and rainfed land.

Data on the relative productivity of irrigated and rainfed land at the national or regional level are surprisingly scarce. For the current accounts, two sources were used. First, for tropical and subtropical areas, Fischer (1993) provides yield and cropping intensity ratios for nine crop categories for five developing regions: Sub-Saharan Africa, Latin America, Middle East and South Asia and Southeast Asia. Second, at the global level, the study by

FAO/IIASA (2000) provides estimates of maximum theoretical yields, at intermediate input levels, for a detailed list of crops by climatic region (temperate, tropical, subtropical).

For developing the current accounts figures, yield and cropping intensity ratios were applied to a disaggregated list of crop commodities, and the results then aggregated to the three crop commodity groupings used in this analysis For countries in Africa, Latin America, Middle East or South and Southeast Asia, the ratios given in Fischer (1993) were applied directly. For China+, cropping intensity ratios are based on figures for China reported in FAO (2000a). For temperate regions (the OECD and transitional regions), and for yield ratios in China+, it is assumed that the ratio of the theoretical maximum yields on rainfed and irrigated land is similar to the ratio of actual yields. For these regions, the yield ratios used to disaggregate the data were set equal to the ratios of the maximum theoretical yields from FAO/IIASA (2000). It is assumed that cropping intensities in temperate areas are similar on irrigated and rainfed land, and they are assigned the same value when disaggregating the base year data. This assumption is consistent with estimates given in FAO/IIASA (2000). Also, this can be expected in principle. In temperate regions, the growing season is limited more by temperature than by rainfall, while the opposite is true in tropical regions, so that in tropical regions irrigation can serve to extend the growing season, and thereby increase the cropping intensity, while in temperate regions it generally serves to make otherwise unproductive land productive. Base year estimates for yields and cropping intensities are shown in Table 4-14.

Table 4-14. Yields and crop intensities in 2005

2005	Yield per Harvest, t/ha						Crop Intensity	
	Wheat + CG		Rice		Non-Cereal Crops			
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
North America	6.5	5.6	7.4	-	10.0	9.2	0.7	0.7
Western Europe	6.2	5.4	7.7	6.0	19.8	18.0	0.9	0.9
Pac OECD	2.4	2.1	6.7	5.3	21.1	18.3	0.5	0.5
FSU	2.2	1.9	4.2	3.3	8.5	7.2	0.6	0.6
Eastern Europe	3.8	3.3	8.2	6.4	13.3	12.0	0.8	0.8
Africa	4.4	1.1	5.2	1.9	11.1	4.8	1.3	0.9
Latin America	5.7	2.6	7.6	2.8	8.4	6.4	1.2	0.8
Middle East	2.3	0.9	3.8	3.9	10.2	6.5	1.2	0.4
China+	5.5	4.2	6.2	4.6	11.5	9.8	1.3	1.1
South Asia	2.9	1.2	4.2	2.5	6.3	3.9	1.4	1.1
Southeast Asia	6.4	2.5	5.0	3.1	18.8	10.2	1.2	1.0

Scenarios

The yield and cropping intensity assumptions in the scenarios are based on several sources. Crop yields were developed taking into account historical trends and the recent estimates of potential yields at intermediate levels of inputs from FAO (2008a) and FAO's report World Agriculture towards 2015/2030 (FAO, 2000a). Long-term trends were developed for the OECD and non-OECD macro-regions. Yields of non-cereal crops are actually projected to decrease in OECD regions, and to increase in non-OECD regions, based on representative changes for non-cereal crops in the FAO historical data. The linear growth rates for the yields of the three crop types are the same in both the *Market Forces* and *Policy Reform* scenarios, and are given by macro-region in Table 4-15.

Table 4-15. Crop yield growth rates for Macro-Regions

kg/ha/year	Yield Linear Growth Rates		
	Wheat + CG	Rice	Non-cereal Crops
OECD	38	41	-15
Non-OECD	32	41	91

Cropping intensities in industrialized regions are based on Leach (1995) and FAO/IIASA (2000), while cropping intensities in developing regions are based on the FAO scenario *Agriculture Towards 2015/2030* (FAO, 2000a). The cropping intensity trends, which are the same in the two scenarios, are shown in Table 4-16. In 2100, all irrigated crop intensity indices stay at the 2050 level, however all rainfed crop intensity indices increase by 5% from the 2050 level.

Table 4-16. Crop intensity in 2100, index relative to 2005

	Crop Intensity Index	
	Irrigated	Rainfed
North America	1.12	1.16
Western Europe	1.00	1.00
Pac OECD	1.25	1.26
FSU	1.00	1.00
Eastern Europe	1.00	1.00
Africa	1.23	1.18
Latin America	1.17	1.20
Middle East	1.13	1.17
China+	1.10	1.13
South Asia	1.12	1.13
Southeast Asia	1.09	1.07

The assumption that trends in cropland productivity are the same in the two scenarios requires some explanation. After all, the social, economic and policy environments in the two scenarios are quite different. However, the relevant factors impact yields in different ways, with some contributing to higher yields and others leading to lower yields, and the quantitative impacts are poorly known. Some of these factors are described below. For the scenarios, given the indeterminacy of the direction of changes in yields – whether they are higher or lower under *Policy Reform* conditions compared to *Market Forces* – yields and cropping intensities are assumed to be the same.

One factor that could lead to increased yields in the *Policy Reform* scenario relative to the *Market Forces* scenario is wider use of small-scale soil and water-conserving technology. Increasing the efficiency of use of available rainwater can effectively extend the growing season, so that more than one crop can be harvested. This can be accomplished in several ways: surface runoff can be captured behind earthen bunds; conservation tillage can be introduced; and in areas with a monsoon season, water storage and mulching can make water available for crops during the dry season (Hudson, 1992; Conway, 1997; Krishnamoorthy, 1983). These and similar efforts can reduce the rate of cropland degradation, in addition to raising yields.

Slowing the rate of crop degradation, and restoring degraded land would also contribute, other things remaining equal, to higher yields in the *Policy Reform* scenario. The effects of degradation are present in the historical yield trends. Since the *Market Forces* scenario projections are based in part on the historical trends, to some degree the effects of future land degradation are incorporated in the scenario (Leach, 1995). In the *Policy Reform* scenario, land degradation is assumed to slow and then reverse, as damaged land is recovered through careful management. The effects of land degradation on yields are poorly understood, but there is some evidence that they may be significant. The areas affected are large: in a study commissioned by UNEP, it was estimated that almost 2 billion hectares of cropland, grazing land and forest has been degraded to some degree as a result of human action since the second world war (Oldeman et al., 1991). Of this, about 30% was due to agricultural practices. In some cases the damage led to reduced yields, through nutrient loss, salinization or other reasons. (More severe degradation is discussed in the section on cultivated land on page 179.) The effects of land degradation on yields have been found to be significant in the few cases where they have been estimated (Scherr and Yadav, 1996). In Africa, for example, as a consequence of erosion, yields may have been between 2% and 40% lower than they would have been otherwise. Thus, reduced land degradation in the *Policy Reform* scenario compared to the *Market Forces* scenario could have a significant impact on yields.

One factor that can lead to lower yields in the *Policy Reform* scenario relative to the *Market Forces* scenario is the replacement of high-input farming practices with low-input approaches. For example, application of manufactured fertilizer is assumed to decrease in the *Policy Reform* scenario relative to *Market Forces* scenario practices (see the section on fertilizers beginning on page 188). The reduction is accompanied by increases in natural inputs, such as organic fertilizer, manure and crop residues. In the analysis it is

assumed that manufactured inputs can be cut in half without a significant decrease in yields or cropping intensities. However, note that this would most likely not be true if inputs were removed completely, as soil nutrients might then be a limiting factor on production, leading to a reduction in yield (Penning de Vries et al., 1996).

Cultivated Land

Current Accounts

Globally, cropland accounts for 12% of total land area (Table 4-17). About 18% of cropland is irrigated, with the proportion differing considerably from region to region. Total irrigated area by region, and changes in irrigated area over the course of the scenarios, is discussed above (page 170). Considering the relative importance of irrigation, it is highest in China+, the Middle East and South Asia, where close to 40% of the total area is irrigated. The lowest percentage of cropland under irrigation is found in Africa, where only 6% of cropland is irrigated.

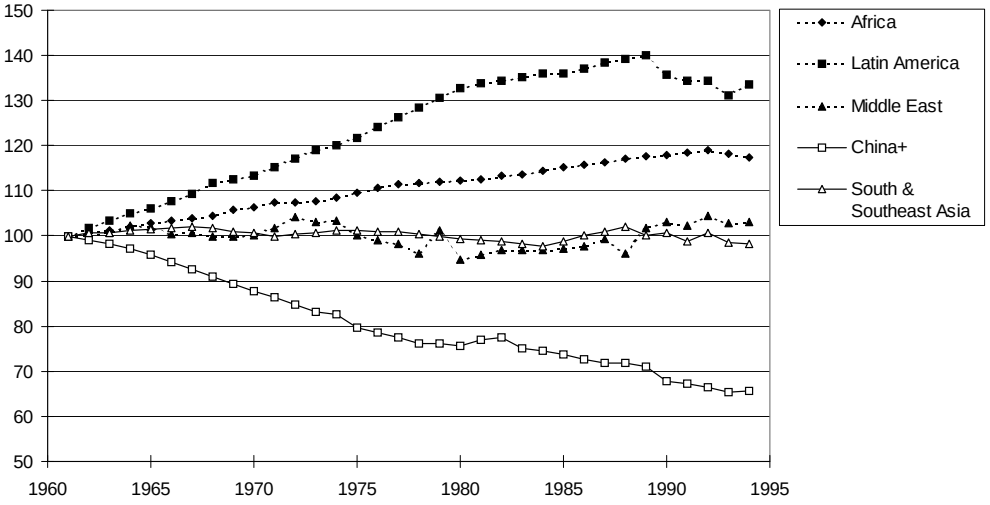
Table 4-17. Cropland area – 2005

	Area (Mha)		Cropland as %
	Rainfed	Irrigated	of Total Land Area
North America	206	23	13%
Western Europe	76	13	22%
Pac OECD	54	6	7%
FSU	183	21	10%
Eastern Europe	55	10	37%
Africa	218	13	8%
Latin America	146	19	8%
Middle East	25	18	7%
China+	102	59	14%
South Asia	124	81	50%
Southeast Asia	75	14	21%
World	1266	277	12%

Historically, rainfed cropland area either remained steady or declined in most of the regions between 1961 and 1994, as seen in Figure 4-21 and Figure 4-22. In only three regions – Africa, Latin America and Pacific OECD – did rainfed area grow over the period, and in each of these regions, the growth is already showing signs of slowing in the figures. The absolute increases in irrigated area (Figure 4-18) have therefore been accompanied by relative increases. Because yields are higher on irrigated land, the

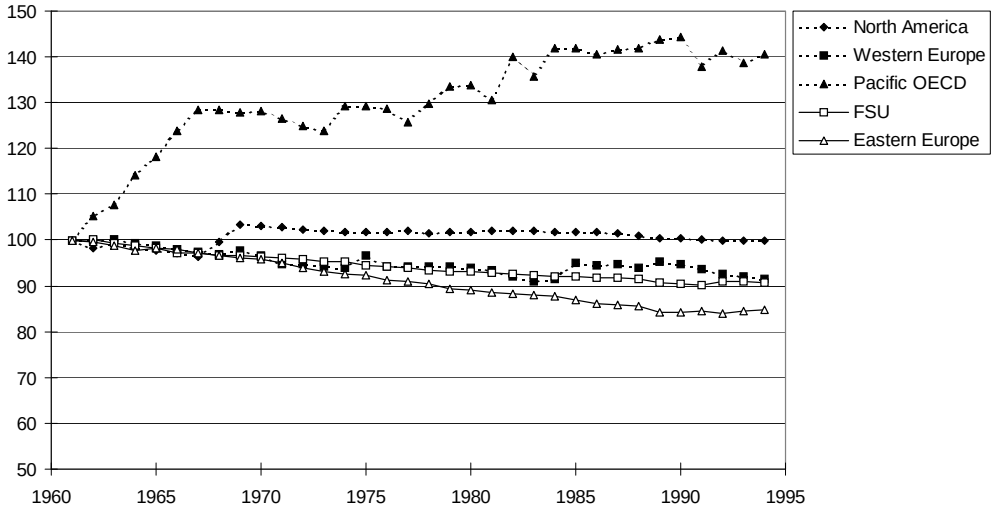
increase in the proportion of land under irrigation has contributed to higher average yields.

Figure 4-21. Rainfed area index – developing regions, 1961-1994



Source: FAO (1996b)

Figure 4-22. Rainfed area index – OECD and transitional regions, 1961-1994



Source: FAO (1996b)

Potentially Cultivable Land

Increases in cropland area in the scenarios are constrained by the suitability for crop production of land currently being used for other purposes. The supply of water must be

sufficient; the temperature must be within a suitable range for a sufficiently long time; the soils must not be too salty, alkaline or acidic, and they must provide essential nutrients. The ability to grow crops is also affected by soil slope and texture, the seasonal pattern of rainfall, and how hard the raindrops strike the ground. Note that these factors are not constant, and some are susceptible to human intervention: the fertility of the soil can be enhanced or degraded by agricultural practices, pollution, or other causes; lime can be applied to acidic soils; and water can be stored from one season to the next, to smooth over variations in rainfall.

A study undertaken jointly by the FAO and the International Institute for Systems Analysis (IIASA), provides estimates of potential cropland for most countries of the world, under different agricultural practices (FAO/IIASA, 2000). The study also includes an assessment of the extent of potential agricultural land currently under forest, an important consideration in the *Policy Reform* scenario, where limiting deforestation is one of the sustainability goals. For the present analysis, national estimates of potential cropland area from the FAO/IIASA study (at "mixed" levels of inputs, optimized for local conditions) were aggregated to give regional totals. In the Middle East and South Asia, the reported current cropped area exceeded the estimated potential. In these regions, potential cropland was increased for the purposes of this analysis.[14]

The values for potential cropland area adopted for this study are shown in Table 4-18, along with the estimated potential crop area under forest and the current extent of cropland as a proportion of the total. For this study we have assumed that all exploitable forest and plantation forest areas could potentially be converted to forest area, adding substantially to the total potential cropland (PCL). Note that while in some areas, such as Africa and Latin America, the estimated potential for the expansion of cropland is considerable, the suitable lands are often remote, and a considerable proportion of the land is currently under forest. In the Middle East and South Asia there is relatively little remaining potential cultivable land, and it is almost entirely under forest.

[14] As noted in Alexandratos (1995), discussing a previous FAO/IIASA assessment, land classified as "not suitable" based on potential yield may still be used for rainfed agriculture in some circumstances. They note that in North Africa and the Near East a large amount of potentially productive land is located in mountainous areas, much of which is judged unsuitable because of the steep slope of the land. Nevertheless, such land may be terraced to make it productive, overcoming one of the criteria used in the assessment (Alexandratos, 1995). In this study it is assumed that the economic and social conditions that make otherwise marginal land attractive for cultivation in the Middle East and South Asia continue in the future, so total potential cropland is set at a higher level than the FAO/IIASA figures would suggest.

Table 4-18. Area of potential cropland (PCL) – 2005

	Potential Cropland (Mha)	% Uncultivated PCL Under Forest	Cropland as % of PCL
North America	875	64%	26%
Western Europe	302	59%	30%
Pac OECD	365	65%	17%
FSU	1323	57%	15%
Eastern Europe	144	50%	45%
Africa	1171	51%	20%
Latin America	964	62%	17%
Middle East	65	77%	67%
China+	428	90%	38%
South Asia	268	99%	76%
Southeast Asia	312	59%	28%
World	6,217	61%	25%

Scenarios

Changes in crop area in the scenarios are determined by three factors: crop production, which is in turn determined by crop requirements and trade; increases in cropland productivity, through higher yields and cropping intensities; and the expansion of irrigated land. Changes in all of these factors have been described in previous sections.

Given the changes in the factors, which determine crop output, crop area in the scenarios can be calculated. The results are shown in Table 4-19. At the global level, crop area is nearly identical in the two scenarios. Despite the higher demand for crops, in the *Policy Reform* scenario, and similar levels of regional productivity, shifts in production from regions with relatively low productivity to regions with higher productivity leave total global cropland unchanged.

The Middle East, China+ and South Asia encounter limits to potential cropland expansion. Combined with the continued loss of cropland to degradation (discussed in more detail below), land constraints lead to a reduction in crop area in these regions, despite sharply rising demand. In the case of the Middle East and South Asia, land constraints are significant enough to be reflected in declining self-sufficiency ratios, as shown in Table 4-3 and Table 4-4. The influence of land degradation on limiting cropland expansion in these regions can be seen in a comparison of the *Market Forces* and *Policy Reform* scenarios. The lower rates of cropland degradation in the *Policy*

Reform scenario generally permits a greater degree of cropland expansion in these regions when compared to the *Market Forces* scenario.

Table 4-19. Cropland area in the scenarios

Areas in Mha	Market Forces					
	2005	2025	2050	2100	2050/2005 Ratio	2100/2005 Ratio
North America	229	281	314	327	1.37	1.43
Western Europe	90	110	115	106	1.28	1.18
Pac OECD	60	55	44	40	0.72	0.67
FSU	204	186	152	118	0.74	0.58
Eastern Europe	65	52	48	34	0.75	0.52
Africa	231	278	298	255	1.29	1.10
Latin America	165	233	260	222	1.58	1.35
Middle East	43	39	33	21	0.77	0.48
China+	162	147	115	65	0.71	0.40
South Asia	204	157	128	84	0.62	0.41
Southeast Asia	89	124	125	97	1.41	1.09
World	1542	1661	1631	1369	1.06	0.82

Areas in Mha	Policy Reform				
	2025	2050	2100	2050/2005 Ratio	2100/2005 Ratio
North America	274	293	278	1.28	1.21
Western Europe	109	111	95	1.23	1.06
Pac OECD	56	45	41	0.74	0.67
FSU	184	143	100	0.70	0.49
Eastern Europe	51	46	28	0.71	0.43
Africa	285	298	243	1.29	1.05
Latin America	216	221	162	1.34	0.98
Middle East	41	42	50	0.97	1.16
China+	148	128	95	0.79	0.59
South Asia	154	124	83	0.61	0.40
Southeast Asia	121	114	74	1.28	0.84
World	1638	1564	1248	1.01	0.75

In the *Market Forces* scenario, most of the increase in cropland area by 2100 occurs in North America, where the increase of 43% over the course of the scenario occurs due to global pressure on agricultural production systems for food and grain as populations increase, and as diets improve and include more meat raised in feedlots. In the *Policy Reform* scenario, the largest increase is again in North America, where cropland expands by 21% between 2005 and 2100. Land areas also increase significantly in Latin America, Southeast Asia, and Western Europe in the *Market Forces* scenario, where cropland expands to supply rising demand in developing regions. Several developing regions see declines in cropland area over the course of the *Policy Reform* scenario, especially South Asia and the FSU, however these regions continue to see increases in their total production due to improved technologies and policies leading to increasing use of irrigation, and improved crop yields and crop intensities. Cropland area in most regions in the *Policy Reform* scenario in 2100 is below the *Market Forces* level, as crop area expansion is restricted in order to meet ecosystem preservation goals.

Cropland Degradation

Even as the requirements for cropland increase in each scenario, some existing cropland becomes degraded to the point where it is no longer productive. Degradation processes add to the total area of forest and grazing land that must be brought under cultivation in the scenario. Globally, cropland is assumed to be lost to severe degradation in the *Market Forces* scenario at a rate of 3 million hectares per year.[15] In addition, cropland is converted to the built environment at roughly more than a million hectares per year. As crop area on average increases by about 3 million hectares per year throughout the scenarios, around 7.6 million hectares must be converted each year from existing forest or grazing land, higher than the estimated rate of 5.7 million hectares per year for years between 1980 and 1990 (see Box 4-2).

[15] This value is higher than the historical rate of 2.15 million hectares per year of severe degradation shown in Table 4-21, but lower than some estimates of current rates of degradation. Kendall and Pimentel (1994) report that cropland is lost to urbanization and degradation at a rate of over 10 million hectares per year. In the *Market Forces* scenario, cropland is converted to the built environment at about 1.6 million hectares per year on average: added to degradation rates, the total loss of 4.6 million hectares per year is about half their estimate.

Turning to regional patterns, historical rates of cropland degradation are shown in Table 4-21. In the table, degraded land is identified as being either “lightly,” “moderately” or “severely” degraded, based on the categories used for the GLASOD study (see Box 4-3) (GRID/UNEP, 1991). Land identified as severely degraded in the table corresponds to a degree of damage severe enough that land must be pulled from production (Oldeman et al., 1991). In the future, some of the land that is “moderately” degraded today is likely to become severely degraded, and in this way serves as an indicator of possible future trends. However, note that in all but one of the transitional and OECD regions rates of moderate degradation are considerably higher than rates of severe degradation, indicating that some effort has been expended to keep cropland from becoming unproductive. After examining the historical rates of moderate and severe degradation, and bearing in mind this pattern in the OECD and transitional regions, the rates of cropland loss due to severe degradation shown in Table 4-22 were adopted for the scenarios for the base year. In the *Market Forces* case, these rates of degradation continue through 2100. In all regions except the Middle East the rate of cropland degradation in the scenario is between the rates of “moderately” and “severely” degraded cropland in the past (See Table 4-21). (In the Middle East there is very little potentially cultivable land left, and it is assumed that even in the *Market Forces* scenario some effort will be made to slow the rate of degradation.)

Box 4-2. Clearing for cropland

Historical rates of land use change were estimated by Houghton and Hackler (1995) for eight regions, six of which are very similar in composition to five of the eleven regions used in this study, and one of which, S+SE Asia, is similar in composition to this studies' South Asia and Southeast Asia combined. Coverage in time, and coverage of ecosystems, was limited by the available data: for South and Southeast Asia they present conversions from six forest types and grassland to cropland, while for tropical Africa they present only total clearing rates for two types of forest. The rates of conversion of all forest types and grassland to cropland for each of their regions for a recent year or period are shown in Table 4-20.

Table 4-20. Clearing for cropland (million hectares per year)

Mha / year	Forest + Woodland		Grass + Scrub		Year of
	Clearing	Shifting Cult.	Clearing	Shifting Cult.	Estimate
N. America	0.00	-	0.00	-	1980
Pacific Dev.	0.08	-	0.12	-	1980
Europe	-0.60	-	-0.20	-	1980
FSU	0.02	-	0.02	-	1985
Tropical Africa	Forest clearing: 6 Mha/year				1990
N. Africa+Middle East	0.15	-	1.32	-	1980
China	0.07	-	0.59	-	1980
S+Central America	1.13	16.25	0.52	-	1990
S+SE Asia	2.46	10.68	0.00	0.00	1990

Source: Houghton and Hackler (1995).

Based on these estimates, about 3.3 million hectares of forest and 2.4 million hectares of grassland are cleared annually for crops. A further 27 million hectares of forest land is cleared each year for shifting cultivation. This temporary clearing is generally part of a long-term cycle, in which previously cleared land is allowed to grow back under native vegetation (Greenland and Okigbo, 1983). However, within the 1990s, at least, the rate of clearing appears to be exceeding the rate of regrowth (FRA, 1996).

In the *Policy Reform* scenario, in keeping with the sustainability goals, land degradation is assumed to proceed in each region at less than the historical rate. For lightly and moderately degraded land this contributes to the maintenance of yields relative to the *Market Forces* scenario. It is also reflected in a lower rate of cropland loss resulting from severe degradation. Between 2005 and 2025, cropland is lost at roughly half the *Market Forces* rate (1.5 Mha/year). The trend reverses between 2025 and 2050, as roughly half the cropland lost to degradation between 2005 and 2025 is returned to production. Between 2050 and 2100, the rate of cropland restoration doubles from the previous time period of 2025 to 2050. For a comparison of the *Policy Reform* assumptions with the *Market Forces* assumptions see Table 4-22.

Box 4-3. Cropland degradation

While the major effect of cropland degradation is to reduce yields, some degradation is severe enough that the land must be pulled from production. Rates for such processes are difficult to estimate, and strongly debated.

A study released in 1991, the Global Assessment of Soil Degradation (GLASOD) was conceived in response to this debate (Oldeman et al., 1991), although these rates have also been disputed (Alexandratos, 1995). The goal of the project was to provide an estimate of the extent of global soil degradation, using a systematic set of criteria for all parts of the world. The study covers land degradation that has occurred roughly in the period following the end of the second world war.

In the GLASOD study (GRID/UNEP, 1991), four degrees of degradation were distinguished: "light," "moderate," "strong" and "extreme." The last two represent land so degraded it must be pulled from production, and are differentiated from one another by the effort required to return them to use. Moderately degraded land is considerably reduced in quality, but can still support some level of production.

Historical values of land degradation from agricultural practices are shown in the text below, in Table 4-21. The rates shown in the table were estimated by dividing the total area by 45 years, roughly the period covered by the GLASOD study. The rate of severe degradation is much higher in the developing regions than in the OECD regions, with the highest rate occurring in Africa. The pattern for moderate degradation is more varied between the macro-regions. The highest rate occurs in North America, mostly as a result of topsoil loss from wind and water action, while the second highest occurs in Africa.

Table 4-21. Cropland degradation: Historical

	Average rate (Mha / year)			
	Light	Moderate	Severe	
Africa	0.59	1.16	1.03	
China+	1.01	0.99	0.38	
Latin Amer	0.73	1.09	0.25	
Middle Eas	0.04	0.21	0.30	
S+SE Asia	0.22	0.40	0.10	
E. Europe	0.12	0.17	0.02	
FSU	0.56	0.25	0.02	
N. America	0.16	1.27	0.00	
Pacific OE	0.09	0.03	0.05	
W. Europe	0.49	0.22	0.01	
World	4.00	5.78	2.15	

Notes: "Severely" degraded land is the sum of "strongly" and "extremely" degraded land in Oldeman et al. (1991). The estimates in the table were developed using the GIS data set constructed by GRID/UNEP from the GLASOD map (GRID/UNEP, 1991).

Table 4-22. Cropland lost to severe degradation in *Market Forces* and *Policy Reform*

Annual Rate of loss of cropland through degradation					
Mha/year	**Market Forces**			**Policy Reform**	
	2005	2050	2100	2050	2100
North America	0.02	0.02	0.02	-0.01	-0.02
Western Europe	0.01	0.01	0.01	-0.01	-0.01
Pac OECD	0.04	0.04	0.04	-0.02	-0.04
FSU	0.07	0.07	0.07	-0.04	-0.07
Eastern Europe	0.05	0.05	0.05	-0.03	-0.05
Africa	1.08	1.08	1.08	-0.54	-1.08
Latin America	0.66	0.66	0.66	-0.33	-0.66
Middle East	0.15	0.15	0.15	-0.08	-0.15
China+	0.68	0.68	0.68	-0.34	-0.68
South Asia	0.20	0.20	0.20	-0.10	-0.20
Southeast Asia	0.08	0.08	0.08	-0.04	-0.08
World	3.04	3.04	3.04	-1.52	-3.04

Note: Negative values in Policy Reform represent the annual rate of net land restoration (rather than degradation) due to policies intended to eliminate loss due to land degradation and to restoration of lost lands.

Fertilizer

Plant growth can be restricted if any of several crucial chemical elements are in short supply. Furthermore, unless nutrients are replenished, agriculture will gradually deplete the soil, as nutrients are carried away from the field with the harvest, or washed away with the soil exposed by land clearing.

Mineral shortages can be corrected, and nutrient levels maintained, by applying fertilizers. Fertilizers play an important role in producing and sustaining the yield increases assumed in both scenarios. However, they also pose both social and environmental problems. They are associated with pollution and health problems and their manufacture consumes nonrenewable resources. In the analysis, the use of manufactured nitrogen fertilizers is reviewed, both because it is the most commonly applied type of fertilizer, and because of nitrogen's role as a water pollutant, discussed in Chapter 7 (page 259).

Current Accounts

Estimated fertilizer application rates by country and crop have been compiled by the FAO's FertiStat database (FAO, 2007). In this analysis, average application rates by region and crop commodity are used to calculate base-year nitrogen application rates. Estimated application rates on cereal and non-cereal crops are shown in Table 4-23.

Table 4-23. Nitrogen application rates on cereal and non-cereal crops – 2005

kg N per ha	Wheat and Coarse Grains	Rice	Non-Cereals
North America	98	0.1	50
Western Europe	66	0.1	77
Pac OECD	116	0.1	44
FSU	63	0.1	89
Eastern Europe	62	0.1	85
Africa	65	0.1	65
Latin America	50	0.1	63
Middle East	72	0.0	54
China+	122	0.0	110
South Asia	73	0.1	61
Southeast Asia	107	0.1	48

Differences in regional fertilizer application rates can be traced in part to population density (Grigg, 1995), where the highest values are to be found in China, due to the fact that landholdings per person are small, and land is cropped very intensively. The relatively high value in Africa for the fertilization rates of cereals reflects the high application rates in North Africa especially, where much of the cereal-growing area is found. West Africa, another major cereal-producing part of the region, has much lower application rates for fertilizer.

Scenarios

In the scenarios, the amount of nitrogen fertilizer applied per hectare is calculated in relationship to yields, so that the trends in fertilizer use are consistent with the yield assumptions. Regional average application rates (for a more detailed set of regions than is used elsewhere in this analysis) are plotted for each commodity against yields in Figure 4-23 through Figure 4-25. In the scenarios, application rates increase with yields, using the regression curves shown the figures. The results are shown in Table 4-24.

Figure 4-23. Nitrogen fertilizer application vs. average yield for Wheat + CG

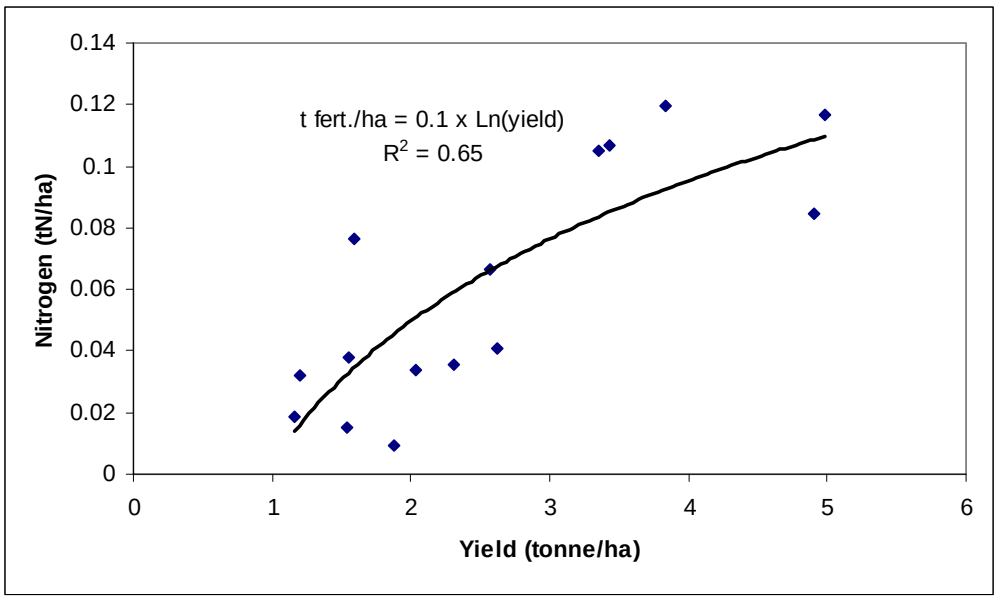
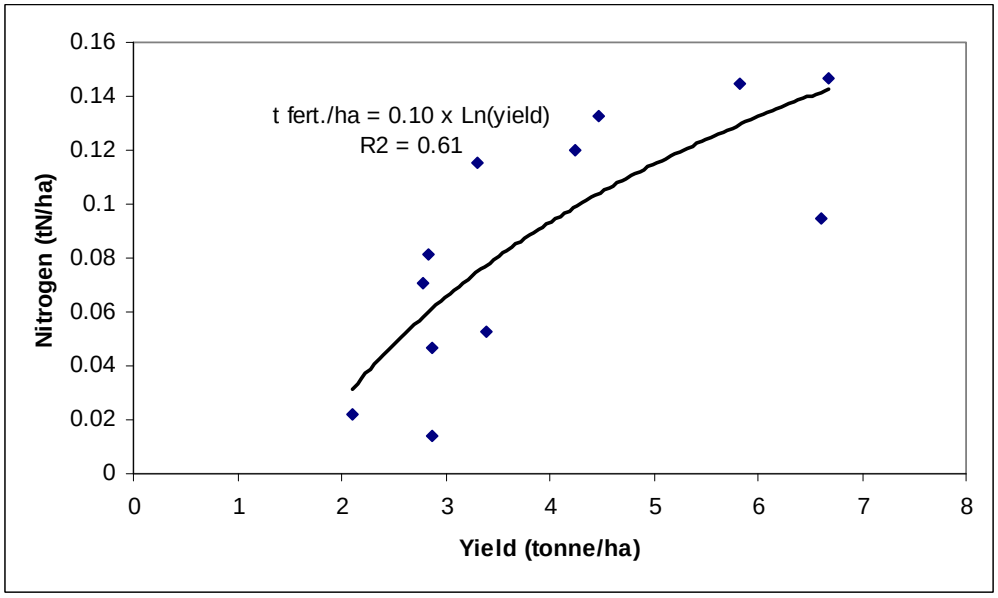
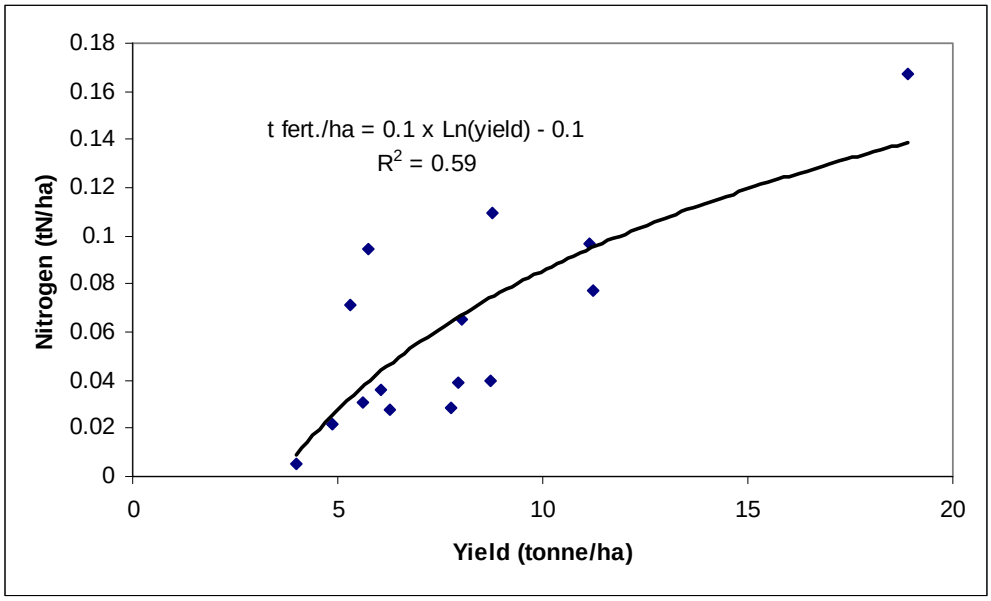


Figure 4-24. Nitrogen fertilizer application vs. average yield for Rice



Note: Western Europe and Australia are not included in the regression, due to lack of data.

Figure 4-25. Nitrogen fertilizer application vs. average yield for Other Crops



In the *Policy Reform* scenario, it is assumed that alternatives to manufactured fertilizer are introduced in varying combinations in different regions in order to reduce pollution. Additionally, it is assumed that practices are modified to make the most efficient use of the applied fertilizer. As yields are the same in the two scenarios, of interest to the scenario analysis is the degree to which manufactured fertilizer use can be reduced without impacting yields. The ideal data set, containing regional estimates of the potential for reducing fertilizer application, is not available, as information on the subject is largely confined to sub-regional field studies. However, the results of those studies suggest that a reduction of one-half may be possible without seriously affecting yields or cropping intensities. Improvements in practice alone, without a change in the source of nitrogen, may reduce nitrogen application rates by 20% or more: Lægreid et al. (1999) report a study in Mexico in which an 18% reduction was achieved., and Conway (1997) reports on the introduction of a novel application method for nitrogen fertilizer, which cut application on some vegetable crops by 25%. Considering in addition the substitution of manufactured fertilizers with organic sources, Conway provides an example for maize production in Rwanda in which mineral fertilizers were entirely replaced with organic substitutes, with minimal impact on yields. Summarizing, he suggests, “Usually the best approach is to combine green manures with small amounts of inorganic fertilizer, say half the usual rate of application.” Given the scarcity of relevant data, in the *Policy Reform* scenario, it is assumed that in all regions, fertilizer application rates can be cut in half relative to *Market Forces* practices, while maintaining yields and cropping intensities at *Market Forces* levels.

Table 4-24. Nitrogen fertilizer use in the scenarios

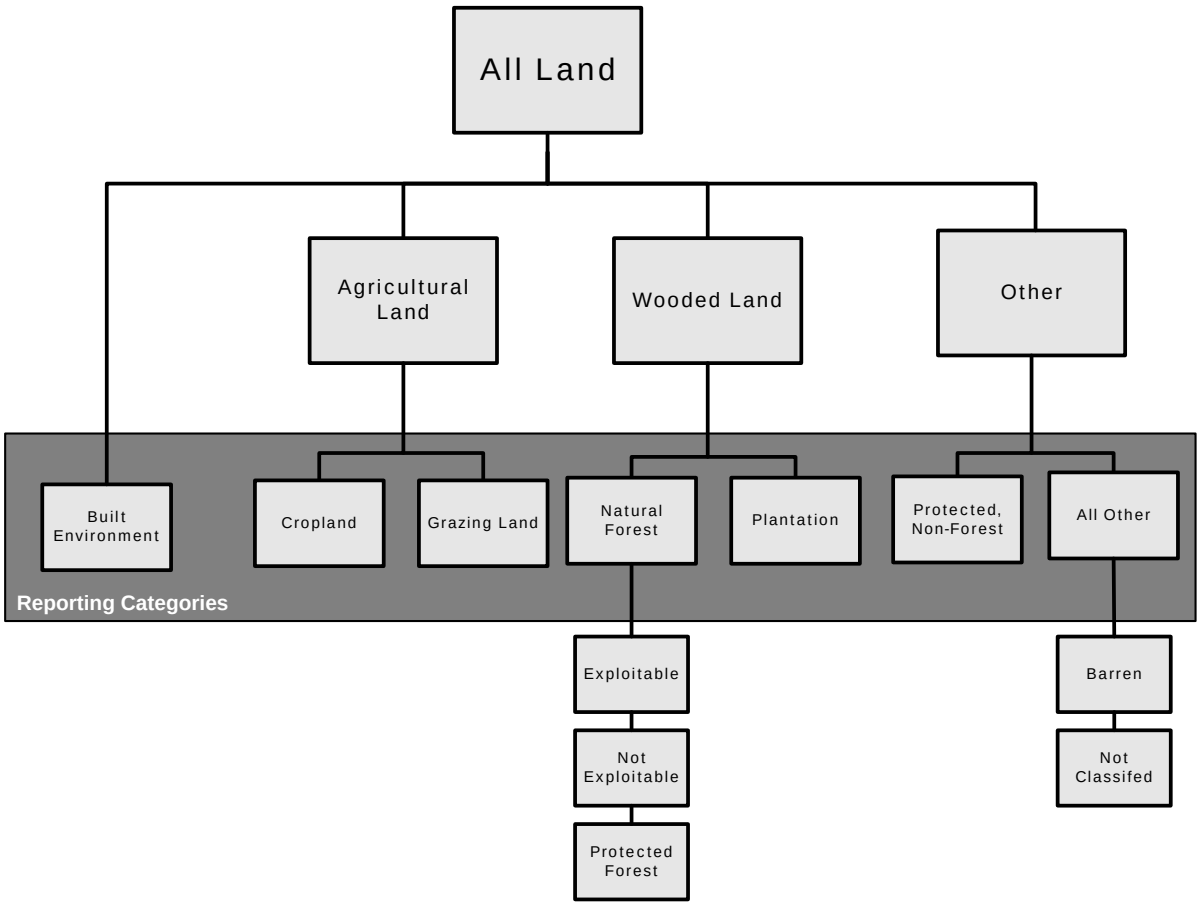
Mtonnes N		Market Forces					Policy Reform				
	2005	2025	2050	2100	2050/ 2005	2100/ 2005	2025	2050	2100	2050/ 2005	2100/ 2005
North America	11	15	18	20	1.63	1.79	11	8	2	0.76	0.23
Western Europe	5	7	8	8	1.43	1.44	5	4	1	0.69	0.22
Pac OECD	3	3	3	3	0.99	1.04	2	1	0	0.52	0.14
FSU	8	10	9	9	1.11	1.07	7	4	1	0.52	0.15
Eastern Europe	4	4	4	3	1.00	0.84	3	2	0	0.48	0.12
Africa	13	24	34	40	2.60	3.02	18	17	8	1.27	0.61
Latin America	8	15	22	25	2.71	3.13	11	10	4	1.19	0.49
Middle East	2	3	3	3	1.52	1.54	2	2	1	0.84	0.43
China+	17	19	17	12	1.00	0.68	15	10	4	0.57	0.21
South Asia	12	17	19	17	1.58	1.42	12	9	4	0.75	0.30
Southeast Asia	3	6	9	11	3.02	3.53	5	4	2	1.39	0.63
World	88	122	147	151	1.68	1.24	91	71	28	0.81	0.23

5 Land Use and Forestry

The increasing requirements for cropland and grazing land, described in Chapter 4, place considerable pressure on existing land resources. These are exacerbated by land degradation in the Market Forces case. Aside from the threat that the degradation itself poses to ecosystems, severely degraded land must be replaced by land elsewhere to maintain crop and animal production. Agricultural demands compete with other demands for land: forests are also required for their products, as carbon sinks and biomass, and land is required for human settlements, recreation, and undisturbed wilderness.

For this study, land is separated into ten land-use types, as shown in Figure 5-1 below: built environment, cropland, grazing land, four different categories of forest and wooded land (commercially exploitable, not commercially exploitable, plantations and protected forest), non-forested protected land, barren land and a residual "other" land category, which might include, for example, grasslands not used for grazing. Also shown in the figure is a set of "reporting categories." In general, in this section, land areas and changes in area will be reported for these aggregate land-use categories.

Figure 5-1. Land use categories



Net rates of conversion between land uses for the Market Forces and Policy Reform scenarios are shown in Table 5-1 and Table 5-2. Overall changes in land areas are shown in Figure 5-2. The methodology for determining land use change is overviewed in the next section. In the Market Forces scenario, the dominant change at the global scale is the conversion of forest to cropland and plantation. To a smaller extent, natural forest is lost to expanding areas of built environment and grazing lands. Similar patterns are seen in the Policy Reform scenario, but strategies to meet the scenario targets of ecosystem preservation lead to significantly lower rates of deforestation and overall land conversion. Moreover, there is greater conversion of "Other" land, as previously degraded land is restored, as land is afforested or reforested, and as unexploited grasslands and savannah are placed under grazing.

Table 5-1. Land areas and conversion in the Market Forces scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
OECD		3094						3094		
	Built Env	80	3%	27				107	3%	0.6
	Cropland	380	12%	(8)	101			472	15%	2.1
	Grazing and Pasture	724	23%	(19)	(104)	107		708	23%	-0.4
	Natural Forest	958	31%	0	0	(96)	(122)	740	24%	-4.8
	Plantation	39	1%	0	0	0	143	182	6%	3.2
	Protected (non-forest)	292	9%	0	0	0	0	292	9%	0.0
	All Other	621	20%	0	3	(10)	(21)	592	19%	-0.6
Non-OECD		9928						9928		
	Built Env	226	2%	221				447	4%	4.9
	Cropland	1163	12%	(121)	117			1159	12%	-0.1
	Grazing and Pasture	2627	26%	(100)	(205)	(3)		2319	23%	-6.8
	Natural Forest	2994	30%	0	(6)	(318)	(211)	2460	25%	-11.9
	Plantation	63	1%	0	0	0	242	305	3%	5.4
	Protected (non-forest)	935	9%	0	0	0	0	935	9%	0.0
	All Other	1921	19%	0	94	321	(31)	2304	23%	8.5

Table 5-1 Continued. Land areas and conversion in the Market Forces scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
World		13022						13022		
	Built Env	306	2%	248				554	4%	5.5
	Cropland	1542	12%	(129)	218			1631	13%	2.0
	Grazing and Pasture	3351	26%	(119)	(309)	104		3027	23%	-7.2
	Natural Forest	3952	30%	0	(6)	(414)	(332)	3200	25%	-16.7
	Plantation	102	1%	0	0	0	385	487	4%	8.6
	Protected (non-forest)	1227	9%	0	0	0	0	1227	9%	0.0
	All Other	2541	20%	0	97	310	(53)	2896	22%	7.9

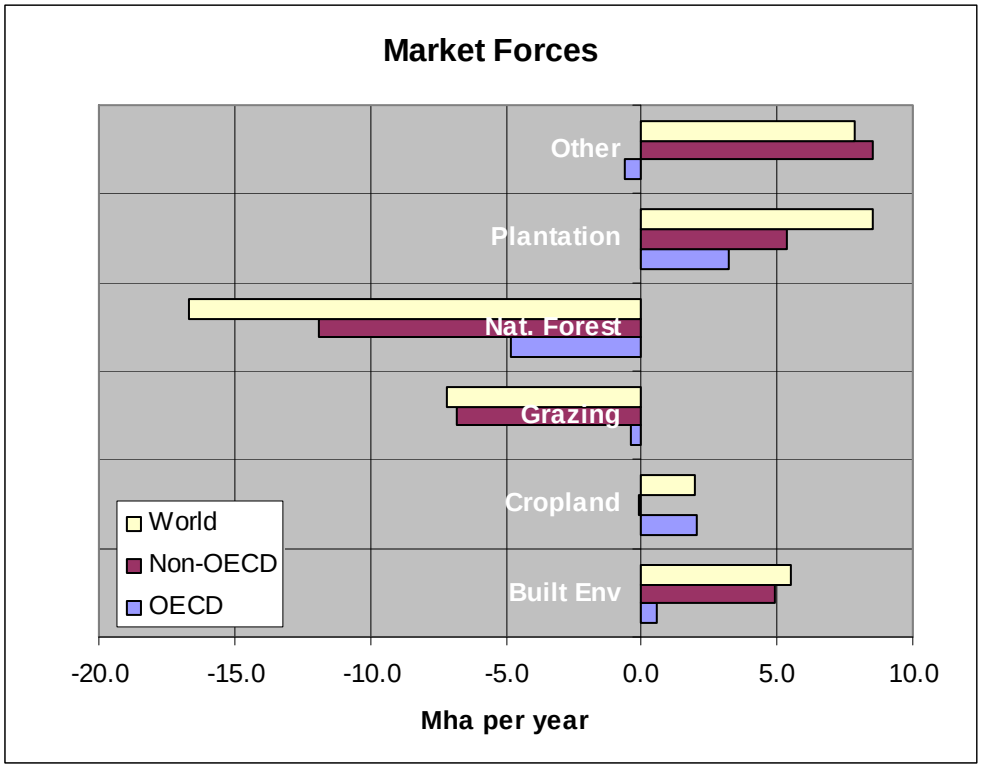
Table 5-2. Land areas and conversion in the Policy Reform scenario

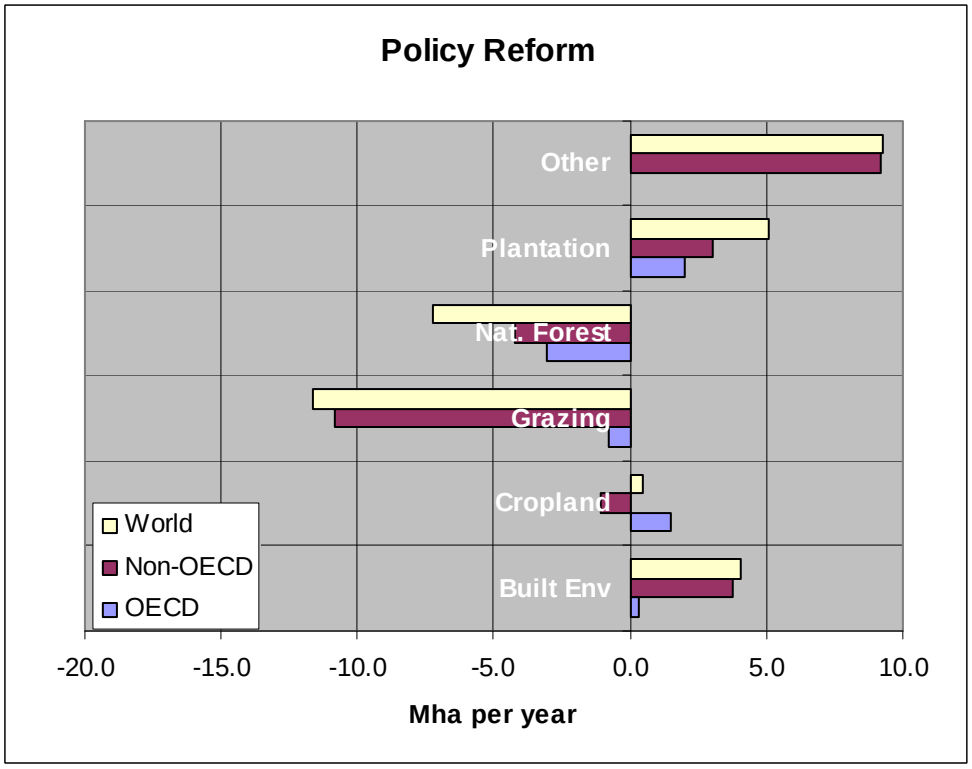
Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
OECD		3094						3094		
	Built Env	80	3%	13				94	3%	0.3
	Cropland	380	12%	(4)	72			448	14%	1.5
	Grazing and Pasture	724	23%	(9)	(71)	44		688	22%	-0.8
	Natural Forest	958	31%	0	0	(82)	(54)	822	27%	-3.0
	Plantation	39	1%	0	0	0	90	130	4%	2.0
	Protected (non-forest)	292	9%	0	0	0	0	292	9%	0.0
	All Other	621	20%	0	(1)	37	(36)	621	20%	0.0
Non-OECD		9928						9928		
	Built Env	226	2%	171				396	4%	3.8
	Cropland	1163	12%	(139)	92			1116	11%	-1.0
	Grazing and Pasture	2627	26%	(32)	(21)	(433)		2141	22%	-10.8
	Natural Forest	2994	30%	0	(3)	(94)	(94)	2803	28%	-4.2
	Plantation	63	1%	0	0	0	138	201	2%	3.1
	Protected (non-forest)	935	9%	0	0	0	0	935	9%	0.0
	All Other	1921	19%	0	(68)	527	(44)	2336	24%	9.2

Table 5-2 Continued. Land areas and conversion in the Policy Reform scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
World		13022						13022		
	Built Env	306	2%	91				397	0.0	2.0
	Cropland	1542	12%	(107)	(78)			1358	0.1	-4.1
	Grazing and Pasture	3351	26%	16	149	(572)		2944	0.2	-9.0
	Natural Forest	3952	30%	0	(7)	(5)	(93)	3846	0.3	-2.4
	Plantation	102	1%	0	0	0	144	246	0.0	3.2
	Protected (non-forest)	1227	9%	0	0	0	0	1227	0.1	0.0
	All Other	2541	20%	0	(64)	577	(50)	3004	0.2	10.3

Figure 5-2. Average annual change in land area in the scenarios, 2005-2050





Overview of Methodology

There is a general methodology employed for the flow of land use. Only certain categories of land are allowed to become other categories, and this flow determines the final land use composition. The top of the hierarchy must be satisfied first, by some combination of the major land-types that follow it, and so on. The following sections describe each of the major land types and the process for assigning an increase or decrease to that type for the scenarios.

1. Protected Land (Forest and non-Forest)
2. Built Environment
3. Cropland
4. Grazing and Pasture land
5. Plantation – used for growing wood/fiber
6. Natural Forest
    a. Unexploitable Forest – cannot be exploited for forestry/wood supply
    b. Exploitable Forest – can be exploited for forestry/wood supply
7. Barren and Other Land

These categories are further separated into or classified as "potentially arable" land area and "not-potentially arable" land area in order to facilitate the conversion calculations to and from cropland. All cropland is considered to be arable. Additionally, all forest area that is used for exploiting forestry products (both Exploitable Forest and Plantation) is classified as 100% arable to simplify the methodology. All of the following land categories only have land which is "not potentially arable": Built Environment, Protected non-Forest land, Barren land, and Other land. Table 5-3 shows the percentage of land-types that is considered arable in the base year.[16]

The order of priorities for shifting land use between categories through the scenario years is shown in Figure 5-3. The brief description of these flows (corresponding to the numbered stars in the diagram) is followed by a detailed description of each land type in this chapter. This is not meant to be a literal depiction of how land categories shift, but rather a way to balance out necessary land modes in the scenarios in a reasonable way. Immediate demands or parameters that affect the land requirements are also included in the figure.

[16]Note that while all exploitable forest area and forest plantation land may not be classified as potential crop land (PCL) or particularly suitable, the assumption made for this methodology is that if needed, this land would be converted to crop area through the necessary means (i.e., slash-and-burn in the rainforest provides fertile land only temporarily, but may not provide long-term arable land).

Table 5-3. Share of land that is potentially arable

2005	Share of land that is potentially arable			
	Cropland	Pasture	Unexploitable Forest	Exploitable Forest and Plantation
North America	100%	40%	18%	100%
Western Europe	100%	76%	16%	100%
Pac OECD	100%	9%	20%	100%
FSU	100%	20%	13%	100%
Eastern Europe	100%	71%	28%	100%
Africa	100%	53%	35%	100%
Latin America	100%	54%	38%	100%
Middle East	100%	2%	2%	100%
China+	100%	4%	4%	100%
South Asia	100%	5%	13%	100%
Southeast Asia	100%	8%	8%	100%
World	100%	32%	48%	47%

The general rules for moving land between categories are as follows: If land requirements can be satisfied by the first category, the land shifting stops, otherwise it proceeds to the next priority to take land from that category, and so on. If the amount of land needed in a category is decreasing with respect to the previous scenario year, then that amount of area will be returned to the categories where land would have otherwise been taken from (in most cases, all returned land will go to the top priority category of land).

1. **Protected land** is designated at the base year levels, and is not allowed to be modified or taken by any category. It also remains at base year levels throughout all scenarios.

2. **Built Environment** is determined by the Built Environment per capita coefficients, multiplied by the population. A coefficient determining the fraction of this land coming from potentially arable land is kept as close to the base year level as possible to balance the land.

    a. Built Environment from Not Potentially Arable land comes first from the Pasture category, followed by the Unexploitable Forest, Barren, and Other land.

   b. Built Environment from Potentially Arable land comes first from Cropland, followed by Pasture and Unexploitable Forest.

3. **Cropland** is determined by the total crop production requirements, trade patterns, the various agricultural coefficients such as yields, and the total available area minus reserved areas which are designated in the Policy Reform and Great Transition scenarios so that crops cannot expand into forests and other desirable land use categories. Before satisfying the cropland needs, additional land may be needed to replace land that has been degraded, which is moved from cropland to Not Potentially Arable "Other" land. If land has been restored (as occurs in the the Policy Reform and Great Transition scenarios), land moves back from this category into the cropland category, reducing the need to take from other categories. The resulting need for cropland is satisfied first from Pasture land, followed by Unexploitable Forest.

4. **Pasture** is determined by the total area of grazed pasture, as determined by the Pasture area Growth Rate selected for each region, as well as by productivity coefficients for the regional pasture areas. Pasture needs are split into Potentially and not Potentially arable land at the same ratio as the previous year.

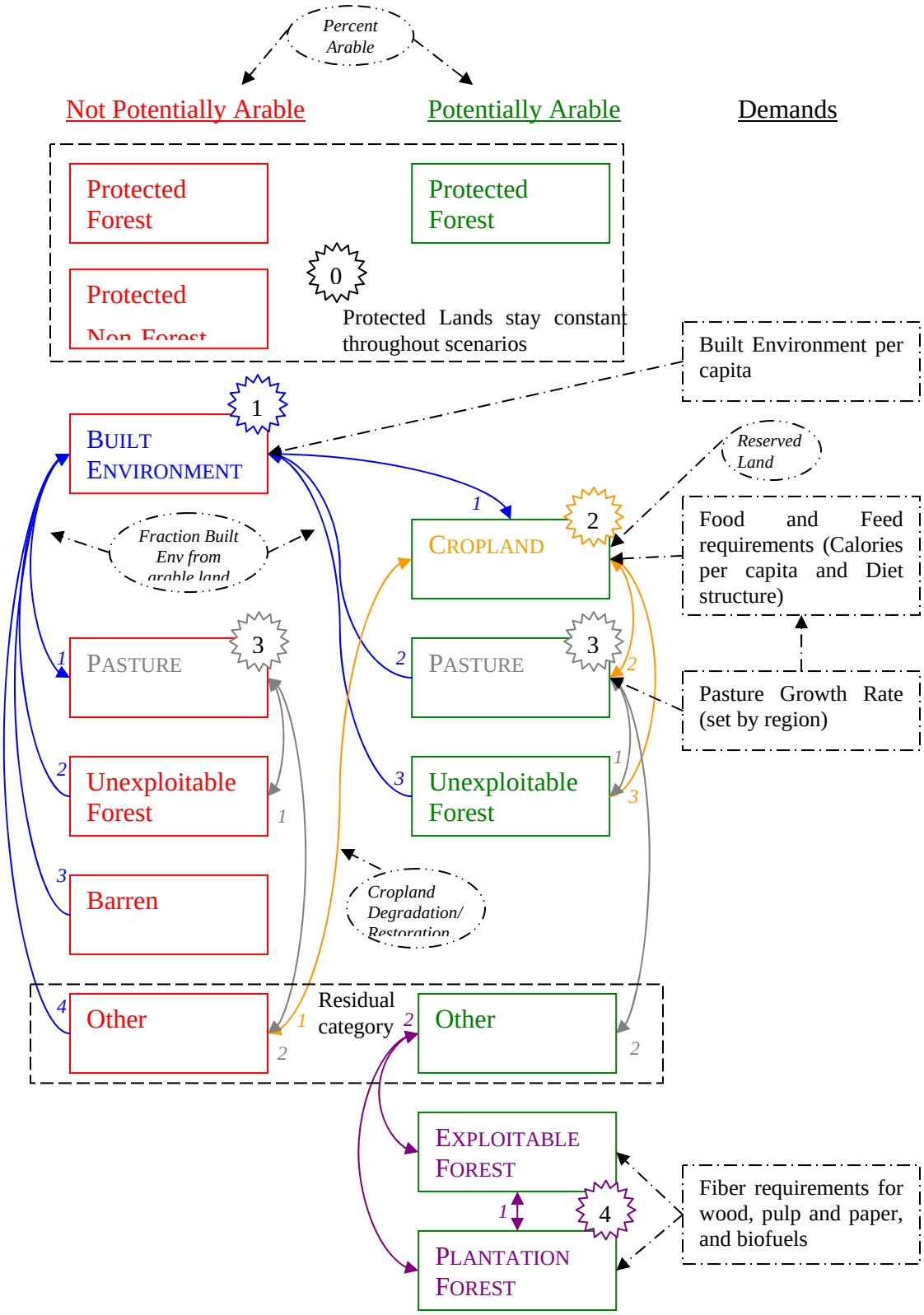
   a. Pasture land needs for Not Potentially Arable are met first by Unexploitable forest, followed by Barren land, and then Other land. When returning land, due to a shrinkage of pastureland area, land is returned both to Unexploitable forest and Other land.

   b. Pasture land needs for Potentially Arable are met first by Unexploitable forest, followed by Other land. When returning land, due to a shrinkage of pastureland area, land is returned both to Unexploitable forest and Other land.

5. Forestry needs are determined by the Fiber requirements for Paper and Pulp, Other Wood, and Biomass Fuel needs, as well as regional productivity coefficients for each type of land. These needs are satisfied by a combination of **Exploitable Forests** and a shift toward more productive **Plantations**. The combined needs of these two land types are satisfied by the Other land type.

The rest of this chapter follows the flow of the land requirements in roughly the same order, and gives further detail on each land type.

Figure 5-3. Land use change schematic



Protected Land

Current Accounts

In many countries, land has been set aside for environmental protection, scientific research, education, maintenance of traditional cultures and other reasons. The extent of this protected land is generally well recorded. For this analysis, total protected land area is taken from the World Conservation Monitoring Centre (WRI, 2007; WCMC, 1998)[17] and the area of protected forest from the FAO's Global Fibre Supply Study (FAO, 1998b). The amount of land protected in each region is shown in Table 5-4, both as a total and as a percentage of total land area. Globally, about 12% of all land is listed as protected. In each of the OECD regions, close to 11% of the total land area is protected. The proportion of protected area is less than 10% of the total land area in the regions of FSU, Eastern Europe, and South Asia. The highest proportion of protected land area is found in Latin America, where an estimated 20% of the total area is protected, with more than half of it under forest.

Table 5-4. Protected land – 2005

	Protected Area (Mha)	% Protected Area Under Forest	Protected Area as % of Total
North America	212	13%	12%
Western Europe	44	21%	11%
Pac OECD	87	16%	10%
FSU	151	44%	7%
Eastern Europe	15	22%	8%
Africa	284	12%	10%
Latin America	396	12%	20%
Middle East	94	0%	15%
China+	138	11%	12%
South Asia	27	36%	7%
Southeast Asia	56	88%	13%
World	1,504	18%	12%

[17] 2005 UNEP-WCMC Protected Areas list, accessed from WRI Earthtrends website (WRI, 2007) at http://earthtrends.wri.org/pdf_library/data_tables/bio3_2005.pdf.

Scenarios

In the *Market Forces* scenario, it is assumed that there is no net change in protected areas, which are kept at the base year value in every region. In the *Policy Reform* scenario some protected land is removed and some added, as a result of changing land-use policies. For example, in the *Policy Reform* scenario, it is assumed that protected forest land increases, as one of several policy measures to reduce the rate of deforestation.[18]

The Built Environment

Current Accounts

In both urban and rural settings, land is cleared and altered for businesses, residences, roads, parking lots, parks, landfills, burial grounds and other uses. The area of this *built environment* is not well known (Crosson and Anderson, 1992; Meyer and Turner, 1994). For this study a combination of different sources and estimates was used to arrive at regional estimates for built-up land. Estimates of the area of the built environment per capita is shown by region in Table 5-5, along with the sources on which the estimates are based. The highest value by far is that for North America, where at 0.13 ha/capita, people on average require more than twice as much space per capita as in other OECD regions of Western Europe and Pacific OECD.

[18] The actual amount of land categorized as protected is not made explicit in the scenarios. Deforestation rates are expected to be much lower in *Policy Reform* than in *Market Forces*, due to a combination of legal protection, economic instruments, expanded markets for non-wood forest products and land reform. No explicit assumption on the relative importance of these factors is needed in order to specify the scenario, and none is made. In the *Policy Reform* case we see a net increase of the total of all types of forest area (including plantation) by 2100.

Table 5-5. Historical data on built environment per capita

ha/capita	Built Environment	Source
North America	0.13	3
Western Europe	0.06	2
Pac OECD	0.06	4
FSU	0.04	4
Eastern Europe	0.04	2
Africa	0.07	1
China+	0.03	1
Latin America	0.05	1
Middle East	0.06	1
South Asia	0.03	1
Southeast Asia	0.03	1

Sources: (1) based on Fischer (1993); (2) based on WRI (1994); (3) estimate given by the area of "built-up land" (USDA, 1994) less the area of state parks (USBC, 1992; 1995); (4) our own estimates based on other regional values.

Scenarios

In the *Market Forces* scenario, the growth in built environment is guided by the assumption that the amount of built-up land each person requires is determined primarily by the amount of land available and secondarily by cultural preferences and income. Support for this view can be found in Table 5-6: regions with relatively low incomes and high population density, such as China+ and South and Southeast Asia, have low built environment per capita; regions with higher income and high population density, such as Europe, have built environment per capita higher than in the Asian regions, but smaller than in North America; finally, in Africa and Latin America, where land is plentiful but incomes are relatively small, built environment per capita is comparable to that of Western Europe.

In the OECD regions, built environment in the *Market Forces* scenario increases at a fixed rate based on historical trends in the United States, consistent with the similar economic growth in those regions. In the U.S., between 1982 and 1992 developed land per capita increased at a rate of about 0.6% per year on average. It is assumed that built environment per capita increases in all OECD regions at half this rate, 0.3% per year, throughout the scenario.

For the non-OECD regions the convergence algorithm was applied (see Annex 1), but with different convergence targets for different regions, consistent with the comments above. Specifically, Africa and Latin America's amount of built environment per capita

converges towards the OECD average built environment per capita, as the GDP per capita approaches the average OECD GDP per capita in 2005. China+, South and Southeast Asia, the Middle East, Eastern Europe and FSU all converge towards the more compact value for Western Europe as their GDP per capita approach the average OECD GDP per capita in 2005.[19]

In the *Policy Reform* scenario, policies to protect forest and cropland from encroaching human settlements are expected to restrain the growth in the built environment in all regions compared to the *Market Forces* scenario, although this tendency is counteracted to some extent by relatively higher income growth in developing regions. Specifically, it is assumed that all non-OECD regions converge upon the Western European average built-environment per capita, while in Western Europe itself human settlements become slightly more compact throughout the scenario. The OECD regions remain at base-year levels of built environment per capita, except for North America, which decreases at 1% per year during the period between 2050 and 2100 when it reaches a similar level as the other OECD regions of Western Europe and Pacific OECD. The developing regions approach the Western European pattern as their incomes approach the base year OECD values, using the convergence algorithm (See Annex 1). The scenario values are shown in Table 5-6.

In most regions, the built environment takes up a relatively small amount of the total land area. However, changes in the area under the built environment are significant. As shown in Table 5-6, the changes are of the same order of magnitude as changes in agricultural land area at the global scale, but smaller. Table 5-7 shows the total kha for land used for built environment in the base year and scenario years. In many of the non-OECD regions, the large present-day populations and the significant population growth in the scenarios lead to both a substantial proportion of land under the built environment in 2005, and to significant changes in the built area. In both scenarios, built environment in South Asia rises from an estimated 11% of total land area in 2005 to just over 20% by 2050, despite relatively compact settlement patterns today – at 0.03 ha per capita, the smallest value of any of the regions – and only modest increases in built area per capita in the scenarios.

In the scenarios, the built environment expands into cropland, pasture land, non-commercially exploitable forest and other land, based on the available land under those land covers. The types of land taken from those categories are both potentially arable and non-arable land, scaled using the fraction of built environment from potential cropland (PCL), given in Table 5-8. The same value is used in all scenarios, and all time-periods, with a few exceptions used to balance land use patterns, as seen in Table 5-8. In Policy Reform, the fraction of new built environment coming from cropland increases in the

[19] In the Middle East land is plentiful, but water is not. The convergence towards the Western European value rather than towards the OECD average is based on an assumption that the costs of expanding water delivery systems will limit the growth of the built environment. The convergence pattern for the FSU region, where land is also plentiful, is based on the assumption that FSU will tend more towards European patterns than towards North American ones. In the case of FSU, alternative assumptions would have little effect on land pressure.

Policy Reform scenario[20] to 0.75 in 2050 (and 0.9 in 2100), to accommodate for land limitations in the not potentially arable category.

Table 5-6. Built environment per capita in the scenarios

ha per capita		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	0.13	0.13	0.14	0.17	0.13	0.13	0.08
Western Europe	0.06	0.07	0.07	0.08	0.06	0.06	0.06
Pac OECD	0.06	0.07	0.07	0.08	0.06	0.06	0.06
FSU	0.04	0.05	0.06	0.08	0.05	0.06	0.06
Eastern Europe	0.04	0.05	0.07	0.08	0.05	0.06	0.06
Africa	0.07	0.07	0.07	0.09	0.07	0.07	0.06
Latin America	0.05	0.06	0.08	0.12	0.06	0.06	0.06
Middle East	0.06	0.06	0.07	0.08	0.06	0.06	0.06
China+	0.03	0.04	0.05	0.08	0.04	0.05	0.06
South Asia	0.03	0.03	0.04	0.07	0.03	0.04	0.06
Southeast Asia	0.03	0.04	0.05	0.08	0.04	0.05	0.06
World	0.05	0.05	0.06	0.09	0.04	0.05	0.06

Table 5-7. Total built environment in 2005 and scenarios

kha		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	42,210	52,575	63,873	78,386	49,518	55,818	35,679
Western Europe	25,544	27,779	29,372	30,255	26,164	25,668	22,762
Pac OECD	12,586	13,626	13,764	16,068	12,834	12,028	12,088
FSU	11,400	12,619	14,897	19,398	12,434	13,632	13,135
Eastern Europe	7,120	9,229	13,101	12,115	9,112	11,014	8,203
Africa	58,890	88,633	133,457	212,799	85,434	118,821	138,271
Latin America	29,521	41,369	60,176	90,039	37,291	43,478	41,501
Middle East	13,950	21,152	31,041	45,280	20,476	27,447	30,659
China+	43,170	56,649	78,417	108,291	55,930	73,032	73,324
South Asia	46,432	63,657	86,329	158,560	62,609	81,395	122,555
Southeast Asia	15,168	20,763	29,227	50,421	20,521	27,476	34,140

[20] The same values are used for the *Great Transition* scenario. Additionally, in only the Great Transition scenario, the built environment coming from potential cropland in Latin America is increased to 0.65 in 2050, and 0.8 in 2100.

Table 5-8. Fraction of new built environment from potential cropland

Fraction of Built Env from PCL		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Western Europe	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Pac OECD	0.30	0.30	0.30	0.30	0.30	0.30	0.30
FSU	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Eastern Europe	0.30	0.35	0.40	0.40	0.35	0.45	0.45
Africa	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Latin America	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Middle East	0.10	0.10	0.10	0.10	0.10	0.10	0.10
China+	0.44	0.44	0.44	0.44	0.60	0.70	0.44
South Asia	0.61	0.80	0.70	0.60	1.00	1.00	1.00
Southeast Asia	0.61	0.61	0.61	0.61	0.61	0.61	0.70

Conversion to Agricultural Land

The future requirements of both agricultural land types are discussed in detail in Chapter 4. This section focuses how the land is allocated to these land types to satisfy the requirements.

Cropland

Current Accounts

Requirements for cropland in the scenarios, and its sources are discussed in Chapter 4 in the section on Cultivated Land (page 179). Cropland area data for 2005 comes from FAOSTAT (FAO, 2007a).

Scenarios

Future demands for cropland are driven by dietary and other requirements for crops, moderated by the assumed increases in cropland productivity and trade.

As cropland expands, it encroaches upon grazing land and forest. In both scenarios, the model takes new cropland first from grazing land, and if there is still a need, then from unexploitable forest. Sources for estimates of total potential cropland and potential cropland under forest are discussed in Chapter 4. For the base-year current accounts, the fraction of forest land that is potentially cultivable is assumed to be the same for each of the forest types, while the area of potentially cultivable land that is not under forest is

assigned to grazing land. All land that is severely degraded and lost to cropland is transferred into the land type "Other", and similarly, when land is restored in the *Policy Reform* scenario, it comes from the "Other" land type.

In the *Market Forces* scenario, cropland in the developing regions expands into grazing land and non–commercially-exploitable forests (that is, forest that is not protected and is not available for commercial exploitation) as described above.[21]

In the *Policy Reform* scenario, land degradation is slowed and then partially reversed over the course of the scenario, as noted above. Also, in order to achieve the ecosystem preservation goals of the scenario, the conversion of forests to cropland is slower than in the *Market Forces* scenario.

Historical estimates for the rates of conversion of forest and grassland to cropland are shown in Box 4-2 on page 186. As in the two scenarios, cropland has historically expanded into grassland (grazing land) and forest. Estimates of the distribution of new cropland under forest and grazing land based on the historical figures are shown for developing regions in Table 5-9. However we have chosen not to follow these estimates for simplification of the land module. The land conversion methodology concentrates cropland conversion to/from grazing land, unless there is need for additional land, in order to simplify the calculations. Scenario-specific figures are also shown in Table 5-10. As a result, the bulk of the new cropland in the scenario is converted from grazing land.

Table 5-9. Historical cropland expansion in select developing regions

Fraction of new cropland by previous land-use (%)		
	Historical*	
	Forest	Grazing
China+	11	89
Latin America	68	32
Middle East	10†	90†
South and Southeast Asia	100	0

* Based on figures in Box 4-2. † Figures are for North Africa and the Near East

[21] Ideally, the amount of land taken from each land type would take into account the suitability of the land for different crops, its availability for exploitation, or the productivity of the additional land compared with land already under cultivation. However, data are not available to this level of detail.

Table 5-10. Scenario-specific cropland expansion through 2100

Market Forces	Land converted to (from) cropland					
2005 to 2100	Grazing		Forest		Other	
	Mha	% of cropland	Mha	% of cropland	Mha	% of cropland
North America	111	34%	0	0%	(2)	-1%
Western Europe	18	17%	0	0%	(1)	-1%
Pac OECD	(15)	-38%	0	0%	(4)	-9%
FSU	(77)	-65%	0	0%	(7)	-6%
Eastern Europe	(24)	-69%	0	0%	(5)	-14%
Africa	213	84%	0	0%	(103)	-40%
Latin America	154	69%	0	0%	(63)	-28%
Middle East	(5)	-25%	0	0%	(14)	-68%
China+	(3)	-5%	0	0%	(65)	-99%
South Asia	(35)	-42%	0	0%	(19)	-23%
Southeast Asia	(8)	-9%	6	6%	(7)	-8%
World	328	24%	6	0%	(289)	-21%

Policy Reform	Land converted to (from) cropland					
2005 to 2100	Grazing		Forest		Other	
	Mha	% of cropland	Mha	% of cropland	Mha	% of cropland
North America	46	16%	0	0%	1	0%
Western Europe	4	4%	0	0%	1	1%
Pac OECD	(22)	-55%	0	0%	3	6%
FSU	(108)	-109%	0	0%	4	4%
Eastern Europe	(39)	-138%	0	0%	3	11%
Africa	(11)	-5%	0	0%	68	28%
Latin America	(37)	-23%	0	0%	41	25%
Middle East	(1)	-1%	0	0%	9	19%
China+	(96)	-101%	0	0%	43	45%
South Asia	(40)	-49%	0	0%	13	15%
Southeast Asia	(39)	-53%	3	4%	5	7%
World	(344)	-28%	3	0%	190	15%

Note: Percent of Cropland represents total land converted to (from) cropland between 2005 and 2100 divided by the total cropland area in 2100. Cropland converted to "Other" category represents degraded land (represented by numbers in parentheses). Cropland converted from "Other" land represents restored land that had previously been degraded.

Grazing and Pasture Land

Current Accounts

Requirements and sources for grazing and pasture land are discussed in the section on Feed Supply (page 156). The base year data for pasture area comes from FAOSTAT, under the category of "permanent meadows and pastures" (FAO, 2007a).

Scenarios

Changes in grazing land area in the scenarios, which are driven by meat and milk production requirements, are discussed in Chapter 4 (Feed Supply, page 156). In addition, unless grazing area declines over the scenario period (as it does in Western Europe), any net conversion of grazing land to either the built environment or to cropland must be made up by conversions to grazing land from other land uses. The total requirements for additional grazing land are met in the scenarios through the expansion into forest and non-barren "other" land (see Figure 5-1 and Figure 5-3). Growth rates for grazing and pasture land area, listed in Table 5-11, were informed by the FAO's Country Pasture Profiles (FAO, 2007d), and adjusted in each region and year to achieve the final land balance in each scenario.

Table 5-11. Pasture land in 2005 and scenario growth rates

		Market Forces			Policy Reform		
	Area (Mha)	Annual Growth Rate			Annual Growth Rate		
	2005	2025	2050	2100	2025	2050	2100
North America	253	-0.05%	-0.05%	-0.05%	-0.05%	-0.05%	0.00%
Western Europe	61	-0.05%	-0.05%	-0.05%	-0.15%	0.15%	0.15%
Pac OECD	410	-0.05%	-0.05%	-0.05%	-0.15%	0.15%	0.15%
FSU	362	0.10%	0.10%	0.10%	0.00%	0.00%	0.00%
Eastern Europe	30.1	0.00%	0.00%	0.00%	-0.50%	-0.80%	-0.90%
Africa	869	-1.50%	-0.60%	-0.60%	-2.00%	-1.00%	-1.20%
Latin America	556	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Middle East	245	-0.10%	-0.15%	-0.15%	-0.15%	-0.20%	-0.15%
China+	530	0.05%	0.05%	0.05%	-0.05%	-0.20%	-0.30%
South Asia	18.3				-1.00%		

		1.00%	1.00%	1.00%		1.10%	1.30%
Southeast Asia	16.3	0.10%	0.10%	0.10%	-0.50%	-0.60%	-0.70%

Source: 2005 land use data taken from FAOStat Database (FAO, 2007a).

There is little data on conversion rates for grazing land. Also, there is limited data on the detailed composition of the residual, non-barren, "other" land category. In the *Market Forces* scenario, it is assumed that grazing land that is not potentially arable expands into non–commercially-exploitable forest that is not potentially cultivable, followed by expansion into non-barren "other" land. Grazing land that is classified as potentially arable expands into potentially cultivable land first from unexploitable forest, followed by non-barren "other" land. Despite these assumptions for land use patterns, pressures on existing potentially cultivable land become acute in some regions.[22] In the *Policy Reform* scenario, in order to achieve the ecosystem preservation goals of the scenario, the conversion of forests to grazing land is slower than in the *Market Forces* scenario, which sometimes results in more drastic reductions in pasture area, as shown in the scenario growth rates above. However the conversion patterns between land types remain the same.

Forestry and Forests

The detailed list of forest sub-categories used in this analysis, and shown in Figure 5-1 – commercially exploitable forest, forest that cannot be exploited commercially (also referred to as "non-commercially exploitable" and "unexploitable"), forest plantations, and protected forest – are introduced in order to facilitate the construction of long-term scenarios of forest production and of deforestation.

Forestry

Current Accounts

Requirements and Production

In the analysis, the commercial use of forest land is driven by the demand for forest products. Three categories of final products are considered: paper and pulp, an aggregate category containing all other industrial wood products (fuelwood is excluded), and biomass for fuel. These final products are made from different kinds of *roundwood*, that is, felled trees from which the twigs, branches and leaves have been removed.

[22] It might at first appear that the scenario assumption runs counter to the experience in the Amazon, where an important land-use change pattern is for forest to first be converted to cropland and then, as the soil is exhausted, to extensive grazing land. However, while this pattern illustrates the ultimate conversion of potential cropland to grazing land, it also suggests that the land is not particularly suitable for crops on a sustainable basis, and indeed, most of the Amazon is listed as only marginally suitable for crop production in the source used for this study (FAO/IIASA, 2000).

Roundwood (such as sawlogs, veneer logs, pulpwood, chips) is used to produce final (or intermediate) wood products (such as sawnlogs, veneer, paper, pulp and plywood). Base year data on production and trade are taken from the online FAOSTAT database (FAO, 2008a).

The fraction of roundwood for paper and pulp is estimated from FAOSTAT statistics as the ratio of "pulp for paper" to the total of "pulp for paper", "recovered paper" and "other fibre" from the ForesSTAT Forestry data set (FAO, 2008a). For other wood products it is assumed that all of the final products are produced from roundwood.

The amount of roundwood needed for the biomass fuel demand is computed using the base-year FAO data for biomass fuel production minus net exports, and calculated from the ratio of the biomass volume compared to the energy requirements from biomass (this is computed and discussed in the energy module, Chapter 3). Table 5-12 below lists the regionally computed ratios, which are held constant throughout the scenarios. This is a way of roughly estimating the amount of woodfuel used for a specific amount of biomass energy required.

Table 5-12. Ratio of biomass volume to biomass energy requirements– 2005

1000 m^3 Roundwood / PJ Biomass Energy	
North America	14.5
Western Europe	21.6
Pac OECD	14.9
FSU	62.0
Eastern Europe	26.2
Africa	68.5
Latin America	77.6
Middle East	59.9
China+	22.4
South Asia	33.9
Southeast Asia	50.5

Resources

The potential production on forested land is given by the product of three factors: forest area, the *increment* of forest land (that is, the additional biomass each year per hectare of land), and the fraction of the increment that is roundwood, rather than bark or twigs. Two types of productive forest land are distinguished for the analysis – commercially exploitable natural forest and plantations (see Figure 5-1). In addition to natural and plantation forest resources, in Asian regions a significant amount of wood production

comes from trees outside of forests, a non-forest resource that is accounted for explicitly in the scenarios.

Data on the area of natural forest was taken from the Global Forest Resources Assessment 2005 (FAO, 2006b), supplemented with data from FAOSTAT (FAO, 2008a). Data on increment on natural forest land was taken from the FAO Global Fibre Supply Study (FAO, 1998b). Data for plantations was taken from a special report on forest plantations from the FAO Global Forest Products Outlook Study (FAO, 2000b). The fraction of the increment that is roundwood is assumed to be 75% in all regions, both for natural forest and plantations, based on the range of figures assumed in FAO (1998b).

Estimates of potential production from trees outside the forest are assigned to South Asia, Southeast Asia and China+, based on the FAO Asia Pacific Forestry Sector Outlook Study (FAO, 1998a), as a fraction of estimated total potential production. Based on these figures, production of roundwood from trees outside the forest amounts to 35% of total production in China+, 73% in South Asia and 30% in Southeast Asia.

Exploitation

Total wood production is compared to estimated potential production to estimate the current level of exploitation of forest resources. Forest area, increment and average levels of forest exploitation estimated using this approach are shown in Table 5-13. Note that the level of exploitation in several regions exceed 100%. This may arise from data errors – given the difficulties of collecting the data it is quite possible that the statistics for forest area, exploitable forest area, increment in volume, and forest production are incompatible. However, a value greater than 100% may also signal unsustainable pressures on existing forest land. In either case, such a high number suggests significant pressure on forest resources.

Table 5-13. Forestry area, annual increment and level of exploitation – 2005

	Commercially Exploitable Natural Forest			Plantations		
	Area (Mha)	% of Total Natural Forest	Increment (m3/ha/yr)	Area (Mha)	Increment (m3/ha/yr)	Exploitation as % Potential
North America	344	56%	1.58	18.4	8.20	167%
Western Europe	115	84%	4.73	7.4	8.21	81%
Pac OECD	180	87%	0.30	13.3	5.81	75%
FSU	586	69%	3.38	22.2	0.88	16%
Eastern Europe	35	86%	3.67	2.7	1.67	107%
Africa	391	62%	0.31	3.2	9.24	554%
Latin America	229	25%	1.81	5.8	8.48	133%
Middle East	16	94%	0.06	0.1	0.04	665%
China+	220	91%	0.84	20.0	1.70	68%
South Asia	56	74%	0.26	4.2	0.93	540%
Southeast Asia	120	58%	1.03	4.9	1.65	127%
World	2293	58%	1.63	102.3	4.26	90%

Source: 2005 land use data taken from FAOStat Database (FAO, 2008a).

Scenarios

Requirements and Production

In the scenarios, the requirements for roundwood are driven by requirements for final wood products. Regional paper and pulp requirements grow at the same rate as value added in the pulp and paper industry. Regional biomass fuel requirements grow with the growth of energy demands from biomass. For other final wood products, requirements are assumed to initially rise with industrial value added, but to gradually taper off, following a general global trend toward lower industrial roundwood demand (FAO, 2000b). Under *Policy Reform*, the demand for non-paper wood products drops off more rapidly than under *Market Forces* conditions as policies reduce demand, such as requiring increased durability or encouraging reuse and repurposing of such products.

Regions that are net importers of final wood products in the base year maintain their self-sufficiency ratios in both scenarios, while self-sufficiency ratios for exporters are kept as close to the base-year value as possible while ensuring that trade balances globally.

The fraction of paper and pulp produced from roundwood sources varies over the course of the scenarios. The remainder of the fiber requirements for paper and pulp is assumed to come from recycled fibers, or other non-forestry fibers (i.e., cotton). In the *Market*

Forces scenario, consistent with past trends for developing regions as a whole, and OECD regions as a whole as recorded in the FAOSTAT database, it is assumed for all regions that for each 1% increase in pulp production, there is a 0.2% decrease in the fraction from roundwood. In *Policy Reform* there is a stronger decreasing trend, reaching and remaining at a mix of 20% roundwood used for paper and pulp by 2050, and remaining at this mix through 2100. This corresponds with an 80% mix of recycled and non-wood fibers used in the pulp and paper industry. Globally, in 2005, around 52% of paper and pulp was produced from roundwood. In the *Market Forces* scenario, that figure drops to 36% in 2050, and about 30% in 2100. In *Policy Reform* scenario, this global figure drops to 20% in 2050, and remains at that level through 2100.

Resources and Exploitation

In the scenarios, wood production expands onto a mix of plantation and forest land. In *Market Forces*, the level of exploitation of natural forest is allowed to reach a maximum of 95% by 2100. In *Policy Reform*, the level of exploitation of natural forest, as measured by production as a percentage of potential production, is constrained to be below 70%, encouraging a shift toward production on plantations. As plantations are generally more productive than natural forest (while also being less genetically diverse), this leads to a smaller increase in exploited forest area. Increments on natural forest remain at base-year levels throughout both scenarios. However, increments on plantations increase as the forests mature. Increments on plantations are assumed to stabilize by 2050, with long-term figures based on FAO (2000d). One exception to this is made, for the Middle East which starts with by far the lowest increment of volume in plantations. In the Middle East, the increment on plantations is allowed to increase slightly between 2050 and 2100.

A fixed fraction of new plantation area comes from natural forest. Data on land-use conversion rates for forests are scarce. For this analysis, the FAO study of changes in tropical forest cover was used as a guide (FRA, 1996). The FAO assessment provides rates of land-use change for three aggregate tropical regions – Africa, Latin America and Asia. Based on the regional figures, in the *Market Forces* and the *Policy Reform* scenarios, in the Middle East, where natural forest area is scarce, only 10% of forest is allowed to be converted to plantations. For *Market Forces*, it is assumed that 85% of all additional plantation area comes from natural forest for most regions, except Eastern Europe and South Asia which have limited forest areas and run into land constraints, and where only 80% of plantations are allowed to come from natural forests. In the *Policy Reform* scenario, only 60% of plantation forests are allowed to come from natural forests, with the exceptions of Latin America where 100% of plantations are allowed to come from forests through 2050, after which 0% of plantations can come from forests due to land pressures. However, while there is a greater level of protection for forest areas in the *Policy Reform* scenario, there is also a great influx in demand for biomass fuels in 2100 in order to sequester carbon and push global emissions negative, which add greatly to the demand for roundwood.

Results

Comparing the *Market Forces* and *Policy Reform* scenarios, there are differences in demand, use of recycled material and other alternative sources of fiber, trade patterns, rates of increase in increments of plantations, and restrictions on the exploitation of natural forests. As a result of these diverse influences, the production from plantations and non-wood sources increases substantially in both scenarios, but with lower use of forest resources in *Policy Reform* (Figure 5-4). In *Policy Reform*, production on natural forests in 2100 is below that in 2005. Furthermore, despite constraints on natural forest production in the *Policy Reform* scenario that encourage plantation development, plantation expansion is also less than under *Market Forces* through 2050, due both to lower demand and to greater use of non-wood fiber. However in 2100, because of the increased demand for carbon sequestration of biomass fuels to meet global carbon targets of negative emissions in the *Policy Reform* scenario (See Chapter 7, page 259), plantation and other sources increase to result in a slightly higher production of forestry products compared to *Market Forces.*

Figure 5-5 shows the global primary fiber demand by end-use. Some of this demand is satisfied by using recycled or non-forestry product biomass. Figure 5-4 shows levels of wood fiber production from plantations and natural forests, as well as from other sources (i.e., recycling or non-forest biomass). However, due to the greater increment on plantation land, and due to lower levels of exploitation of natural forest, the area of natural forest suitable for forestry remains considerably higher than the area of plantations throughout both scenarios, as shown in Figure 5-6.

Figure 5-4. Global forestry fiber production in the scenarios by source

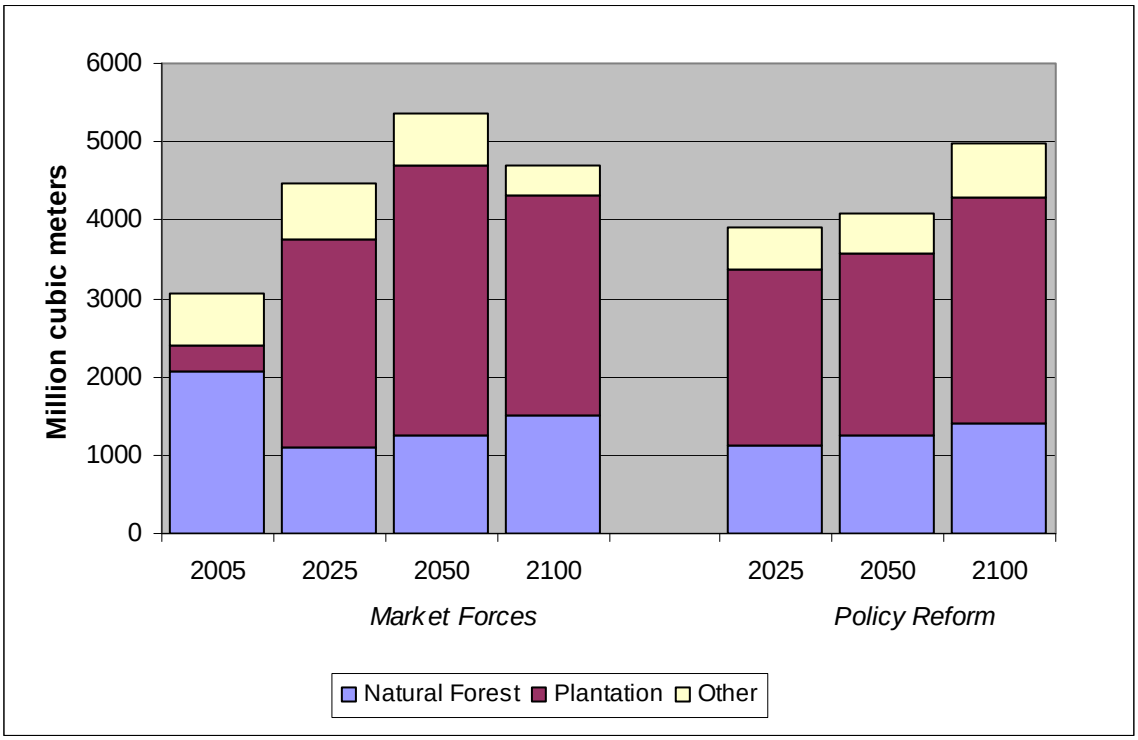


Figure 5-5. Global primary fiber inputs for secondary products in scenarios

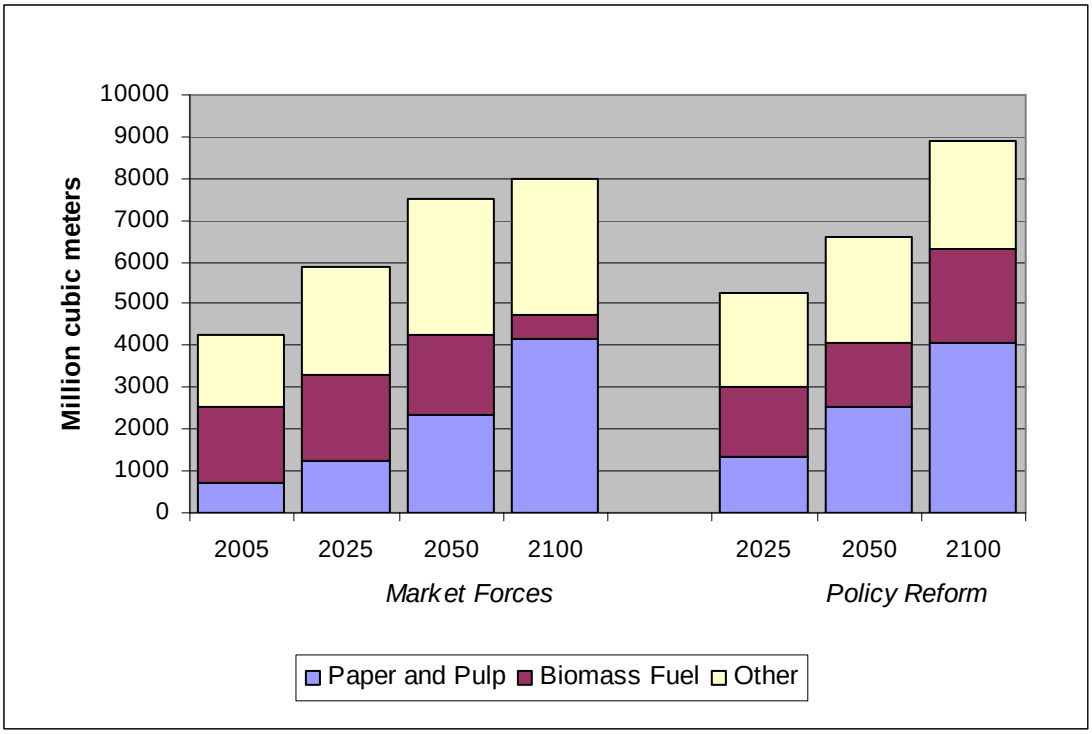
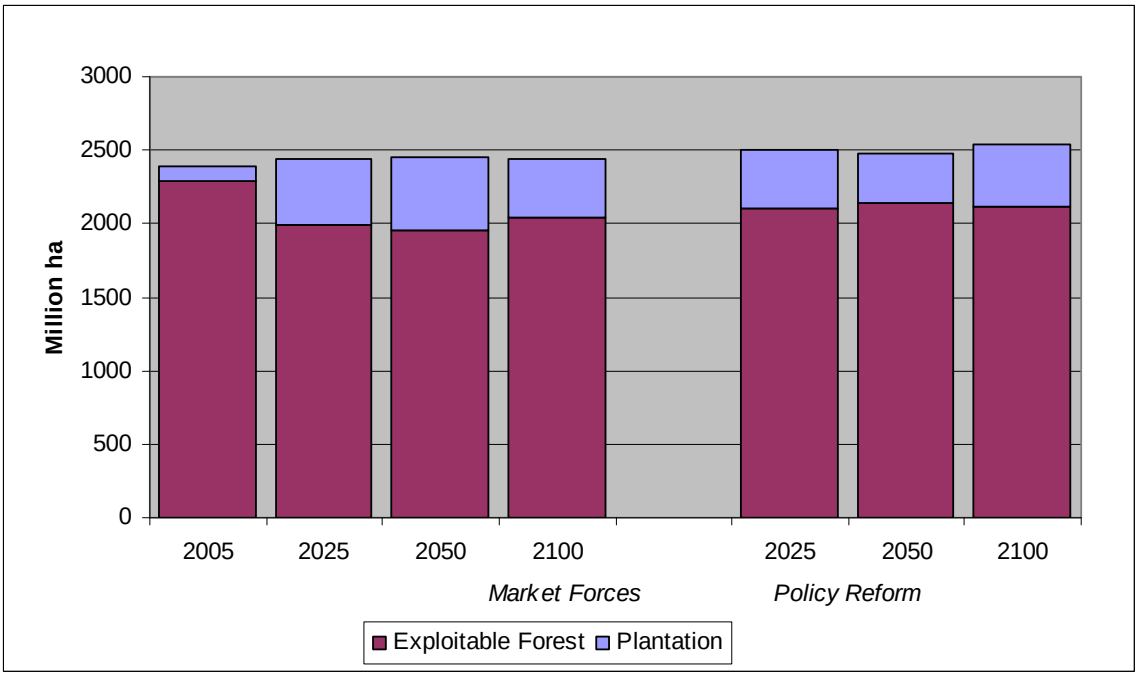


Figure 5-6. Forest area available for production in each scenario



Tree Crops for Energy

One potentially important type of energy crop is fast-growing tree crops for energy production. In the base year, such crops make a negligible contribution to either land cover or energy. It is anticipated that targeted policies will be required if this crop is to become an important energy source. It is assumed it will not make a significant impact in the *Market Forces* scenario. However, in the *Policy Reform* scenario this crop is expected to make an important contribution to modern biomass fuels. In the scenarios, requirements for biomass fuels drive production of biomass from forest resources.

The "biomass" category in the energy sector covers a diverse set of fuels, including wood and wood residues, charcoal, dung and agricultural residues (while municipal solid waste is considered separately). The land-use implications of ethanol as derived from sugarcane are taken into account through increased cropland demand (sugarcane-based ethanol is only important in Latin America, and not measured elsewhere). Cellulosic ethanol is assumed to have no land-use impact, as it would either be created from crop-waste, or cellulosic ethanol plants could be grown on marginal lands not used elsewhere in this analysis.

The use of tree crops for energy is estimated in this analysis, as described above based on the estimated ratio of biomass volume produced to biomass energy required. The ratio of the volume of biomass fuel produced to the amount of energy from biomass fuels consumed is calculated for the base year, shown in Table 5-14 below. For OECD regions, this value is kept constant throughout the scenarios. In the non-OECD regions, the volume per PJ (petajoule) is reduced to a level more similar to the OECD regions by 2100. This reflects a convergence of technologies and practices for collecting and consuming the roundwood for energy, such as more efficient furnaces. This also reflects the shift to and improvement of plantation practices, such as the planting of more energy dense species. Figure 5-5 shows that the increase of biomass demand for energy in the *Policy Reform* scenario is balanced by the reduction in demand for "Other" wood products, and by a slight reduction in paper and pulp requirements. Thus, both the *Market Forces* and *Policy Reform* scenarios result in a similar overall level of fiber production and land-use in 2100.

Table 5-14. Ratio of biomass fuel volume to biomass fuel energy used

1000 m^3 / PJ	2005	2025	2050	2100
North America	15	15	15	15
Western Europe	22	22	22	22
Pac OECD	15	15	15	15
FSU	62	53	42	20
Eastern Europe	26	25	23	20
Africa	68	58	46	20
Latin America	78	65	50	20
Middle East	60	51	41	20
China+	22	22	21	20
South Asia	34	31	27	20
Southeast Asia	50	44	36	20

Deforestation

Current Accounts

From 1980 to 1995, the average rate of forest loss worldwide was about 12 million hectares each year (FAO, 1997b). From 1990 to 1995, the average rate of loss was about 11 million hectares each year (FAO, 1999b).

From 1990 to 2005, the rate of decrease has been 0.2 percent per year, or on average about 8 million hectares per year, leading to a loss of 3 percent of the world's forests (FAO, 2007f). The annual rate of change globally was a loss of 8.9 million hectares per year between 1990 and 2000, but has slowed down between 2000 and 2005 to a loss of 7.3 million hectares per year.

In developing regions, there was a net loss of 131 million hectares of forest area over the period from 1990 to 2005, while net reforestation and afforestation in the industrialized countries added about 6 million hectares. This reduction of forest area means the loss of many valued services (FAO, 2007f): forests, which cover about 30% of the world's land area, are believed to contain two-thirds of the world's species; they are home to forest-dwelling people; they provide a potentially renewable supply of a variety of products for human needs; they are a source of income for the poor; and they are a potentially important component in mitigating global climate change. In both scenarios, deforestation continues as a result of expanding human settlements and agricultural land.

The term "forest" can be applied to a wide range of land covers, which gives rise to widely varying estimates of forest extent (see, for example, different totals reported in WRI, 2007). For this study, the FAOSTAT category "forest and woodland" is used (FAO, 2008a). Within this category are included natural forests and plantations, and such diverse habitats as closed forests and sparse woodlands. In an assessment of forest cover change in tropical countries, it was found that between 1980 and 1990, 92 million hectares of closed forest were lost in the survey area, while only 4 million hectares were added (FRA, 1996). Of the total lost, about 60% was converted to land types with some woody cover, but with significantly reduced biomass, such as open or fragmented forest; much of this change would result in no net loss of "forest land" as the term is used here. Also, the forest land category does not take into account the quality of the forests – their health, genetic diversity and age profile (WRI, 2007). Finally, the total area does not capture the extent of fragmentation of forests, which affects their resilience, as fragmented forests cannot provide secure habitats for native plants and animals (WRI, 2007).

As a result of the diverse set of types of land cover included within the forest land category, the deforestation rates arising in the scenarios here are consistent with a range of detailed scenarios for biomass and biodiversity loss. However, some indications can be gained from detailed studies of past land-use changes. From the study mentioned above of forest cover changes in tropical regions, between 1980 and 1990 the most stable land-cover classes were forest plantations and non-forested land. Thus, afforestation and reforestation were not dominant trends. For both plantations and non-forested land about 99% of the land area that was in the category in 1980 was still in that category in 1990. The least stable category was fallow land associated with shifting cultivation ("long fallow"), with 86% remaining in the same category, while 8% was converted to short fallow or non-forested land. Note that even in the case of shifting cultivation, where in traditional systems forest cover is allowed to regenerate, the dominant change is to land with lower biomass content. The percentages of closed and open forest in 1980 that remained in 1990 were similar to each other, about 93%, but because of the much larger area of closed forest, the absolute changes were larger. Overall, conversion of forest land was dominated by the loss of closed forest, and nearly all of the changes were to land with smaller biomass content.

Scenarios

In both scenarios, deforestation rates are determined as a net result of the conversion of forest to the built environment, cropland, rangeland and forest plantations. In the *Policy Reform* scenario there is also some afforestation to meet the forest preservation targets of the scenario. The resulting land areas are shown in Table 5-15.

Table 5-15. Natural forest area in the scenarios

Mha		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	614	472	410	356	514	472	469
Western Europe	136	126	114	110	131	128	126
Pac OECD	208	210	216	219	213	223	232
FSU	851	813	786	752	823	811	828
Eastern Europe	41	34	28	30	35	38	45
Africa	635	600	584	651	680	711	805
Latin America	923	703	574	529	725	691	757
Middle East	17	17	18	20	15	20	23
China+	243	239	241	238	245	257	307
South Asia	76	54	58	75	89	93	98
Southeast Asia	208	170	170	170	174	183	196
World	3,952	3,439	3,200	3,150	3,644	3,626	3,885

Source: 2005 land use data taken from FAOStat Database (FAO, 2008a).

Barren and Other Land

Current Accounts

Any land that is not forested, protected, part of the built environment or used for agriculture (cropland and grazing land) is placed for this study in a residual, "other" category. Within this category, barren land is considered separately in the analysis, where it is assumed that while non-barren "other" land can be converted to agricultural land or forest, barren land cannot be so converted. The area of barren land in each region is based on the Global Land Cover Characteristics database (USGS/UNL/JRC, 1999). Aside from barren land, the "other" land category contains any land that is not included in any of the previous categories. It might include wetlands, semi-desert areas with vegetation too sparse to support livestock, or grasslands not used for grazing. The estimated areas of the residual "other" land-use category, and the fraction that is barren, are shown in Table 5-16. Note the very high percentages that are barren in the Middle East, South Asia and Africa. This places strong restrictions on the expansion of agricultural land in these regions.

Table 5-16. Area of "Other" land – 2005

	Total "Other" Area (Mha)	% "Other" that is Barren	"Other" Land as % of Total
North America	489	48%	27%
Western Europe	59	18%	14%
Pac OECD	73	3%	9%
FSU	615	19%	29%
Eastern Europe	19	0%	11%
Africa	913	99%	31%
China+	4	0%	0%
Latin America	200	100%	33%
Middle East	40	88%	3%
South Asia	41	100%	10%
Southeast Asia	90	0%	21%
World	2,541	61%	20%

Source: 2005 land use data taken from FAOStat Database (FAO, 2008a).

Scenarios

In the scenarios, the area of "other" land is determined by its conversion to other types of land use, as described above. Land in this category can be converted to the built environment and grazing land, and to forest through afforestation. Land is added to the "other" land category through cropland degradation. Net conversions to and from this category in OECD and developing regions are shown in the introduction to this section in Table 5-1 and Table 5-2, as well as below in Table 5-17.

Table 5-17. Total “Other” land area in the scenarios

Mha	Market Forces				Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	489	466	468	490	458	480	492
Western Europe	59	40	34	40	41	40	46
Pac OECD	73	79	89	97	84	101	121
FSU	615	658	701	734	661	712	736
Eastern Europe	19	23	22	31	20	24	37
Africa	913	1007	1050	1148	1033	1080	1201
China+	4	96	174	253	83	138	137
Latin America	200	202	206	218	172	204	205
Middle East	40	37	40	49	44	60	113
South Asia	41	55	67	53	65	72	71
Southeast Asia	90	48	44	59	36	47	66
World	2,541	2,709	2,896	3,174	2,697	2,957	3,224

Source: 2005 land use data taken from FAOStat Database.

6 Water

The availability of water for agriculture, domestic (including commercial), and industrial uses will likely be one of the defining issues of the 21st Century. Increasing agricultural production requires the expanded use of irrigation, rising incomes and living standards tend to be accompanied by greater household water use, and growth in industries requires more water for production processes and for cooling. All of these requirements increase in the future in the *Conventional Development* scenarios. Yet the resource base, which is under severe pressure in some regions today, is assumed to remain unchanged. With the worsening of climate change, the resource base may even decline in many regions.

In this section the 2005 *Current Accounts* and *Conventional Worlds* scenarios for water use are described. Water withdrawals, which are equal to or greater than water use depending on the purposes involved, are then compared to the magnitude of water resources in order to develop an indicator of water stress. The scenario methodology is based largely on two earlier studies (Raskin et al., 1995; Raskin et al., 1997). Some of the text in this chapter is adapted from the reports of those studies.

Resources

Data on national renewable freshwater resources used for this study are drawn from the Pacific Institute World Water data (Pacific Institute, 2007). For the national-level analysis, river inflows from adjacent countries are included in the resource totals, which may lead to double counting of freshwater supplies in some cases. Nonrenewable resources – such as "fossil" aquifers that are either not being recharged, or are being recharged very slowly, are not included in total resources, since their use cannot be sustainable over the long term.

Total annual water resources are shown for each of the eleven regions in Table 6-1. For the regional totals, national cross-border flows have been excluded in order not to double-count. The contribution from cross-border flows was estimated using ratios of total flows to local resources using data from Shiklomanov (1999). Resources per person vary from 1,600 cubic meters per year in the Middle East to 33,000 cubic meters per year in Latin America – a twenty-fold difference. The variation of water resources per capita within regions is hidden when examining the regional totals, of course, but is captured to some degree in the estimates of national water stress levels, as described below.

In the *Conventional Worlds* scenarios, it is assumed that renewable resources remain at base-year levels. This assumption would be violated if the global climate changes significantly, as current models suggest will occur (IPCC, 2007). Also, in many places, water pollution is reducing the usable freshwater resources (Postel, 1992). In theory, it is also possible to add to the useful resources, by capturing water that is currently lost as

runoff using small-scale technology (Conway, 1997; Hudson, 1992; Postel, 1992), but this is not likely to overcome the increased pollution of renewable water resources. In addition to these changes in useable renewable resources, many countries today effectively increase their resources by recycling wastewater and desalinating brackish water and sea water. In some countries, these sources contribute significantly to total water supplies (FAO, 2007e; Postel, 1992). In the analysis, these supplies are included explicitly for countries in arid areas, as discussed below. The annual renewable water resources for the *Conventional Worlds* scenarios are reported in Table 6-1 below. Since the last set of scenarios were performed, the estimate of global renewable water resources has increased by about 40 percent, a large increase.

Table 6-1. Annual renewable water resources – 2005

	Total* ($1000\ km^3$)	Per Person ($1000\ m^3$/capita)
North America	6.4	19.0
Western Europe	2.2	5.2
Pac OECD	1.4	6.7
FSU	5.3	18.6
Eastern Europe	0.9	5.0
Africa	5.7	6.3
Latin America	18.4	33.0
Middle East	0.4	1.6
China+	4.2	2.9
South Asia	3.6	2.5
Southeast Asia	6.7	14.2
World	55.1	8.5

Source: Pacific Institute (2007). * Totals exclude cross-border river flows

Desalinated Water and Wastewater

In the base year, several countries in the Middle East, the FSU, and North Africa in addition to China supplied some of their water needs from desalinization and wastewater treatment plants. In the context of the various levels of water stress found in the scenarios, these countries may be forced to rely more heavily on this expensive option in the future, with negative but uncertain implications for economic growth and energy consumption.

The scenario assumptions for supplies from these sources are shown in Table 6-2. In the *Market Forces* scenario, supplies roughly double in the Middle East, Africa, and China+ between 2005 and 2050, while in FSU they increase by about 11 percent. All regions

maintain the same share of their water supply coming from desalinized water and recycled wastewater throughout the scenarios.

In the *Policy Reform* scenario, as part of the effort to meet the sustainability goals outlined in Chapter 1, supplies from desalinization and wastewater treatment plants increase more rapidly than in the *Market Forces* scenario. By 2025 in the *Policy Reform* scenario, all regions employ a combination of desalinization and/or wastewater recycling for a significant contribution to future water resources. The share of the total water supply coming from desalinization and treated wastewater is set to grow by 4 percentage-points for all regions. The absolute increase is greatest in South Asia, where production from these sources increases by nearly 70,000 million cubic meters over the course of the scenario. However, as a fraction of withdrawals, the supply from desalinization and wastewater treatment plants in the Middle East in 2005 is only 2% of the withdrawals, and by 2100 in the *Policy Reform* scenario only reaches 10% of the withdrawals of that year. This is close to the value for Oman in the base year (at 11.5% of total withdrawals), but well below that of Bahrain, the United Arab Emirates, Qatar and Kuwait, where between 20% and 60% of water withdrawals were supplied by treated water.

Table 6-2. Desalinized water and recycled wastewater in the scenarios

Million cubic meters		***Market Forces***			***Policy Reform***		
	2005	2025	2050	2100	2025	2050	2100
North America	0	0	0	0	8,732	17,503	32,112
Western Europe	0	0	0	0	3,411	6,313	10,465
Pac OECD	0	0	0	0	2,144	4,028	7,292
FSU	5,756	6,349	6,547	6,834	8,745	13,313	24,686
Eastern Europe	0	0	0	0	1,451	3,035	6,344
Africa	1,025	1,494	2,088	3,185	5,272	11,642	25,208
Latin America	0	0	0	0	4,480	11,223	24,868
Middle East	4,425	5,414	6,748	7,610	7,359	11,532	20,212
China+	15,844	22,156	30,369	34,638	24,576	33,828	56,751
South Asia	0	0	0	0	16,029	35,367	69,370
Southeast Asia	0	0	0	0	4,209	9,225	17,320
World	27,049	35,412	45,751	52,267	86,410	157,009	294,628

Sources: 2005 values based on AQUASTAT data (FAO, 2007e)

Withdrawals and Water Stress

In the scenarios the relationships between water supply and demand are translated into indices of *water stress*, a condition in which inadequate water supplied for human, economic and environmental needs leads to competition over resources. The estimation of water stress in this analysis is based on national level calculations, since regional

aggregation can too easily mask local problems. (This can be a problem, of course, even with national level analyses.) The national-level results are then aggregated to the regional level, and the regional figures are used to parameterize water-stress curves, as described below.

As the methodology for developing water stress scenarios is tied intimately to the water withdrawal scenarios, both the approach to analyzing water stress and the methodology for developing scenarios of withdrawals are summarized in this subsection. A detailed discussion of withdrawals by sector is taken up in later subsections.

Methodology for Water Withdrawal Scenarios

Water withdrawals are defined as the total demand for water in each region minus all water obtained through desalinization and wastewater recycling. Thus, water withdrawals relate to the amount of water which must be withdrawn from freshwater surface and underground sources. Water withdrawals are disaggregated at the sectoral and sub-sectoral level. Ideally, withdrawals would be disaggregated to the level of end-uses; for example, toilets in households, or particular processes and technologies in industries. However, data limitations do not permit this level of detail in this study. Instead, withdrawals are assigned to the agriculture, domestic (which includes withdrawals coming from the service/commercial sector), industry and energy sectors, and are further broken down by manufacturing sub-sector and energy conversion process (in this study, thermal electric generation). However, even at this level of disaggregation, data are rarely available, so in constructing the current accounts for several regions, sectoral water withdrawals are estimated, based on available data, as described in later sub-sections.

In the analysis, sectoral withdrawals are expressed as the product of an activity level such as population in the household sector or subsectoral value added in the industrial sector, and an intensity. The activity levels are determined by assumptions made external to the water analysis: population and income growth, changing sectoral composition of GDP, and irrigated harvested area. The emphasis in the water-use analysis is, therefore, on the changing water use intensities. The relationship between sectoral withdrawals, activity levels and intensities can be expressed simply as:

$$\text{Withdrawal} = \text{Activity Level} \times \text{Intensity} . \qquad (6\text{-}1)$$

In the *Market Forces* scenario, intensities for OECD regions are based largely on historical patterns, as well as on business-as-usual expectations for the future. Intensities in non-OECD regions generally converge toward those of the more efficient OECD regions.

In constructing the *Policy Reform* scenario, withdrawals are constrained by a sustainability target based on limiting increases in water stress. Before describing the methodology for the *Policy Reform* scenario, the analysis of water stress is first presented.

Water Stress Analysis

As described above, water withdrawals in both scenarios are computed at the regional level. However, because water-supply issues are very local in nature, the analysis of the degree of water stress is performed at the national level. The connection between regional withdrawals and the national-level stress analysis is provided by a set of water stress curves developed using national data.

Several measures of water stress have been introduced in the past (Raskin et al., 1997). Depending on the measure, they are intended to provide rough indicators focusing on different aspects of water stress: the pressures placed on sustainable water resources, the reliability of water supplies, or the ability for society to cope with limited renewable freshwater supplies. The measure used in the current analysis is the *use-to-resource ratio*, the ratio of total freshwater withdrawals to renewable freshwater resources. The ratio is a measure of the pressure placed on water resources in the long run, since in the short run many regions rely on the unsustainable use of ground water supplies. In some countries, part of the withdrawal demand is also supplied by desalinization and wastewater treatment plants. These withdrawals are excluded when computing the use-to-resource ratio, since they do not put pressure on renewable water resources. Expressed as a formula, the water-stress indicator used in this study is given by:

$$\text{Use - to - Resource Ratio} = \frac{\text{Withdrawals - (desalinization \& wastewater)}}{\text{Renewable resources}}. \qquad (6\text{-}2)$$

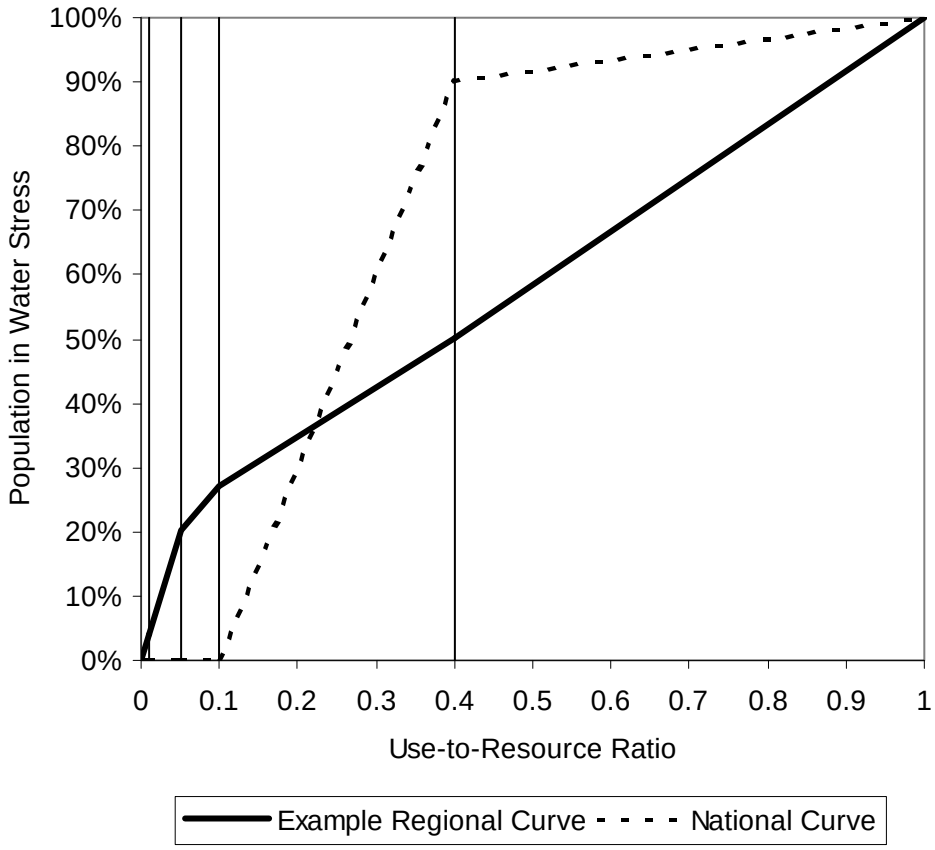
A population in a given area is considered to be in water stress if the use-to-resource ratio for that area exceeds certain critical values. In Raskin et al. (1997), the following criteria were used: a use-to-resource ratio of less than 0.1 indicates no stress, between 0.1 and 0.2 low stress, between 0.2 and 0.4 stress, and greater than 0.4, high stress. At use-to-resource ratios higher than 0.2, water stress can begin to be a limiting factor on economic development (Raskin et al., 1997).

For the current analysis, using an approach adapted from that of Raskin et al. (1997), the population within a country in areas of water stress, expressed as a proportion of the total population in the country, is assumed to increase linearly as the national use-to-resource ratio rises from 0.1 to 0.4, and then at a different linear rate from 0.4 to 1.0. When the national use-to-resource ratio is 0.1 or below, none of the population in the country is assumed to be in water stressed areas; when the use-to-resource ratio is 0.4, 90% of the national population is assumed to be experiencing water stress; and when the use-to-resource ratio is 1.0, 100% of the population is experiencing water stress. The withdrawal-water stress curve applied in all countries is shown in Figure 6-1.

The national-level estimates of the population in water stress are aggregated to the regional level, at different values of the regional use-to-resource ratio. The approach is illustrated in Figure 6-1. The result of adding up the national-level curves is used to parameterize regional curves of water stress as a function of the regional use-to-resource ratio. An example of a regional curve is shown in the figure. Regional values for water stress are specified at values for the regional use-to-resource ratio of 0.01, 0.05, 0.1 and 0.4, indicated by vertical lines. For all regions, water stress is assumed to be zero when

the regional use-to-resource ratio is zero, and 100% of the population when the use-to-resource ratio is 1.0. Otherwise values are linearly interpolated between these fixed points.

Figure 6-1. Dependence of water stress on water use-to-resource ratio



Methodology for the Policy Reform *Water Withdrawal Scenario*

In the *Policy Reform* scenario, using curves of the use-to-resource ratio vs. water stress such as that illustrated in Figure 6-1, the water stress target for the population is translated into a corresponding target for the maximum use-to-resource ratio. That ratio, multiplied by resources, gives the maximum level of withdrawals from renewable freshwater sources consistent with the water stress target. Combined with contributions from desalinated water and recycled wastewater, this gives the maximum total water available for withdrawal, within the constraints placed by the scenario goal or target.

Next, in each sector, two levels of water withdrawals are calculated, one under *Market Forces* assumptions, and one under "best practice" assumptions, where the best practice intensities are determined separately for each sector. The *Market Forces* and best practice

levels of withdrawals are opposite extremes. Comparing these extreme cases to the withdrawal target, there are two possibilities:[23]

1. The *Market Forces* withdrawals are less than the maximum target withdrawals.

2. The maximum target withdrawals are between the *Market Forces* and best practice withdrawals.

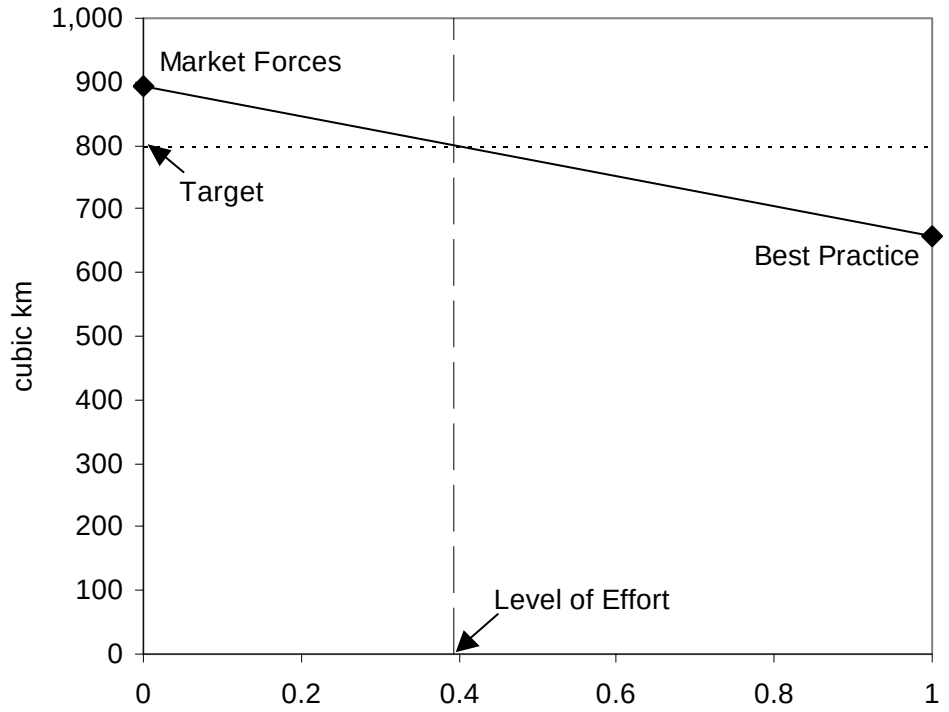
The first case signals that even under *Market Forces* development rates, regional resources are not under significant pressure. In this case, regional withdrawals are left at the *Market Forces* level. In the second case, the region must make some effort to achieve the target, relative to the results using *Market Forces* assumptions. This situation is illustrated in Figure 6-2, where "Level of Effort" is indicated on the figure as the degree to which the region must move away from *Market Forces*-style development over time toward best practice. It is assumed that the same level of effort is made in all consumption sectors. The targets are set so that the level of effort is below 75% in 2025, and up to 100% in 2050 and 2100.

Table 6-3. Effort levels toward best-practice water use in *Policy Reform* scenario

	Policy Reform		
	2025	2050	2100
North America	0.20	0.35	0.51
Western Europe	0.23	0.44	0.62
Pac OECD	0.43	0.72	0.96
FSU	0.69	1.00	1.00
Eastern Europe	0.68	0.97	1.00
Africa	0.75	1.00	1.00
Latin America	0.75	1.00	1.00
Middle East	0.75	1.00	1.00
China+	0.68	0.94	1.00
South Asia	0.75	1.00	1.00
Southeast Asia	0.75	1.00	1.00

[23] In principle, there are three possibilities. The third, in which maximum withdrawals are below the best practice withdrawals, indicates that the specified target is unachievable under best practice assumptions. However, this situation is not encountered, as the target values take into account the possibility of reaching the goals within each region.

Figure 6-2. Determining "level of effort" in the Policy Reform Scenario



Withdrawals by Sector

The data source on withdrawals used for this study (Pacific Institute, 2007) reports withdrawals for three sectors: domestic, industrial and agricultural. Withdrawals for these sectors are shown by region in Table 6-4. The domestic sector includes water use in households and in the service (commercial) sector. The industrial sector includes energy conversion sector uses (for this study, thermoelectric generation), in addition to standard industrial activities (manufacturing, mining, quarrying, and construction).[24] Water is used in agriculture for irrigation, watering livestock and aquaculture. However, nearly all of the water withdrawn for agriculture is used for irrigation (Raskin et al., 1995; Luyten, 1995), and in this study, all of the reported agricultural withdrawals are assumed to be for irrigating crops. In this study, withdrawals are assigned to just three main sectors: domestic uses, industrial (split between manufacturing and energy conversion processes), and agriculture. The allocation as seen in Table 6-3 below, is based on available supplemental data, described by sector in the following sections.

This 2005 data indicates that global level withdrawals have increased by about 20% in the previous ten year period, while certain developed regions such as North America and Western Europe have significantly decreased their amount of water withdrawals.

[24] Water is also used for petroleum refining. However, this accounts only for an estimated 3% of total energy water withdrawals (Heaps et al., 1998). Water for refining is not considered in this study.

Globally, industrial water withdrawals have not changed significantly from 1995 – 2005, but both domestic and agricultural withdrawals have increased substantially, by 32% and 25%, respectively.

Table 6-4. Freshwater withdrawals (demand) by sector and region – 2005

	Total Withdrawals (km^3)				Share of Total Withdrawals (%)		
	Domestic	Industrial	Agricultural	Total	Domestic	Industrial	Agricultural
North America	69	250	202	522	13%	48%	39%
Western Europe	33	105	75	214	16%	49%	35%
Pac OECD	29	21	83	133	21%	16%	62%
FSU	30	79	178	288	11%	28%	62%
Eastern Europe	11	35	43	90	13%	39%	48%
Africa	20	8	177	205	10%	4%	86%
China+	46	161	185	392	12%	41%	47%
Latin America	12	27	176	215	5%	13%	82%
Middle East	44	5	429	477	9%	1%	90%
South Asia	59	40	819	917	6%	4%	89%
Southeast Asia	16	8	218	241	6%	3%	90%
World	368	740	2586	3694	10%	20%	70%

Domestic

Current Accounts

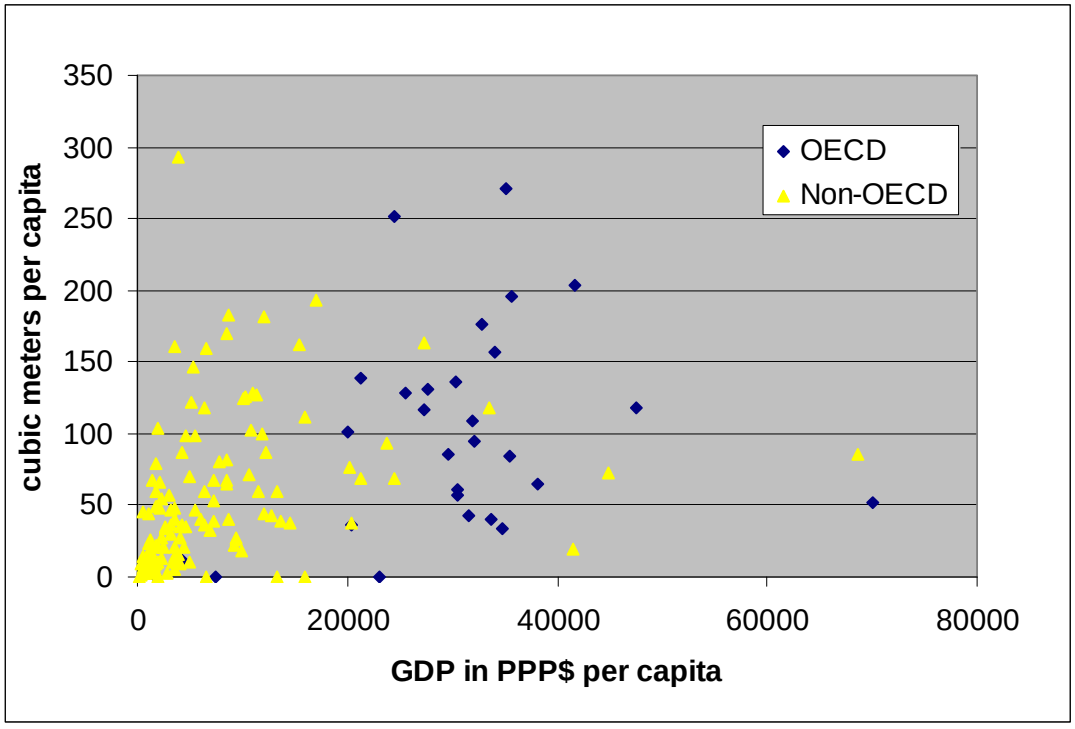
Water is used in households for human consumption, toilets, dish washing, bathing, cleaning and outdoor use (e.g., lawn watering, car washing and decorative uses). The service sector includes such water-intensive establishments as restaurants, cleaners, hotels and hospitals. Unfortunately, data limitations require that we aggregate over these diverse activities.

Water requirements in each sector are calculated as the product of two factors: an activity level and a water intensity. For domestic withdrawals, the activity level is population and the water intensity is water use per person. Domestic water intensities in a given region reflect many factors, for example, income levels, water infrastructure, technology and water availability. As illustrated in Figure 6-3, 2005 domestic water intensities vary widely between countries and regions, and generally increase with income. Yet, there is a lot of overlap in per capita water consumption data between middle income countries and much richer countries. Regional annual per capita withdrawals are shown in Table 6-5. Values range from as little as 22 cubic meters per person each year in Africa to over 200 cubic meters in North America. However, over the period 1995 – 2005 the domestic water intensities in OECD countries have tended to fall, on average, while the intensities for all other regions have risen. The most significant change comes from South Asia, whose domestic water withdrawal intensity more than tripled between 1995 and 2050.

Table 6-5. Domestic freshwater withdrawal (demand) intensities – 2005

m^3/capita	Withdrawl Intensities
North America	207
Western Europe	81
Pac OECD	141
FSU	107
Eastern Europe	64
Africa	22
China+	30
Latin America	83
Middle East	52
South Asia	40
Southeast Asia	33

Figure 6-3. Domestic withdrawals vs. income



Note: Lithuania and Estonia were removed as outliers in the Non-OECD macro-region. Lithuania has an average income of $14,085 per cap, and a domestic water withdrawal of 757 m^3/cap. Estonia's average income is $16,654 per cap, with a domestic water withdrawal of 591 m^3/cap. Sources: For water withdrawals, Pacific Institute (2007); for GDP per capita, World Bank (2008a) and CIA (2007).

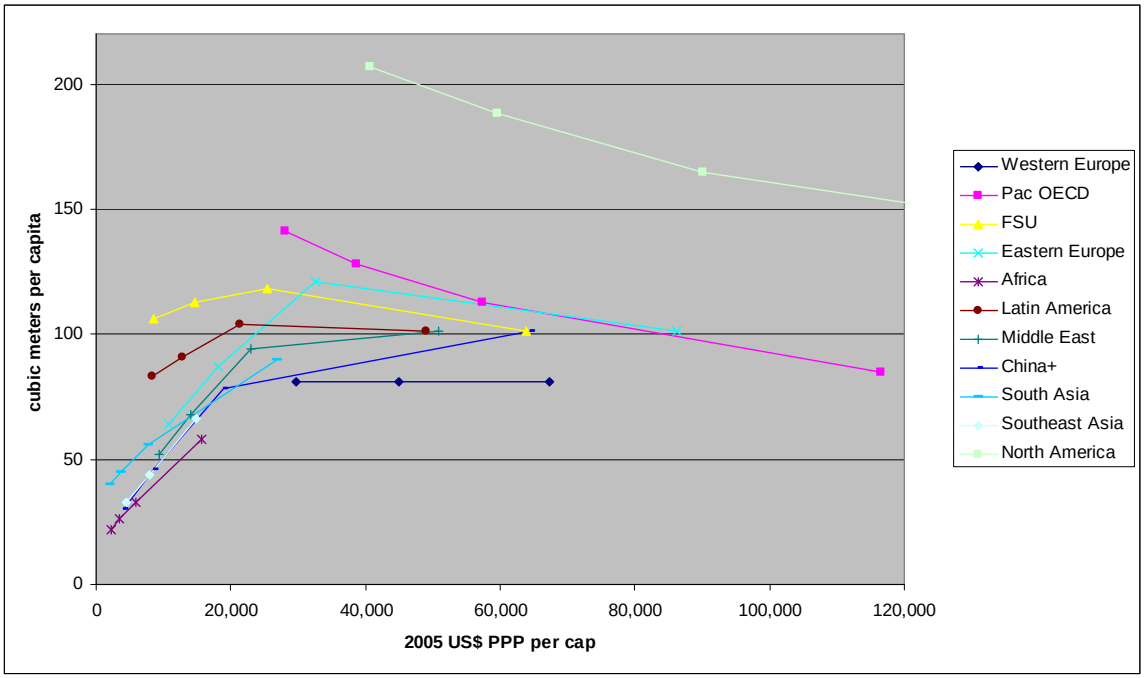
Scenarios

Domestic water intensities in the *Market Forces* scenario are based on trends in the OECD regions. Historically, in the United States, the intensity of domestic water withdrawals increased between 1960 and 1980, after which it leveled off. The earlier rise

in water use was due in part to the growth in single-family suburban housing, where large lots required more water, especially for outdoor use (Raskin et al., 1995). In the future, domestic water withdrawals per capita are expected to decline in the United States, based on recent policies and available technologies, including new building codes.

In North America and Pacific OECD, domestic water intensities are assumed to decrease by 20% over the course of the *Market Forces* scenario. In Western Europe, at about 81 cubic meters per capita, 2005 domestic intensities are much less than those in the other OECD regions, which are close to 180 cubic meters per capita (Table 6-5). In the scenario, domestic water intensities in Western Europe are assumed to remain at the relatively low base-year level. In the developing regions, intensities converge toward the average OECD levels following a convergence algorithm (see Annex 1) as each region's average income approaches the average income in the OECD in the base year. The resulting intensities are shown in Figure 6-4. They are plotted against average income to better illustrate the effect of the convergence algorithm.

Figure 6-4. Domestic water intensities in the *Market Forces* scenario

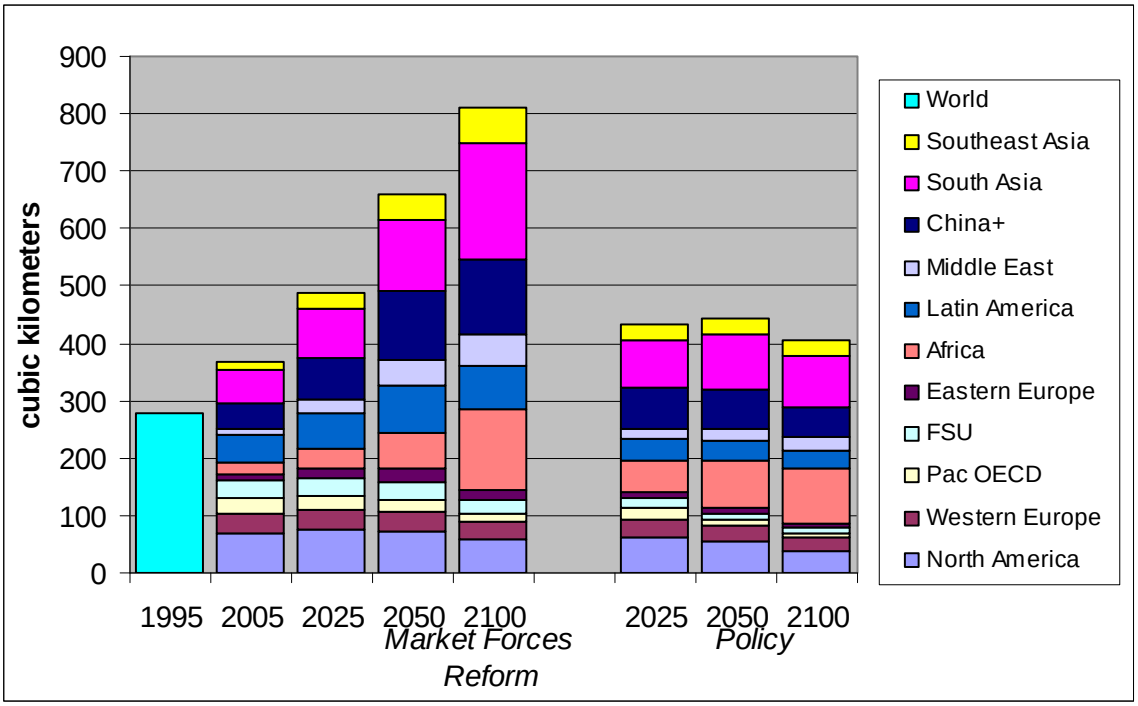


Note: The ticks on each line represent the data or scenario results of 2005, 2025, 2050, and 2100. North America in 2100 is not shown on the graph, but reaches 124 cubic meters per capita at 190,000 U.S. $/capita

Domestic water withdrawals are computed by multiplying the intensities by the population assumptions in the *Market Forces* scenario. The results are shown in Figure 6-5. Water use in the OECD and transitional regions changes little, due to low population growth and relatively steady water intensities; however, the developing regions show large increases. Withdrawals for the non-OECD regions as a whole more than double

over the course of the *Market Forces* scenario. This increase dominates the global trend, in which domestic withdrawals reach 487 km^3 in 2025 and 658 km^3 in 2050 and 809 km^3 in 2100, compared to 368 km^3 in 2005.

Figure 6-5. Domestic withdrawals by region in the scenarios



As discussed in the previous subsection, in the *Policy Reform* scenario, best practice intensities are set for each sector. Over the course of the *Policy Reform* scenario, regional intensities move toward the best practice value relative to the *Market Forces* value, defined by the "level of effort" each region employs in order to meet their water withdrawal targets. For the domestic sector, several factors were considered when setting the best practice: current water use patterns, basic needs, the potential for efficiency improvements, and the global convergence that is part of the *Conventional Worlds* story. The final domestic water intensities used in the *Policy Reform* case are shown below in Figure 6-6.

Current domestic withdrawals per capita are given in Table 6-5, and there is almost a tenfold difference between the value for Africa, at 22 cubic meters per capita per year, and North America, with 207 cubic meters per year. The lowest intensity in the OECD is in Western Europe, with annual withdrawals of about 81 cubic meters per capita, as noted above. Data from the OECD (2006) indicate that within Western Europe, domestic withdrawals per capita vary considerably. The lowest values are in Germany and Belgium, withdrawing about 66 and 71 cubic meters, respectively, per person per year for domestic purposes. The highest level of withdrawals are in Iceland, with an average of

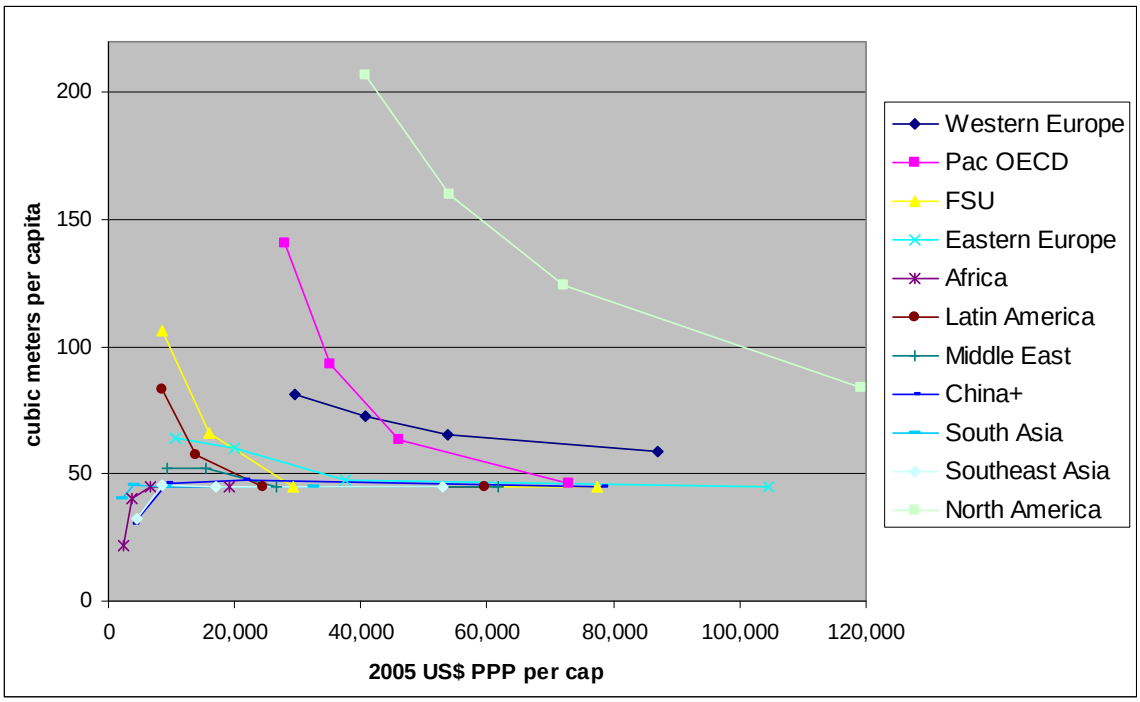
257 cubic meters per capita per year. Among OECD countries as a whole, the lowest levels of domestic withdrawals per capita are in Poland, at 57 cubic meters per capita. Withdrawals in Israel, a high-income but very arid country, are slightly lower, at 45 cubic meters per capita for domestic use (Gleick, 1998).

The regional estimates shown in Table 6-5 can be compared to estimated minimal requirements for metabolic, hygienic and domestic uses. According to Gleick (1998), considering drinking water and sanitation alone is consistent with a basic requirements of 25 liters per person per day, or about 9 cubic meters per person per year. Adding minimum levels for bathing and cooking doubles the basic requirement to about 18 cubic meters per person per year (Gleick, 1998). The average values for domestic withdrawals per capita are above this basic requirement in every region, though just barely above in Africa, with an average domestic water use of 22 cubic meters per year.

In OECD regions, domestic intensities can be reduced through expanded use of water-efficient appliances and tighter plumbing codes. In addition, water use for landscaping and lawns can be reduced through better practices, and in arid regions native plants can be used for landscaping, rather than more water-intensive ones (Postel, 1992; Gleick et al., 1995). In non-OECD regions, the increased use of water-consuming appliances as incomes rise as part of the process of convergence is expected to increase water consumption, leading to increasing withdrawals as we have seen over the last ten years. For the *Policy Reform* scenario the best practice value is set to 45 cubic meters per capita per year for every region. The domestic water intensities in the scenario are shown in Figure 6-6. They generally rise for developing regions and decline for transitional and OECD regions. Domestic withdrawals per capita in North America and Pacific OECD decline sharply from high base-year levels.

Domestic withdrawals are computed by multiplying the intensities by the populations assumed in the scenarios (discussed in Chapter 1). The results are shown in Figure 6-5. In the *Policy Reform* scenario there is a 50% decrease in the total OECD regions' water withdrawals in 2100 relative to 2005, compared to the smaller decrease of withdrawals by 2100 in the *Market Forces* scenario of only about 20%. Most non-OECD regions have increases in domestic water withdrawals, with Africa showing particularly large increases by a factor of 7 in *Market Forces* and by a factor of 5 in *Policy Reform.* However, for the non-OECD regions as a whole, domestic withdrawals in the *Policy Reform* scenario are significantly below those in the *Market Forces* scenario in all scenario years (See Figure 6-5).

Figure 6-6. Domestic water intensities in the *Policy Reform* scenario



Note: The ticks on each line represent the data or scenario results of 2005, 2025, 2050, and 2100.

Manufacturing

Current Accounts

Water withdrawals for manufacturing are disaggregated by the six sub-sectors introduced in Chapter 2 (page 22): iron and steel, non-ferrous metals, non-metallic minerals, paper and pulp, chemicals, and a miscellaneous "other" category. The five sub-sectors that are treated explicitly are relatively more water-intensive than the ones grouped into the "other" category (Raskin et al., 1995). The activity level for the industrial sector is sub-sectoral value added, while water intensity is defined as withdrawals per unit dollar value added.

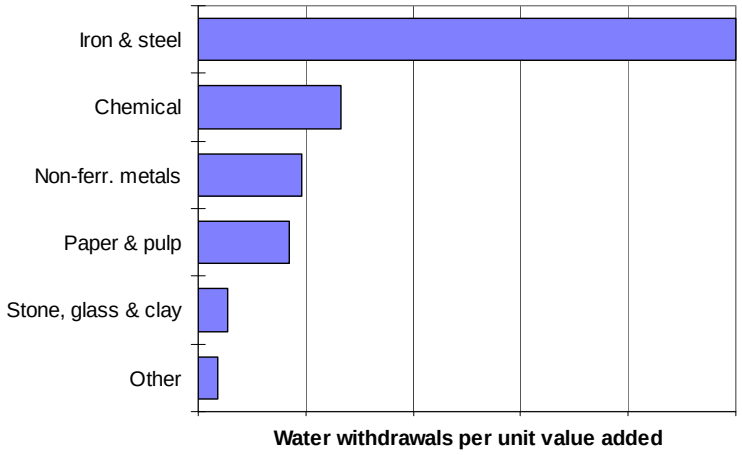
Withdrawals for manufacturing (described in this sub-section) and withdrawals for energy conversion, (described in the following sub-section) contribute to the total industrial withdrawals, the conventional category in international compilations of water use. Separate data on withdrawals for each of these purposes are available for OECD regions. For the non-OECD regions, in order to construct current accounts figures for manufacturing and thermal cooling withdrawals separately, the methodology of Strzepek and Bowling (1995) was applied. In this approach, provisional water intensities are set at the country level, as a multiple of U.S. intensities. Then the provisional intensities are adjusted to meet the total reported industrial withdrawals.

Aggregate manufacturing intensities by region as estimated using the procedure of Strzepek and Bowling, and using industrial withdrawal data from Gleick (1998) are shown in Table 6-6. The values vary over a wide range. Generally, the intensities are lowest in the developing regions, and highest in the transitional regions. The highest value for any region is that for the FSU, at 43 cubic meters of water per $1,000 of value added, with the lowest occurring in the Middle East and Africa close to 3 cubic meters per $1000 value added. Again, this is more than a factor of ten difference between regions. As shown in the next subsection, the estimated intensity for thermoelectric generation is also high in the FSU.

Table 6-6. Manufacturing water intensities in 2005

Manuf. Withdrawal Intensities	
	m^3/$1000 VA
North America	13.6
Western Europe	21.1
Pac OECD	11.2
FSU	43.0
Eastern Europe	19.7
Africa	3.1
Latin America	8.0
Middle East	2.6
China+	4.4
South Asia	4.9
Southeast Asia	3.8

Figure 6-7. Relative values for manufacturing intensities



Note: Iron & Steel = 1.0; Chemical = 0.2648; Non-Ferr. metals = 0.1937; Paper & Pulp = 0.1699; Stone, glass & clay = 0.0553; Other = 0.0371

Within the manufacturing sub-sector, data on water withdrawals by manufacturing sub-sector are scarce. For this analysis, in every region, manufacturing intensities are based

on data for the United States in the mid-1980s (Gleick, 1993; UN, 1990). The relative intensities in each sub-sector, shown in Figure 6-7, are the same for every region, with iron & steel equally 1.0. The absolute sub-sectoral intensities are set so that when they are multiplied by the base-year sub-sectoral value added, they reproduce the total regional manufacturing withdrawals.

Scenarios

Sub-sectoral water intensities in the scenario are based on historical and anticipated trends in the United States, where disaggregated time-series data are available. The water withdrawal intensity in manufacturing decreased by about 50% between 1960 and 1990, but then increased to 2005. The drop was due both to the decreasing share of total manufacturing output from water-intensive sub-sectors and the penetration of more efficient water-use practices (Raskin et al., 1995). The two effects that caused a decrease in the U.S. in the past play a role in the scenarios as well.

In *Market Forces*, it is assumed that in the OECD regions water intensities in all industrial sub-sectors decline by 20% from the 2005 levels by 2050, and by 40% by 2100 (See Composition Effect in Table 6-7 below). Moreover, the rising share of the less water-intensive manufacturing sub-sectors, in itself, lowers aggregate manufacturing water intensity. This is shown in Table 6-7, where the effect of changing sub-sectoral composition on intensities is separated from that of the reduction of water intensities at the sub-sectoral level. The shift in sub-sectoral composition within the manufacturing sector can be traced to the stable per capita output of traditional heavy industries that occurs in the scenario (Chapter 2), such as in iron and steel, non-ferrous metals, paper and pulp and chemicals. Consequently, the mix of manufacturing output shifts toward less water-intensive sub-sectors, thereby lowering the aggregate manufacturing water intensity. The combination of increasing efficiency and the changing mix of industrial activities is reflected in the aggregate manufacturing intensities shown in the aggregate index in Table 6-7.

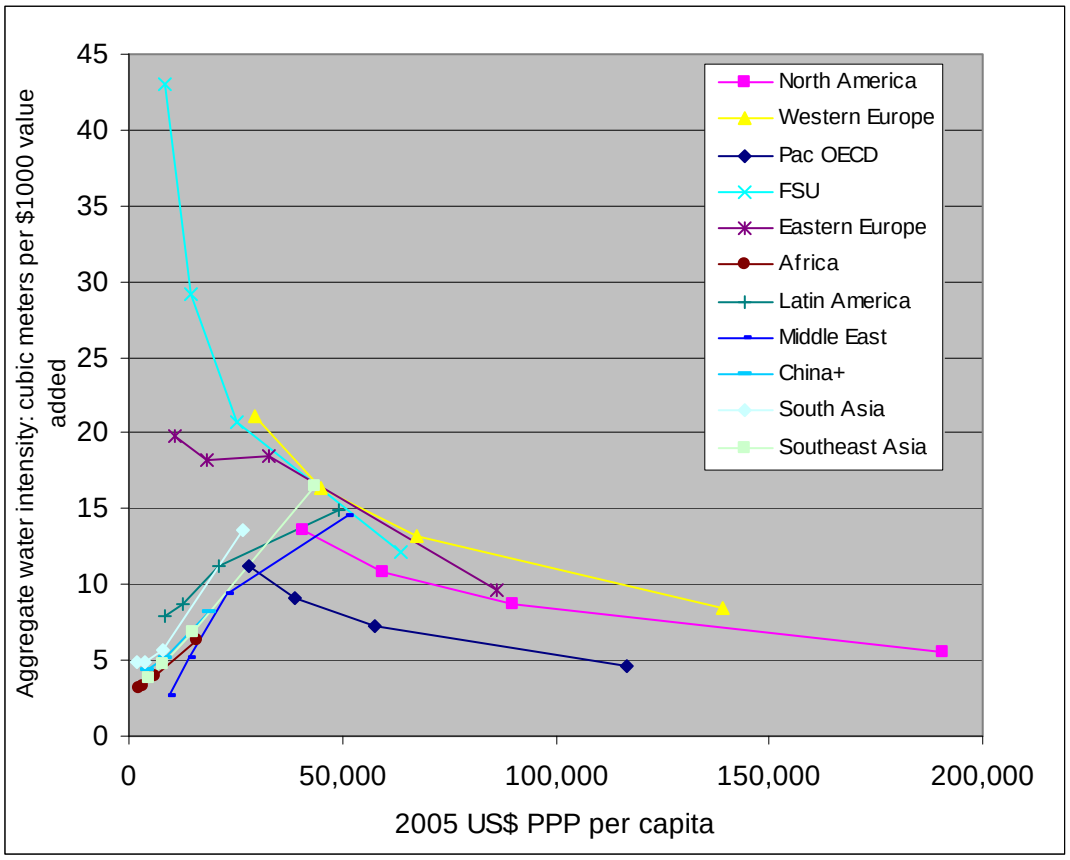
Table 6-7. Manufacturing intensities in OECD in the *Market Forces* scenario

Index (2005 = 1)						
	Composition Effect			Aggregate Index		
	2025	2050	2100	2025	2050	2100
North America	0.90	0.80	0.60	0.80	0.64	0.41
Western Europe	0.90	0.80	0.60	0.77	0.62	0.40
Pac OECD	0.90	0.80	0.60	0.82	0.65	0.42

Manufacturing intensities in the non-OECD regions are assumed to converge toward the average for the OECD regions as incomes rise (see Annex 1). The changing subsectoral

intensities, combined with the sub-sectoral composition of industrial value added, leads to the aggregate manufacturing intensities shown in Figure 6-8.

Figure 6-8. Manufacturing aggregate water intensities in *Market Forces*



Note: The ticks on each line represent the data or scenario results of 2005, 2025, 2050, and 2100. Industrial water intensity averaged for water use in all industrial subsectors.

Manufacturing water withdrawals in the *Market Forces* scenario are given by the product of the sub-sectoral intensities and sub-sectoral value added. Results are shown by region in Figure 6-9. Globally, annual water withdrawals in the sector increase by 2100 to 2.2 times the 2005 value. Regional variations are due to the interplay of region-specific assumptions about industrial scale, structure and water intensity. The dramatic growth in developing regions is particularly striking: mainly as a result of economic growth, withdrawals for the developing regions as a whole in 2100 are greater than the world total in 2005.

In order to develop a *Policy Reform* scenario, the best practice value for manufacturing intensities are first set, and then the best practice water withdrawal amount is calculated as discussed previously. Then the level of effort in each region is applied to determine

final actual withdrawals for the sector. The best practice value is based on industrial water use in Israel, since this is assumed to be a minimum reasonable level. As a result of water pricing policies and efficiency standards, industrial water use in Israel today is very efficient compared to other countries (Lonergan and Brooks, 1994). It is likely that new, more water-efficient technologies will be introduced as the scenario progresses. Methods for achieving efficiency improvements include water recycling, using saline or brackish water for cooling, and changing to less water-intensive industrial processes. For setting the best-practice intensity in the scenario, it is assumed that continued improvements lead to a 20% drop over current best-practice, the same assumption made for the non-European OECD regions in the *Market Forces* scenario. With this assumption, the best practice intensity in all regions (Table 6-8) is set to 80% of the estimated sub-sectoral value for Israel in 1995.[25,26] The manufacturing intensities in the *Policy Reform* scenario are shown in Figure 6-10.

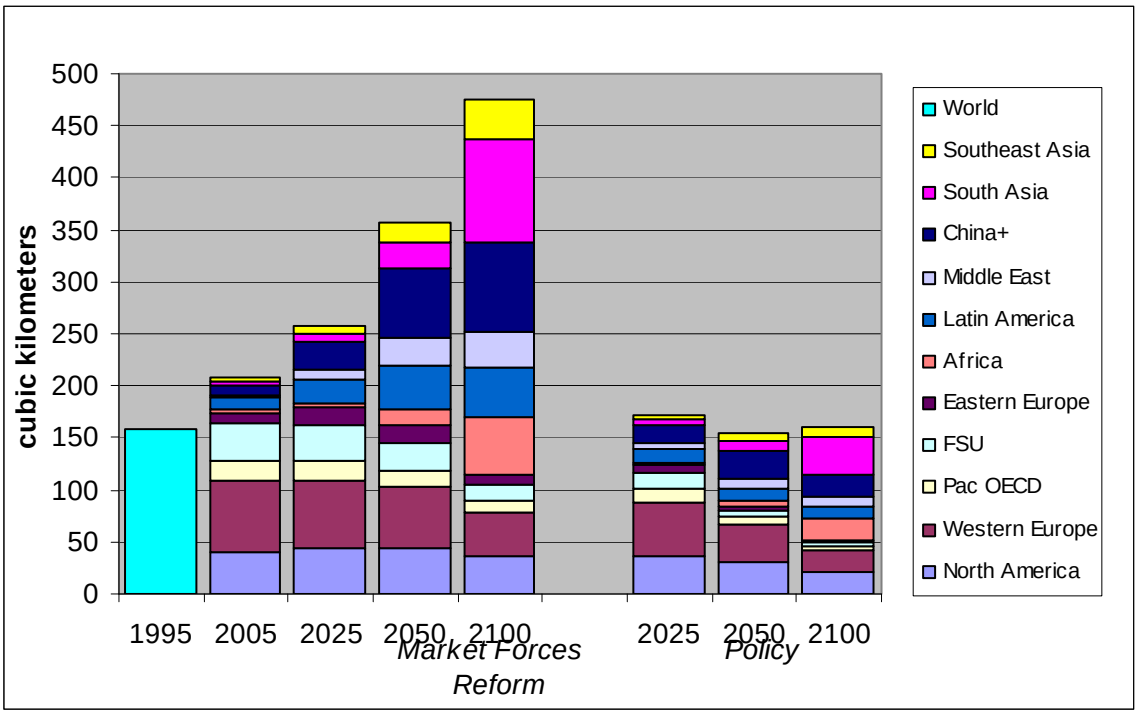
Table 6-8. Best practice manufacturing intensities

m^3 / $1000 VA	
Iron & Steel	51
Chemical	14
Non-ferr. Metals	10
Paper & Pulp	9
Stone, Glass & Clay	3
Other	2

[25] Subsectoral intensities for Israel are estimated assuming the same relative subsectoral intensities in Israel as for the United States in the mid-1980s (the most recent data available at the time of this study). Since electric generating plants in Israel use salt water for cooling (Lonergan and Brooks, 1994), and oil refining generally makes a small contribution to industrial withdrawals, all of the reported industrial water withdrawals may be assigned to manufacturing.

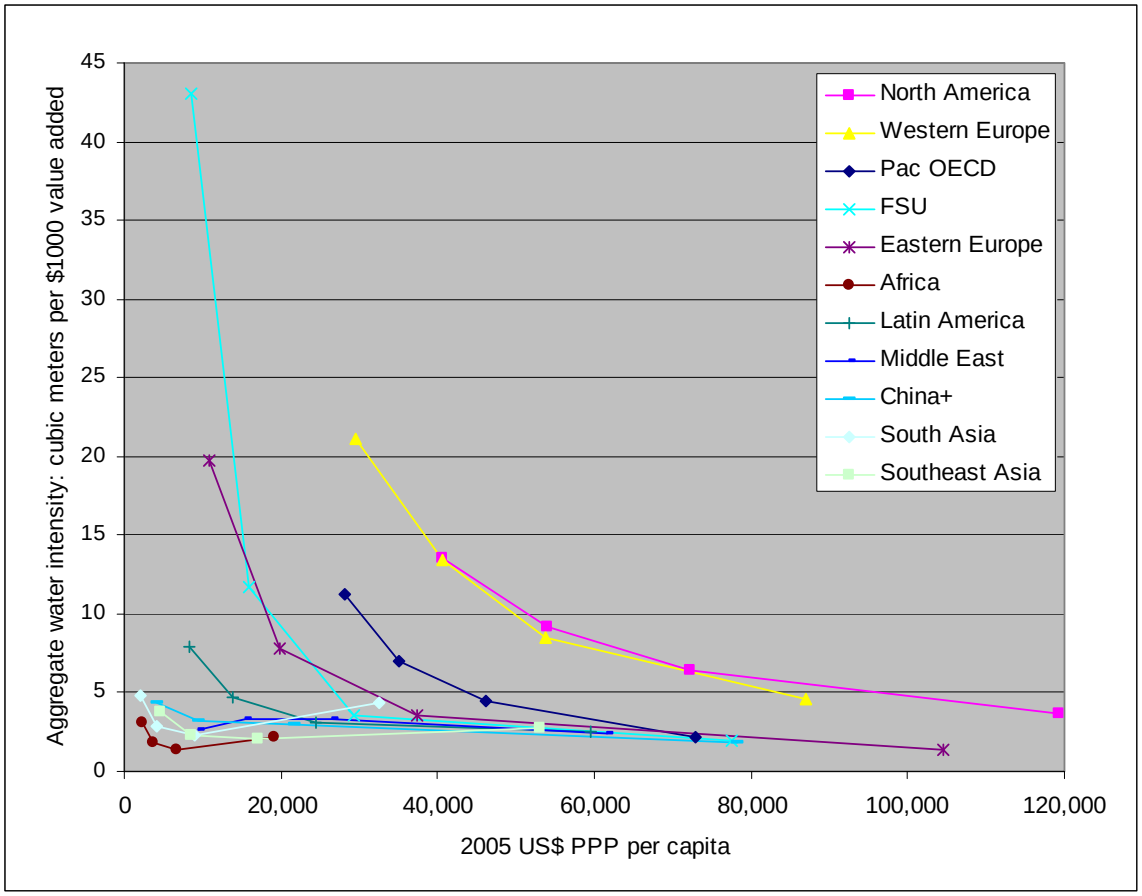
[26] For some regions, including the Middle East, the base-year values were below the standard. Although this may reflect real differences, such as use of saline or brackish water, or highly water-efficient processes, it may also indicate inconsistencies in the base-year data, or the limitation of using value added, rather than physical production, as a measure of activity. In view of the considerable water-supply constraints in the Middle East, the manufacturing intensities for the region were kept at their base-year values in the scenario. (The decline in *average* intensity seen in Figure 6-10 is the result of subsectoral shifts within the industrial sector.)

Figure 6-9. Regional manufacturing withdrawals in the scenarios



Total manufacturing withdrawals are given by the product of sub-sectoral value added and the intensities. Scenarios for value added in manufacturing sub-sectors are described in Chapter 2. The resulting water withdrawals are shown in Figure 6-9. For the OECD regions, slower economic growth in the *Policy Reform* scenario compared to the *Market Forces* scenario, combined with sharp reductions in manufacturing intensities, lead to withdrawals in 2100 less than half those of the *Market Forces* scenario. In the developing regions the reductions in water withdrawals for manufacturing are similar, despite higher economic growth.

Figure 6-10. Manufacturing water intensities in the *Policy Reform* scenario



Note: The ticks on each line represent the data or scenario results of 2005, 2025, 2050, and 2100. Industrial water intensity averaged for water use in all industrial subsectors.

Energy Conversion

Current Accounts

As for the other sub-sector, water withdrawals for energy conversion processes – in this study, limited to thermal electric generation – are again expressed as the product of an activity level and an intensity. Unlike other industrial sectors, in the energy conversion sector a single physical measure of activity – electricity production – is available, and is used to drive water use in the scenario. Electricity generation is discussed in Chapter 3 (page 106). Water use for other energy conversion processes, such as petroleum refining, are not included in the study.

Water is used in thermoelectric generation principally for cooling purposes. A variety of cooling technologies are available. These include once-through systems, which have high withdrawal rates, but low consumption rates (Gleick, 1993); cooling towers, which have low withdrawal rates but relatively high consumption rates (Gleick, 1993); and closed systems, which have both low withdrawal and low consumption rates (Willenbrock and Thomas, 1980). Closed systems are usually introduced when little or no water supply is available, and are not widely used. Additionally, cooling water may be supplied from non-freshwater sources, such as brackish water or salt water. For example, Japan meets much of its requirements for thermoelectric cooling using salt-water along the coast (Raskin et al., 1995).

Data on water withdrawals for energy conversion are relatively scarce. The OECD collects data on water use for thermoelectric generation from its members (OECD, 2004; 2008). In addition, data on water use for oil refining are available for the United States. Estimated thermoelectric intensity values vary over a wide range, due to differences in the mix of generation and cooling technology, as discussed above, and in the fraction of total water requirements that are supplied from freshwater sources.

As discussed in the previous subsection, withdrawals for thermoelectric cooling in non-OECD regions are separated from total industrial withdrawals using the approach of Strzepek and Bowling (1995). In this approach, provisional water intensities are set at the country level as a multiple of the U.S. intensity, and then adjusted to meet the total reported industrial withdrawals. The estimated regional water intensities obtained through this approach are reported in Table 6-9.

Table 6-9. Thermoelectric water intensities in 2005

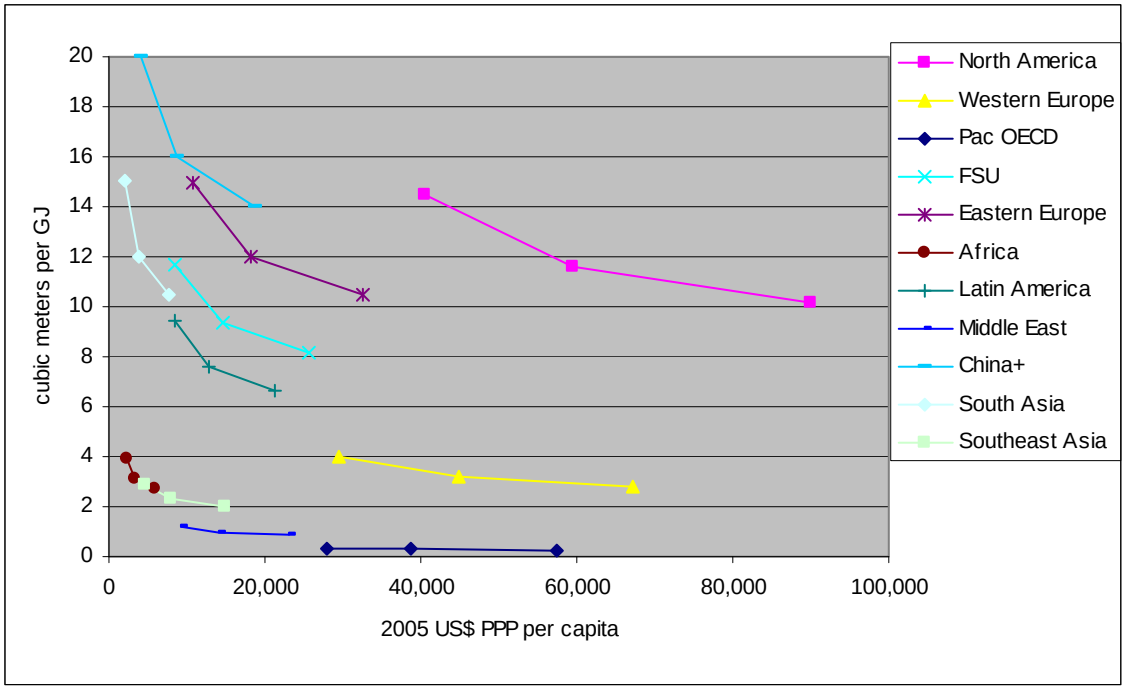
	Withdrawals m^3/GJ
North America	14.5
Western Europe	4.0
Pac OECD	0.4
FSU	11.9
Eastern Europe	15.2
Africa	3.7
Latin America	6.5
Middle East	1.2
China+	22.3
South Asia	10.3
Southeast Asia	2.7

Scenarios

For thermoelectric generation intensities, the scenarios are based on historical patterns in the United States. Between 1960 and 1990, average freshwater intensity in the U.S. decreased by 60%, as cooling systems became less water-intensive and power plant efficiencies improved (Raskin et al., 1995). This trend toward lower water intensities is assumed to continue in the future, though at a slower rate.

In the *Market Forces* scenario, it is assumed that in all regions thermoelectric generation water withdrawal intensities decrease by a further 20% between 2005 and 2025 and by 30% between 2005 and 2050. The resulting intensities are shown in Figure 6-11.

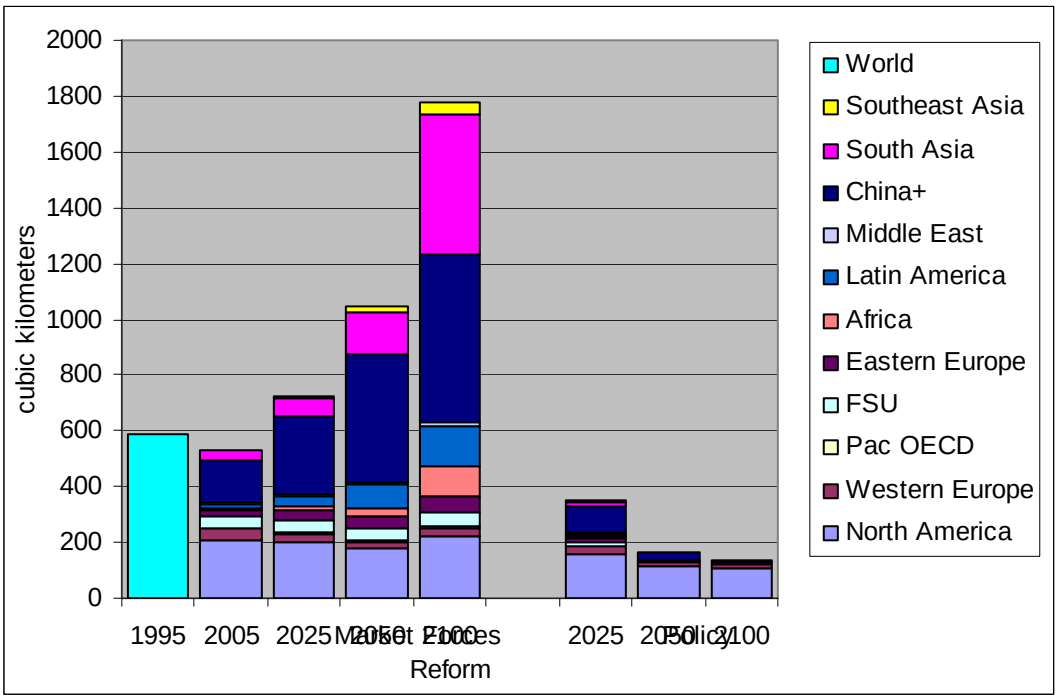
Figure 6-11. Thermoelectric intensities in the *Market Forces* scenario



Note: The ticks on each line represent the data or scenario results of 2005, 2025, 2050.

Multiplying the intensities with the scenario assumptions for thermal electric generation (see Chapter 3) gives the withdrawals shown in Figure 6-12. Withdrawals for the OECD and transitional regions stay fairly steady, while those of the developing regions increase sharply, a result of increases in electricity consumption.

Figure 6-12. Water withdrawals for energy conversion in the scenarios

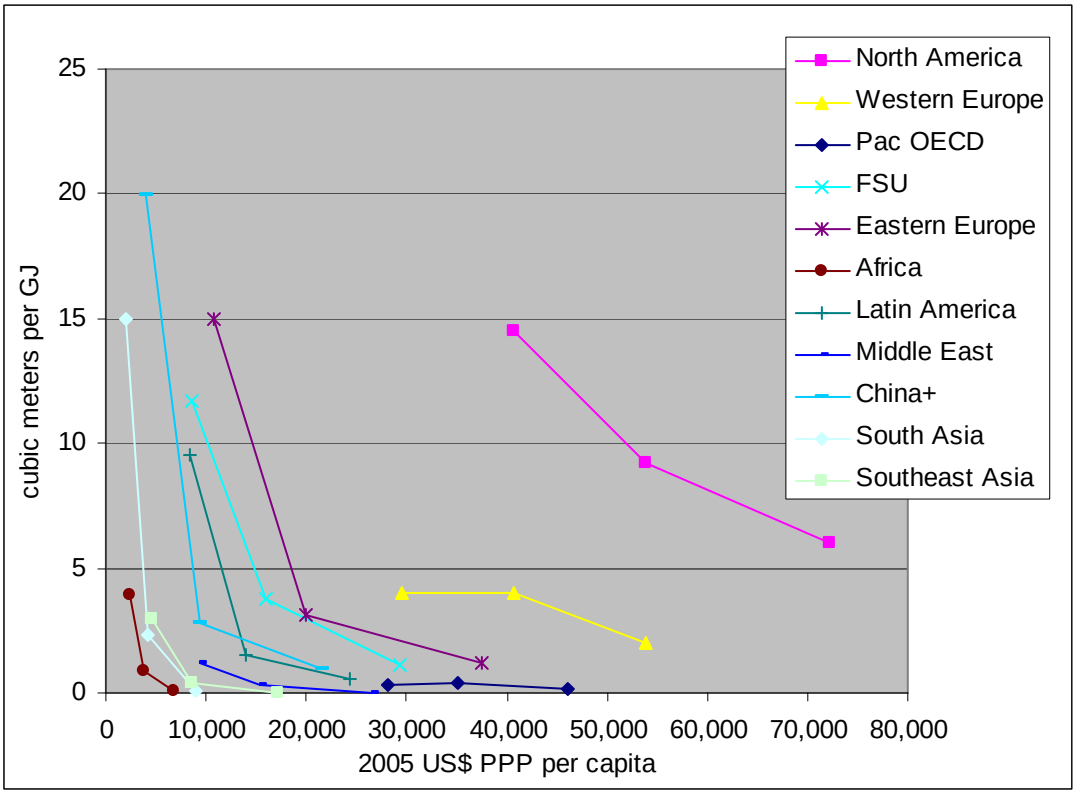


A wide range of technologies is available for cooling thermoelectric plants. The water withdrawal requirements range from over 30 cubic meters per GJ to nearly zero, indicating considerable scope for reducing withdrawals. However, the technologies that result in essentially zero withdrawals are either very expensive and not thoroughly tested on a large scale (closed systems), or are relatively expensive and require special siting (once-through cooling with sea water). Consequently, it is not expected that regions will reach these levels. However, in the spirit of the "best practice" intensities, it is expected that regions will move toward using technologies that require no withdrawals. So, for the *Policy Reform* scenario, a value of near zero withdrawals is used by choosing the Pacific OECD's thermoelectric water intensity of 0.35 cubic meters per GJ in 2005 as the best practice.

The water intensities for thermoelectric plants in the *Policy Reform* scenario are shown in Figure 6-13. Note that values are only shown through 2050 because there is little change between 2050 and 2100. Because of the OECD regions' relatively slow population growth and abundant water resources, there is not as much pressure to shift technology at first. However in the *Policy Reform* scenario, through a massive technology transfer, the non-OECD regions drastically reduce their thermoelectric intensities by 2025, to under 5 cubic meters per GJ, and continue to decline more gradually through 2050. These regions

are under more water stress, and must move more quickly, as they also greatly expand electricity supplies to accommodate the improved incomes of the regions.

Figure 6-13. Thermoelectric intensities in the *Policy Reform* scenario



Note: The three ticks on each line represent the data or scenario results of 2005, 2025, 2050 (left to right).

Combining the thermoelectric intensities with the values for electricity production results in the withdrawals shown in Figure 6-12. Withdrawals in each of the macro-regions are much lower in the *Policy Reform* scenario than in the *Market Forces* scenario. This results both from the lower intensities shown in Figure 6-13 and from the greater use of renewable fuels in electricity production.

Agriculture

Current Accounts

Nearly 70% of current global fresh water withdrawals are for agricultural applications, as seen in Table 6-4. In the developing regions, agriculture claims the dominant share of freshwater withdrawals. In the OECD regions, agricultural withdrawals are also important, roughly equaling the total requirements from industry.

For this analysis, all agricultural withdrawals are assigned to irrigation. In the agriculture sector, the activity level is the harvested irrigated area, and the intensity is water withdrawal per harvested area. The distribution of irrigated land is discussed in Chapter 4 (page 170). Roughly 18% of the world's cultivated land is currently under irrigation, with yields typically much higher than for rain-fed agriculture, as shown in Table 4-14. Irrigation water intensities depend on a number of factors, including the local climate and soils, crop mix, practices, efficiency of water use and economic conditions. As a result of these interacting factors, aggregate irrigation intensities, shown in Table 6-10, show considerable variation between regions.

Table 6-10. Irrigation water intensities in 2005

	Irrigation Water Intensities
	1000 m^3/ha
North America	8.7
Western Europe	5.6
Pac OECD	13.2
FSU	8.5
Eastern Europe	4.4
Africa	13.4
Latin America	9.9
Middle East	9.8
China+	7.2
South Asia	10.2
Southeast Asia	16.1

Scenarios

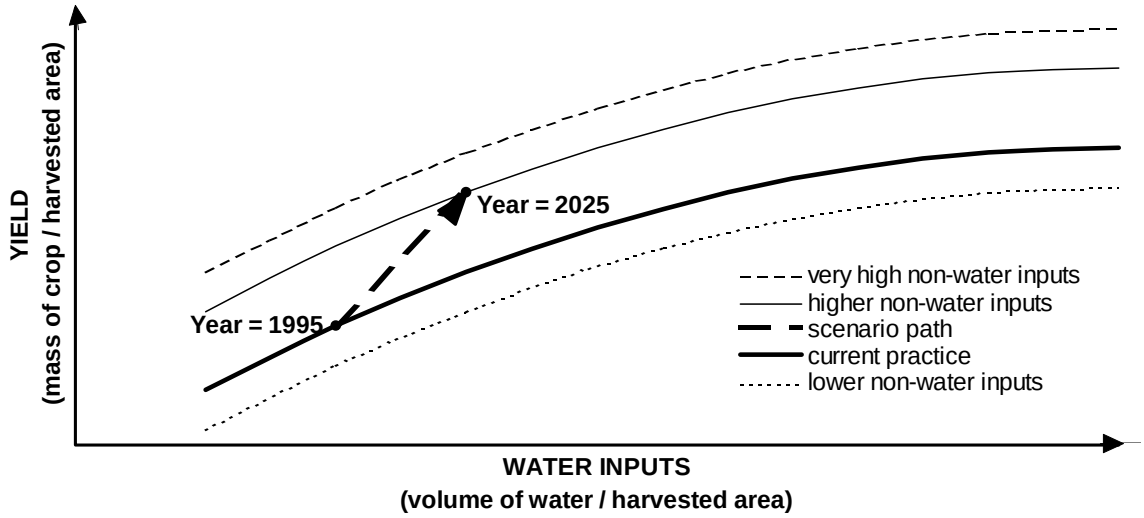
Following Raskin et al. (1997), for this study the increase in yield associated with an increase in water intensity is estimated based on empirical yield-response curves (Hexem and Heady 1978). Figure 6-14 provides a schematic illustration of the relationship between yield response and water intensity for irrigated agriculture. Different curves are shown for different levels of non-water inputs (which might also include changes in crop varieties and agricultural practice). As illustrated in the figure, the crop yields in the scenarios are assumed to increase for two reasons: 1) increases in water intensity; and 2) improvements in non-water agricultural inputs, such as management practices, chemical applications, and improved crop varieties.

For developing the scenarios, irrigation intensities are broken down into three factors: an efficiency factor, multiplied by the yield and divided by the "crop per drop,"

$$\text{Irrigation Intensity} = \text{Efficiency Factor} \times \frac{\text{Yield}}{\text{Crop - Per - Drop}} \qquad (6\text{-}3)$$

The crop-per-drop is the amount of the crop produced (in tonnes) per volume of water that reaches the plant, while the efficiency factor is the ratio of the water applied to the water that reaches the plant.

Figure 6-14. Yield response to water and non-water inputs



Note: Figure from Raskin et al. (1997).

Based on reported data in Hexem and Heady (1978), the crop-per-drop factor is assumed to increase with yields such that each 1.00% increase in yield is accompanied by a 0.75% increase in the crop-per-drop factor. As a result, increases in irrigation intensity, expressed as an index relative to the base year or a previous scenario year, can be expressed as:

$$\text{Irrigation Intensity Index} = \text{Efficiency Factor Index} \times \left(\text{Yield Index}\right)^{0.25} \qquad (6\text{-}4)$$

From this equation, as yields increase, if the efficiency factor remains the same, then the irrigation intensity increases. However, the increase in the irrigation intensity is slower than the increase in yields, rising by 0.25% for each 1.00% rise in yields.

In the *Market Forces* scenario, the efficiency factor in Equation (6-4) is left at base-year levels. The resulting intensities are shown in Figure 6-15. Irrigation withdrawals in the scenario are determined by multiplying the intensities by the irrigated harvested area (Chapter 4, page 170). The result is shown in Figure 6-16. Both the relative and absolute increase in withdrawals is highest in the non-OECD regions, which experience a 48% increase in total withdrawals.

Figure 6-15. Irrigation water intensities in the *Market Forces* scenario

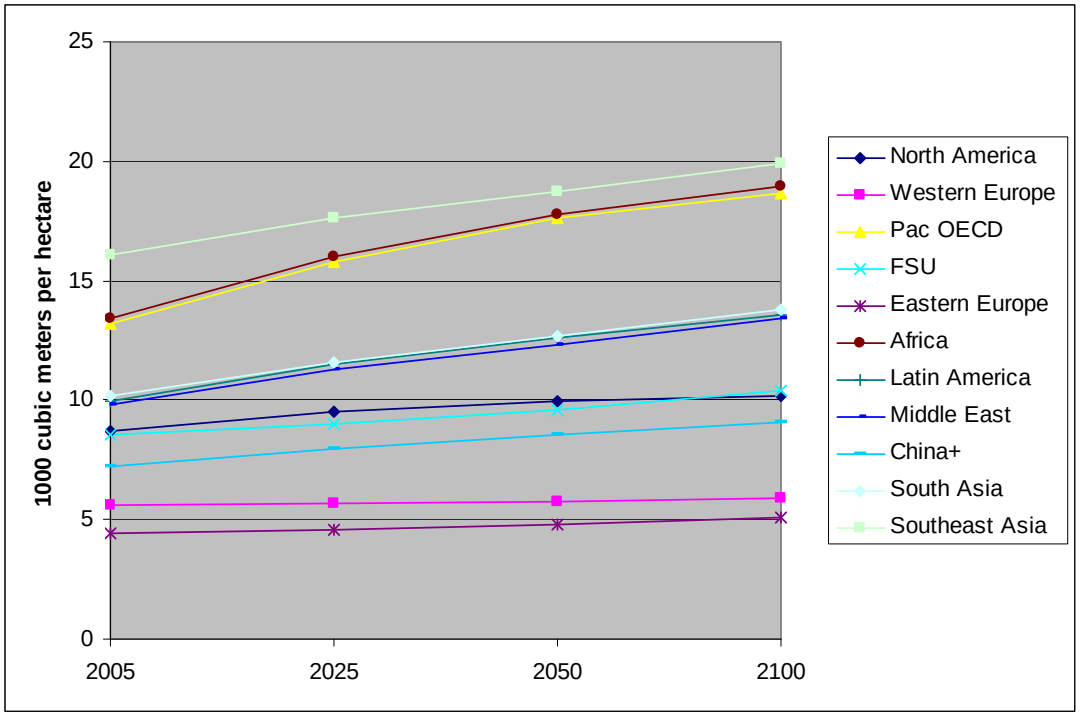
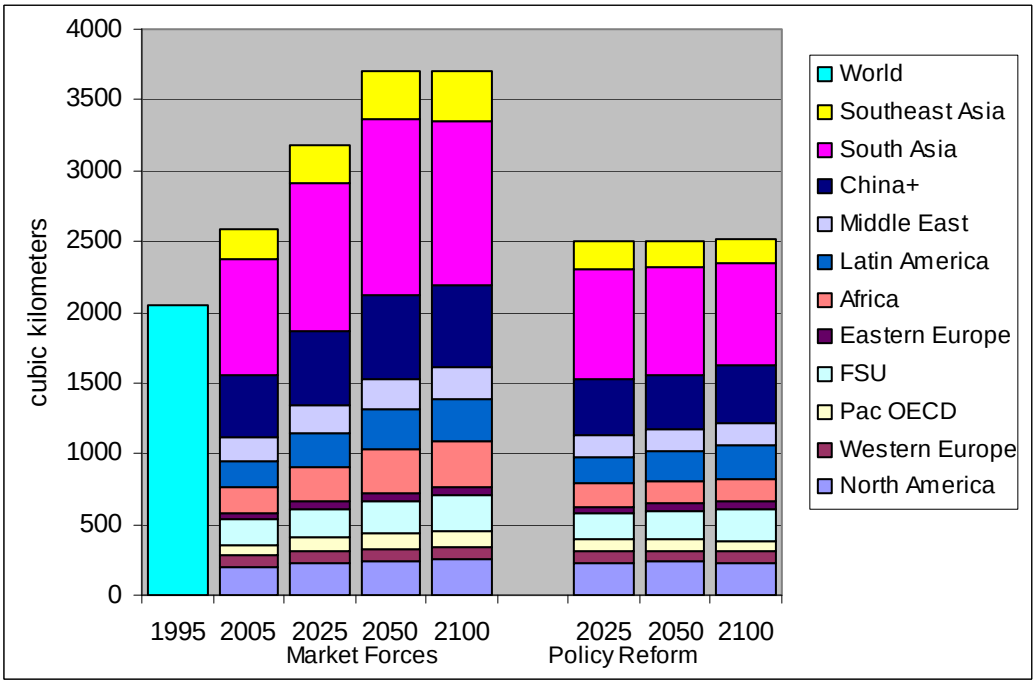


Figure 6-16. Irrigation water withdrawals in the scenarios



Irrigation intensities for the *Policy Reform* scenario are developed following the same approach as for the *Market Forces* scenario, with crop water requirements assumed to increase consistent with the increases in yields. However, moderating the increase in water requirements are improvements in irrigation efficiency over base-year practices, expressed through changes in the "efficiency factor" that appears in Equations (6-3) and (6-4). The potential for reducing irrigation intensity through increases in efficiency varies by region. For this study, separate potential improvements were developed for each region, based on a study by Seckler et al. (1998). In Seckler et al., potential efficiency improvements were estimated by country, covering all of the regions used in this study except the FSU. Current irrigation efficiencies were estimated by Seckler et al. by comparing reported water withdrawals to the water requirements of a reference crop, taking into account the water supplied by rainfall, and allowing for water storage between planting seasons. The current efficiencies were then compared to a potential efficiency of 70%, to determine the potential level of improvement. For this study the potential efficiency for the Middle East was assumed to be 85%, rather than the 70% used by Seckler et al. as a standard, anticipating that water shortages will make more expensive but water-conserving alternatives more cost-effective than in the other regions.[27] The potential improvement in the FSU, which was not included in the study of Seckler et al., was set close to the value for Western Europe. The potential improvements in irrigation efficiency were set as the best practice values for the agriculture sector.

Regions approach the best practice efficiency improvements over the course of the *Policy Reform* scenario, as the level of "effort" in reaching regional water withdrawal targets is increased.. The resulting improvements over the reference case (*Market Forces*) practices in 2050 are shown in Table 6-11, along with the best practice efficiency improvement in each region. Improvements in the non-OECD regions range from 22% to 44% in 2100 (except Eastern Europe at about 8%). The corresponding intensities are shown in Figure 6-17.

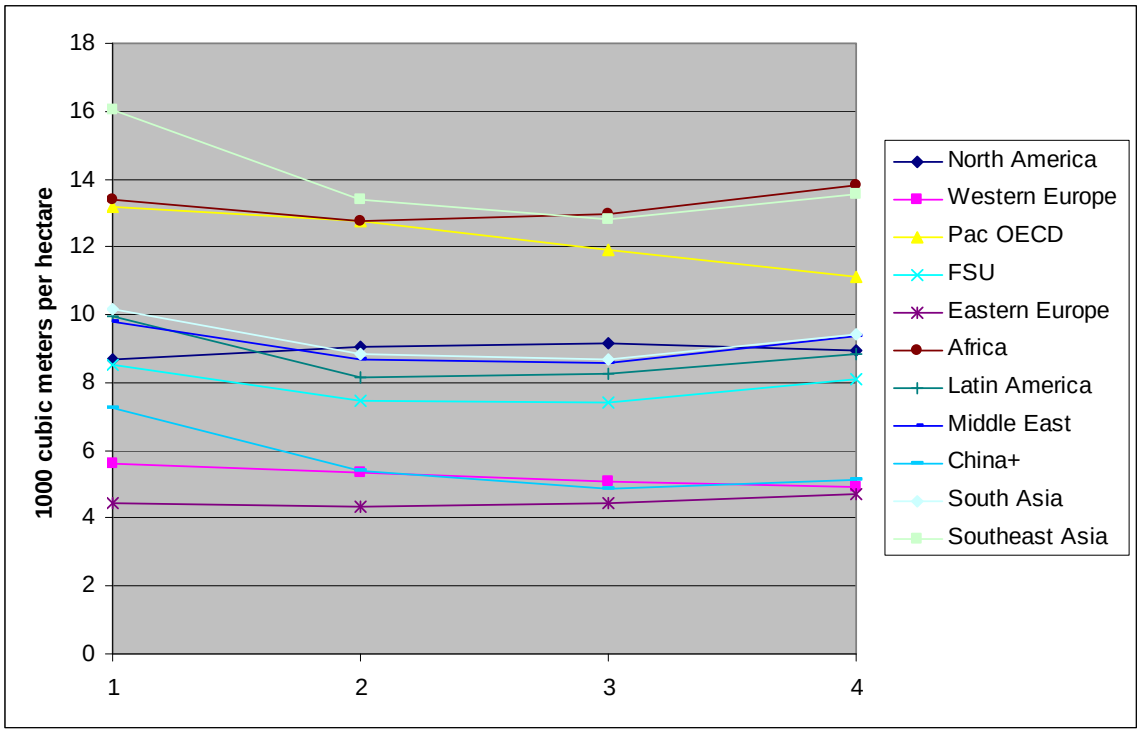
Multiplying the intensities by the irrigated harvested area (Chapter 4) gives the irrigation water withdrawals shown in Figure 6-16. Irrigation withdrawals increase, but more slowly than in the *Market Forces* scenario, as a result of the assumed irrigation efficiency improvements and increased irrigated harvested area across all regions.

[27] For comparison, at the farm level, the efficiency of drip irrigation systems can reach 95% (Lonergan and Brooks, 1994).

Table 6-11. Irrigation efficiency improvement over base-year practices

	Best Practice (%)	Scenario % Improvement by 2050	Scenario % Improvement by 2100
North America	24	-5.3	-2.8
Western Europe	26	9.3	11.9
Pac OECD	45	9.7	15.6
FSU	25	13.0	5.1
Eastern Europe	8	0.4	-6.2
Africa	27	3.2	-3.1
Latin America	39	16.9	11.0
Middle East	30	12.1	4.5
China+	48	32.8	28.7
South Asia	32	14.7	7.3
Southeast Asia	32	20.4	15.6

Figure 6-17. Irrigation water intensities in the *Policy Reform* scenario



Water Stress

Current Accounts

Estimated levels of water stress in the base year, using the methodology described earlier in this section, are shown in Table 6-12. The local nature of water-supply problems is evident from the patterns seen in the table, in that there is no sharp distinction between the OECD and developing regions. This is in contrast to many of the other issues explored in the *Conventional Worlds* scenarios. At a global level, about one-third of the world's population experiences some degree of water stress.

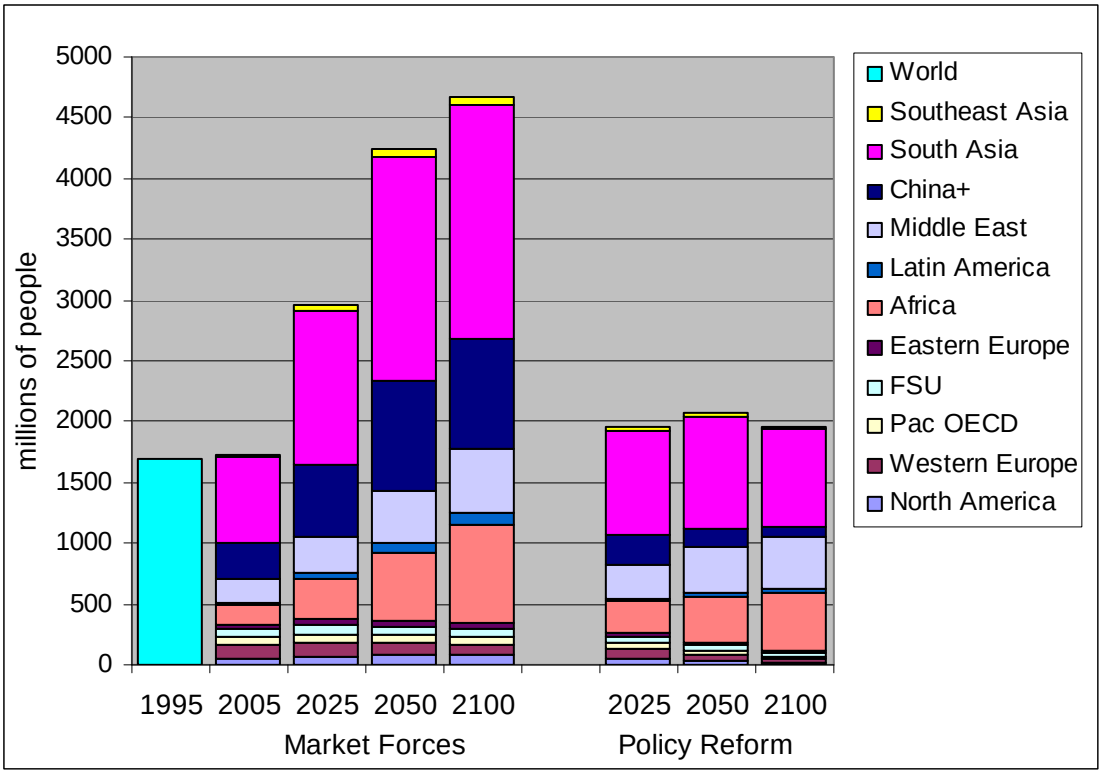
Table 6-12. Population in water stress in 2005

	Millions of people	% of Regional Population
North America	52	15
Western Europe	107	26
Pac OECD	65	32
FSU	73	26
Eastern Europe	34	19
Africa	159	18
Latin America	21	4
Middle East	193	86
China+	293	20
South Asia	710	49
Southeast Asia	25	5
World	1,733	27%

Scenarios

The incidence of water stress in the scenarios is reported in Figure 6-18. The population in water stress increases significantly in the *Market Forces* scenario, increasing by 2.7 times between 2005 and 2100. In the *Policy Reform* scenario, the increase in the water-stressed population is much lower than under *Market Forces* assumptions (only 1.2 times the number in 2005), and the non-OECD regions actually reduce the number of people in water stress by over 70%. The *Policy Reform* scenario hits a peak in 2050 for number of people in water stress, and a reversal of the trend becomes apparent in 2100, with a small decline in the number of people in water stress.

Figure 6-18. Population in water stress in the scenarios



For the discussion on the methodology for calculating the number of people in water stress, see the section on Withdrawals and Water Stress above on page 229.

7 Pollution

Conventional Worlds scenarios are implicated in causing numerous regional and local environmental impacts. Problems such as oil spills, indoor air pollution, poor air and water quality, regional acidification and human exposure to toxic and hazardous wastes will be affected in different ways by the *Market Forces* and *Policy Reform* scenarios.

The development patterns of the *Market Forces* scenario present a huge and probably insurmountable challenge for controlling future environmental stress. The environmental sustainability goals of the *Policy Reform* scenario (e.g. climate change mitigation and toxic waste reduction) generally reduce various other local and regional environmental impacts. Yet, even with this "tech fix" oriented scenario, a wide range of environmental impacts will probably prove to be severe. We begin by discussing the emissions of greenhouse gases and the implications for global climate change. Then we focus on six examples of environmental impacts at the local and regional level: indoor air pollution from the use of traditional biomass fuels, acidification from the deposition of regional sulfur and nitrogen oxide pollutants, pollutant loadings to water bodies, levels of production of toxic wastes, and solid waste generation.

Greenhouse Gases and Climate Change

The climate change mitigation goals of the updated *Policy Reform* scenario are informed by the World Energy Outlook 2007 450 ppm CO_2 Equivalent stabilization scenario (OECD/IEA, 2007), which is presented in detail in another paper (Nakicenovic, 2007). It is also informed by the SRES B1-480 ppm CO_2-equivalent scenario (IIASA, 2006), scaled back to 450 ppm CO_2 equivalent. The *Policy Reform* scenario achieves approximately a 350 ppm CO_2 concentration and a 450 ppm CO_2-Equivalent concentration by 2100. While the current atmospheric concentration at the time of writing is 387 ppm CO_2 concentration, the target of 350 ppm CO_2 has been widely discussed as the necessary maximum concentration that we must return to in order to limit climate change to less than 2°C (Hansen, et al., 2008). This translates into total cumulative CO_2 emissions from 1990 to 2100 of about 325 GtC (gigatons of carbon). Our allocation between OECD and non-OECD regions is done with consideration for equity between regions, as shown in Figure 7-1. A striking result is that by ~2065/2070, all regions must have net negative emissions in order to meet this scenario's target atmospheric concentration by 2100.

Figure 7-1. CO_2 emissions pathways for *Policy Reform* scenario by macro-region

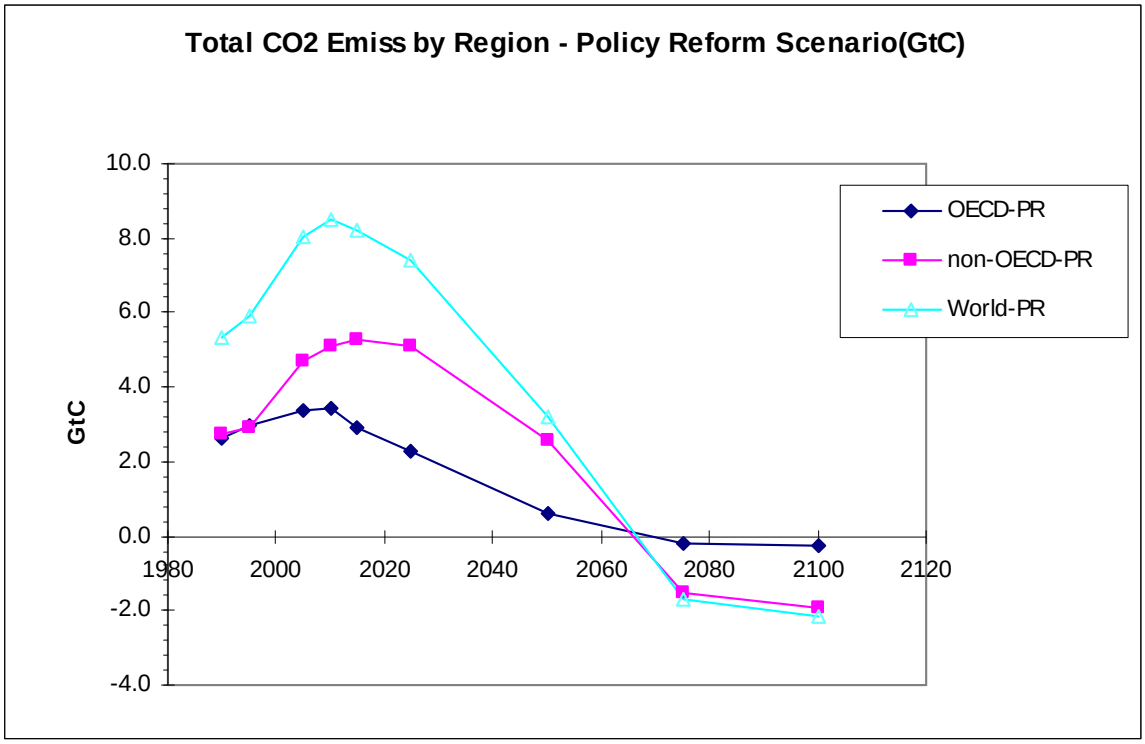
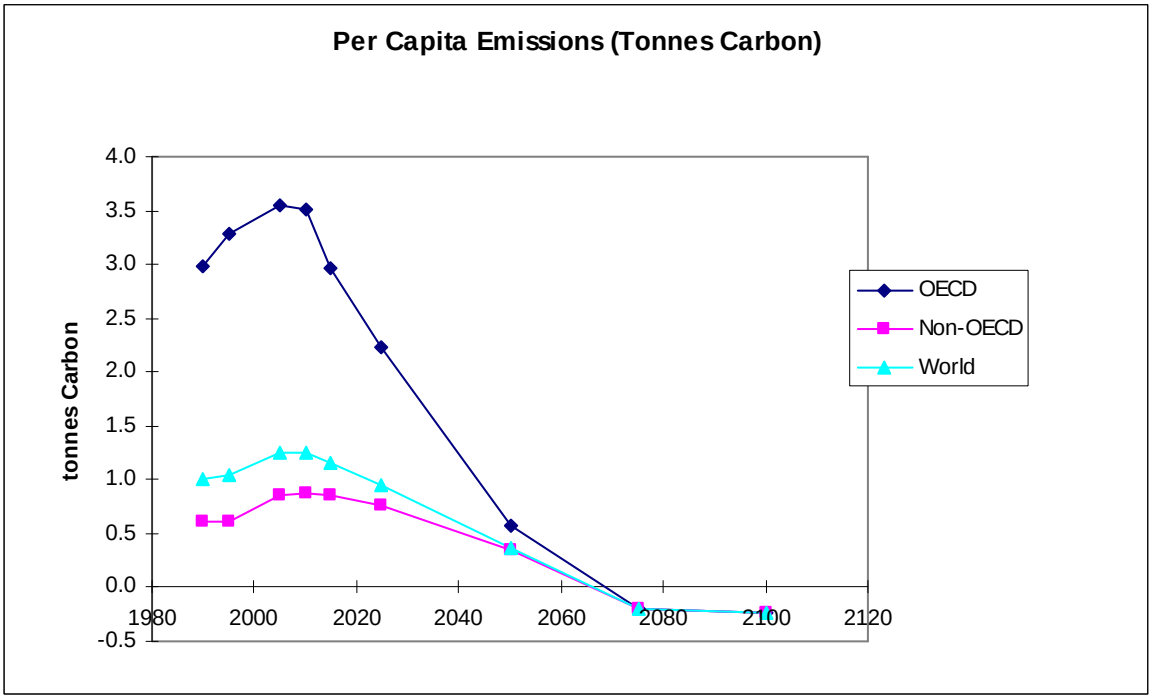


Figure 7-2. *Policy Reform* emissions per capita by macro-region



Energy-related emissions are computed by applying standard fuel-specific CO_2 emission factors (IPCC, 2006) to energy use. In addition, land-use change emission factors (SEI, 1993; Houghton and Hackler, 1995; IPCC, 2000) are applied to land-use change patterns in each scenario. In the *Market Forces* scenario, total CO_2 emissions are projected as a consequence of the energy and land-use change projections. In the *Policy Reform* scenario, targets for reducing deforestation lead to lower land-use change total CO_2 emissions than in the *Market Forces* scenario.[28] Emissions from the energy and industrial sectors in the *Policy Reform* scenario are constrained via a range of mitigation policies so that total emissions fall within the target carbon emissions budget for the scenario.

Energy and industrial sector emissions are allocated between regions in a manner reflecting the general spirit of improved interregional equity in the *Policy Reform* scenario, described below in detail. The *Policy Reform* emissions scenario is developed in full regional detail through 2050, but from 2050 through 2100, the scenario is developed only for the macro-regions. After 2050 emissions from all regions are assumed to converge toward a common annual per capita amount of CO_2 per capita. This is first achieved by 2075 at -0.19tC per capita, and then all regions continue with equal per capita emissions thereafter, and all decline to -0.24tC per capita in 2100. In 2100, annual global emissions are constrained to be -2.15 GtC per year.

Methodology for Policy Reform Emissions Scenario

When developing the *Policy Reform* scenario, there are different allocation levels of carbon emissions. All of these levels must be set in order to fully define the scenario in the model, through the use of sector- and region-specific parameters. The levels, which are described in detail below, are also computed in the following order:

1. *Global Allocation:* Global CO_2 Emissions are allocated to regions so that the desired total CO_2 Concentration is achieved.

2. *Macro-Region Allocation:* The global CO_2 target is split between OECD and Non-OECD regions, taking into consideration equity in terms of per-capita-emissions, and emissions per dollar of Industrial Value Added (2005 $PPP).[29]

3. *Regional Allocation:* The Carbon Targets for OECD and Non-OECD regions are allocated to each of the 11 sub-regions with equity concerns in mind.

4. *Sectoral Allocation:* Within each Region, the shares of the Regional Carbon Target is allocated to the carbon-emitting sectors.

5. *End-Use Fuel Mix:* Within each Sector, for each major end-use category the fuel mix is allocated so that the allocated carbon target for that sector is reached, and the total energy demanded by that sector is provided.

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[28] After 2025, net reforestation acts as a net carbon sink.

[29] 2005 Purchasing Power Parity dollars.

1. Methodology for setting the Global CO_2 Emissions Target

Global CO_2 emissions are allocated so that the desired CO_2 concentration is achieved by 2100. This broken into two components: 1) the total fossil fuel and cement emissions, and 2) the total emissions from land-use change. The *Policy Reform* emissions targets are informed by the World Energy Outlook 2007 450 ppm CO_2 Equivalent stabilization scenario (OECD/IEA, 2007; Nakicenovic, 2007) and by the SRES B1-480 ppm CO_2-equivalent scenario (IIASA, 2006), scaled back to 450 ppm CO_2 equivalent. The scenario reaches approximately 350 ppm CO_2 concentration by 2100, and a 450 ppm CO_2-Equivalent concentration by 2100 and it is understood that this is a stabilization scenario. The results of our scenario show that Fossil and Cement emissions alone will amount to 309 GtC, with the rest emitted by land use changes.

2. Methodology for Macro-Region Allocation

The *global* carbon target developed in the previous step is then divided into emission allocations for the OECD and the Non-OECD regions. Our allocation between OECD and non-OECD regions is done with consideration for equity between regions. Furthermore, by approximately 2070, all regions must have net negative emissions. The emissions from land-use change for OECD and non-OECD regions are input into an external worksheet directly from the modified IIASA scenario data.

First the non-OECD region's allowable emissions are determined, and then the OECD's emissions are set as the remainder (i.e., OECD allocation = global allocation - non-OECD allocation).

The process for developing the non-OECD's allowable emission levels is as follows. For 2010 and 2015, the regions' emissions are calculated as a percentage below the *Market Forces* levels of emissions. In 2010, they are set to 5% below the *Market Forces* scenario emissions level and in 2015, to 8% below the *Market Forces* scenario emissions level.

For 2025 and 2050, a more sophisticated methodology is used, whereby each developing region is required to reduce emissions intensities (tonnes per dollar GDP_{PPP})[30] relative to the *Market Forces* scenario. First, the tonnes of CO_2 generated by fossil fuels or cement production per \$1000 GDP_{PPP} are calculated for the *Market Forces* scenario for each of the non-OECD regions. Then, the *Policy Reform* scenario is developed as follows:

(1) For the MacroRegion allocation, we first reduce the emissions per unit of GDP for 2025 and 2050 by a chosen percentage from the *Market Forces* values for each region

(2) In 2025, we reduce by 30% (taking only 70% of the *Market Forces* Emissions per unit GDP value), and in 2050, we reduce by 80% (taking only 20% of the *Market Forces* Emissions per unit GDP value)

[30] GDP measured in 2005 Purchasing Power Parity dollars.

(3) Using these regional numbers (intermediate *Policy Reform* Emissions per GDP) for each of the 8 non-OECD sub-regions, we sum them up to determine the total Non-OECD Emissions allocation.

3. Methodology for Regional Allocation

The global carbon target is allocated to each of the 11 regions with equity considerations in mind. First, the non-OECD intermediate *Policy Reform* emissions per GDP values from the previous step are taken, then the equivalent emissions per capita values is calculated for each region. The general idea is to reduce the variance from the mean for non-OECD regions' emissions per capita compared to the variance in the base year of 2005. In 2025 the variance is reduced by 50% and in 2050 it is reduced by 90%.

There are some exceptions to this regional allocation of emissions made in order to smooth out the results to fit the story-line better for the scenario. This is needed because in some cases there was too much or not enough carbon allocated to a region, relative to the region's GDP and technology patterns. Thus, we have made some adjustments, taking care to keep the final total CO_2 allocation for the non-OECD regions equal to the macro-region total.

The OECD macro-region allocation is split among the three OECD regions by specifying how far above or below each region will be to the average OECD emissions per capita (see Table 7-1), taking care to reach the original macro-region CO_2 allocation for the OECD region.

Table 7-1. Index of OECD regions emissions per capita value

GtC per Capita	2025	2050
North America	*1.3*	*1.05*
Western Europe	0.77	0.95
Pac OECD	0.9	1
Weighted Avg GtC per cap in OECD	*1.647*	*0.409*

4. Methodology for Sectoral Emissions Allocation within a region:

The initial carbon emission shares are set by expert judgment hand for each region. The first cut for sectoral allocations for each region comes from looking at the 1995 and 2005 data on sectoral shares of carbon. After we set the End-Use Fuel Mixes for each sector and region (Step 5 below), judgments are made about how the technology will change over time. An iterative process is then used which re-adjusts the sectoral shares of carbon to better represent the technology mix chosen.

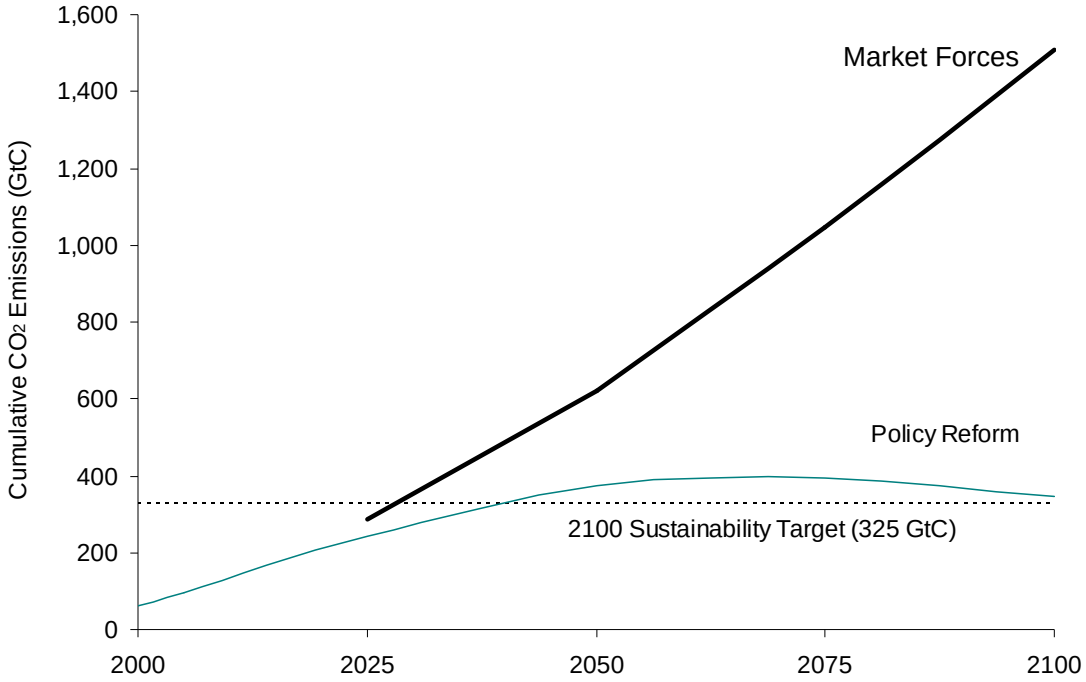
5. Methodology for calculating the End-Use Fuel Mix and Emissions Allocations within a Sector:

First, initial or reference allocations for *fuel shares* within a sector are made using expert judgment, as influenced by relevant studies/research. Each sector and each end use has its own reference fuel share mix and is handled in slightly different ways. Some sectors have assumed reference fuel shares input for all scenario years, some sectors have fuel shares 'hard coded' into the script, and some sectors have fuel share trends entered as equations into the script, allowing for trends such as having the share of some fuel used (e.g., coal) go to 0% by 2050.

The resulting Reference Fuel Shares are all a starting point within each sector to meet the CO_2 Emissions targets set for that sector. First a Reference Total Emissions is calculated by taking the reference fuel shares multiplied by the total energy needed by each sector and end-use, and then also multiplied by the carbon intensities of each fuel. Then this total is compared to the actual CO_2 emissions allowed for that sector as described by step 4 above. A Renormalization Fraction is calculated for each region which is used to scale the reference fossil fuel shares by the right amount to reach the relevant CO_2 Emissions Cap.

Thus, if the Reference Total Emissions is too low compared to the CO_2 Emissions cap for that region and sector (i.e., the cap allows for more CO_2 pollution), then we scale-up the CO_2-emitting sources of energy by the Renormalization fraction. Any remaining energy needed would then be filled by the non- CO_2-emitting sources of energy (renewables, biofuels, electricity, etc.), which would have their shares scaled down to accommodate the increased CO_2-emitting sources. If the Reference Total Emissions is too high compared to the CO_2 Emissions cap for that region and sector, then we scale-down the CO_2-emmitting sources of energy by the Renormalization fraction. The remaining energy that needs to be produced to meet the demands of the sector will come from scaling up non-CO_2-emitting sources.

Figure 7-3. Cumulative global CO_2 emissions and atmospheric concentrations



Notes: The *Market Forces* and *Policy Reform* scenarios are shown, For reference, current CO_2 concentrations stand at about 387 ppmv, while concentrations prior to the industrial revolution (pre-1850) stood at 280 ppmv. Achieving this concentration would require cumulative emissions of approximately 220 GtC between 1995 and 2100.

Results

Figure 7-3 summarizes the cumulative global emissions pathways of the *Market Forces* and *Policy Reform* scenarios, with detailed results of the two scenarios through the year 2100. The figure includes estimates of total industrial emissions since 1850 from combustion of fossil fuels and cement production, plus estimates of net emissions from land-use change. The cumulative emissions from the *Market Forces* scenario are assumed to continue to increase indefinitely. It is clear that the *Market Forces* scenario does not come close to meeting the target (the dotted line) for cumulative CO_2 emissions. Cumulative carbon dioxide emissions between 2005 and 2100 would be about 1500 GtC, roughly 4.6 times the emissions from the *Policy Reform* scenario of 325 GtC.

In the *Market Forces* scenario, per capita emissions from both macro-regions initially continue to grow as incomes increase, although after 2050 the rate of increase declines greatly. The *Policy Reform* scenario shows dramatically different trajectories for each macro-region, as shown in Figure 7-4. In the non-OECD regions, emissions per capita start from a much lower level than in the OECD ones, and they grow until 2010, without ever even approaching the OECD rates, then drop gradually to reach the 2075

convergence point at negative 0.19 tonnes C per capita. Per capita emissions from all regions converge on this figure in 2075 and decline thereafter to negative 0.24 tonnes C per capita.

Figure 7-4. Per capita CO_2 emissions in the *Policy Reform* scenario

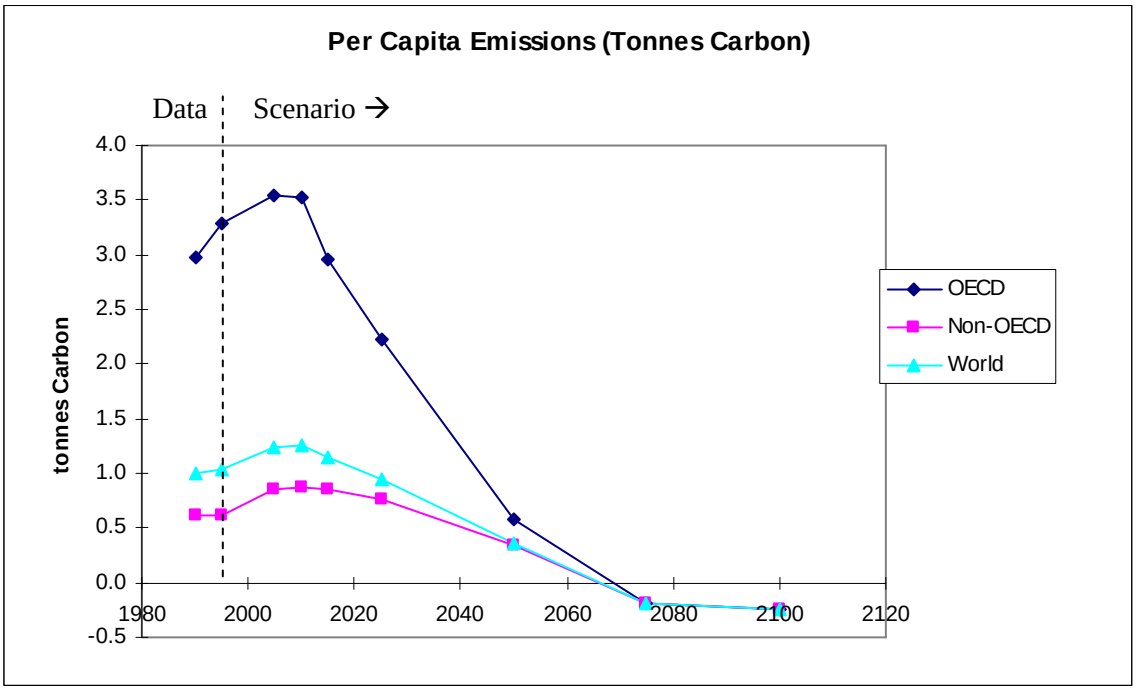


Figure 7-5 summarizes annual emissions by major source category for the years 2005 - 2100 (including land-use change emissions). In the *Market Forces* scenario emissions continue to grow from about 8.25 GtC in 2005 to 20 GtC in 2100. In the *Policy Reform* scenario, total emissions increase to 2025, reaching 9.6 GtC annually. Thereafter in the scenario, the carbon emissions decline, reaching 2.9 GtC in 2050, and are actually absorbing a negative 1.38 GtC in 2100. Annual global net CO_2 emissions from land-use change, estimated at about 0.7 GtC in 2005, decrease in the *Market Forces* scenario, reaching -0.02 GtC/year in 2100. In the *Policy Reform* scenario, net deforestation rates are reduced quickly and afforestation is quickly implemented, resulting in a reduction of carbon emissions from land-use change to -0.5 GtC/year in 2100 (Note: the negative value implies carbon sequestration or removal from the atmosphere).

In the *Policy Reform* scenario, the cumulative emissions between 1990 and 2100 from fossil fuel combustion, cement production, other industrial CO_2 emissions, and net emissions from changes in forest area total about 325 GtC, as noted above, which achieves the climate change mitigation target for the scenario.

In absolute terms, in 2005, emissions are close to split between the OECD and non-OECD regions, with the OECD accounting for about 42% of the total (See Figure 7-6). By 2100 in the *Market Forces* scenario, this proportion has dramatically changed, so that the non-OECD regions account for 81% of total industrial emissions. In the *Policy Reform* scenario, the developing regions share of the total increases even faster. By 2050, in a drastically reduced CO_2-emissions world, they account for 81% of total global emissions, and by 2100, the non-OECD regions account for nearly 90% of the negative emissions required.

Figure 7-5. Annual global CO_2 emissions by source

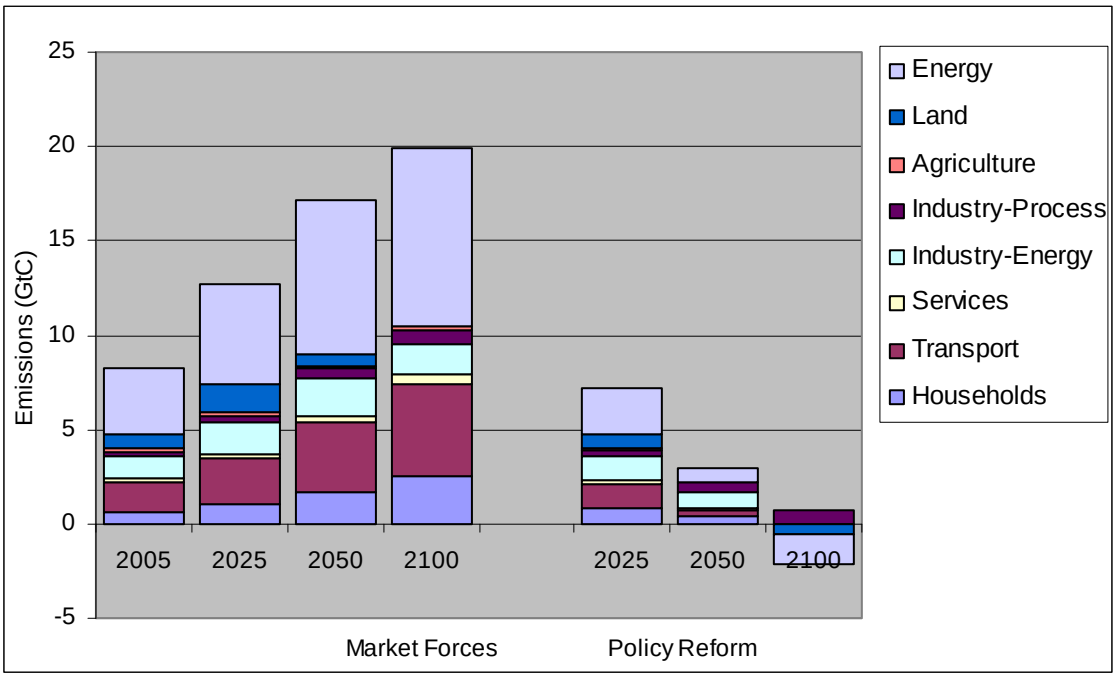
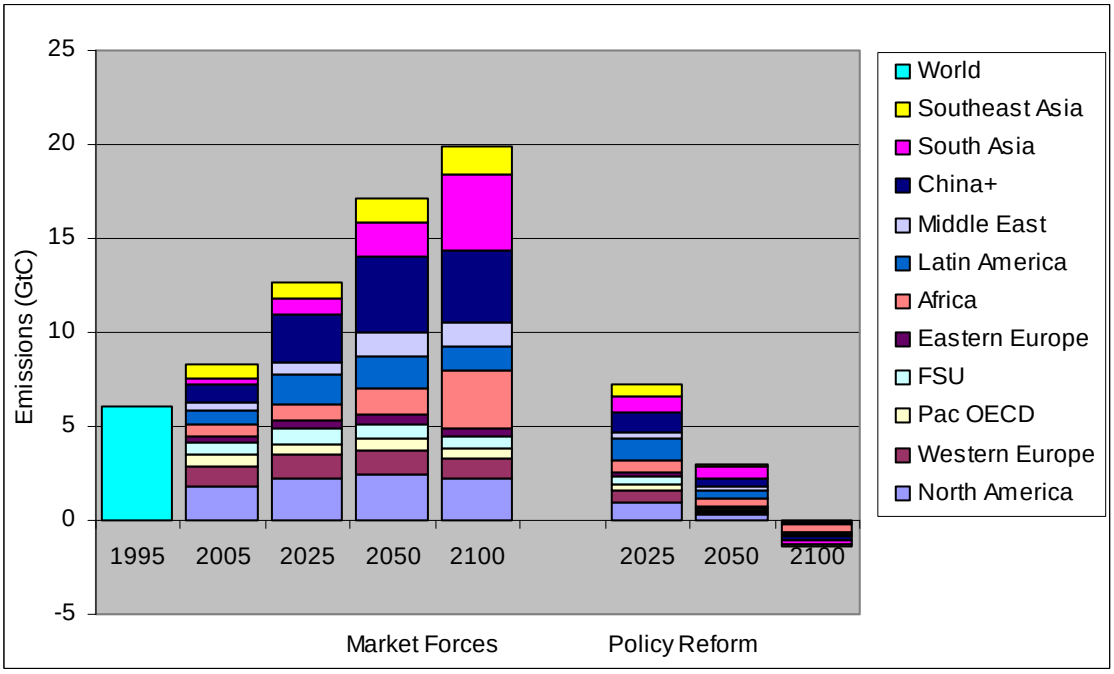


Figure 7-6. Annual CO_2 emissions by Region



Computing Carbon Emissions in each sector

The targets for carbon emissions in each sector of the economy include the emissions related to energy conversion required by that sector. For instance, if a sector requires electricity to meet its energy demands, then the carbon emitted in making that electricity will also be counted as part of that sector's target. The end-use fuel mix which is set initially (see above) as reference shares must then be adjusted to final shares based on the renormalization process. This methodology is outlined here.

1. For the purpose of computing the carbon emissions due to Reference Shares, allocate the efficiency losses due to oil refining to the sectoral combustion of petroleum fuels on a proportional basis. (This removes oil refining carbon emissions from the energy conversion sector).

2. Compute the Renormalization Factor using the results of #1 above, and the sectoral targets. (Don't worry that conceptually the original sectoral target for the energy conversion sector assumed the inclusion of oil refining carbon emissions. This difference will imply a small change in the Renormalization Factors for all sectors).

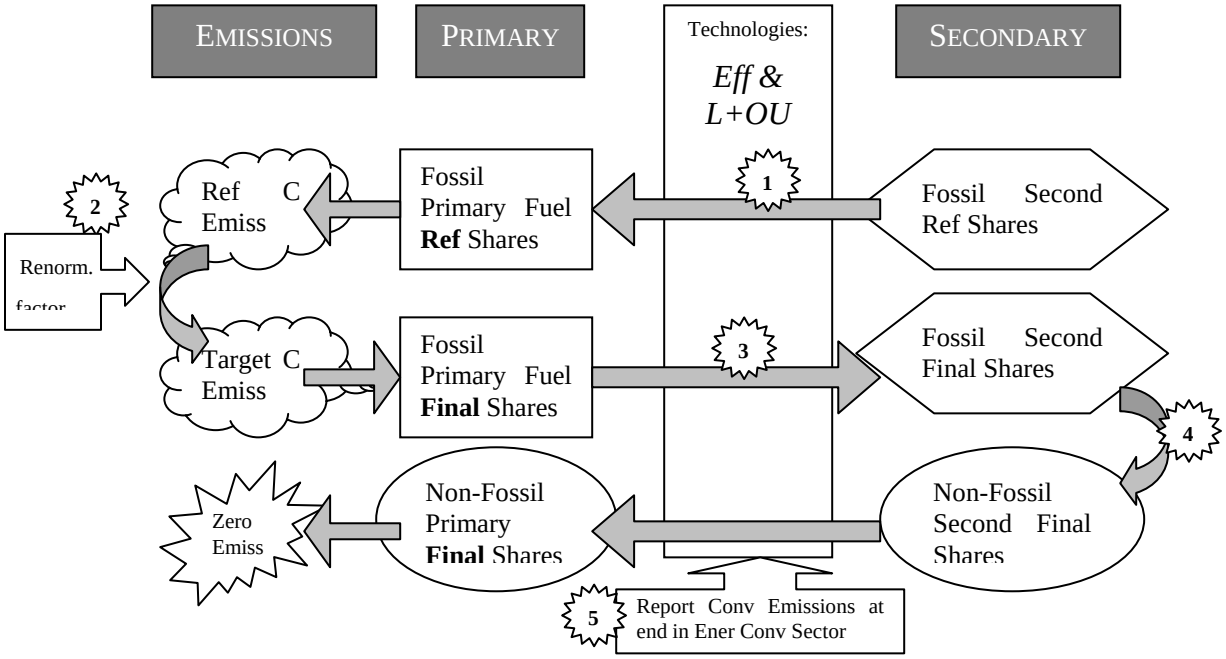
3. Apply the renormalization multiplier to the Reference Fuel Shares at the primary carbon-based fuel (input fuel) level to get the final primary carbon-based fuel shares. (This should cause the final carbon emissions to exactly equal the sectoral target as allocated previously)

4. From the renormalized final amount of primary carbon-based fuels for each sector from #3 above calculate the amount of final *non-carbon-based* secondary fuels (e.g., electricity, renewables) that these final *carbon-based* fuels shares imply. Then calculate the share changes in non-carbon secondary fuels back into the changes in the non-carbon-based primary fuels required to derive the final quantities of non-carbon-based primary fuels required. (This completes the renormalization methodology).

5. For reporting purposes, at the end, include carbon emissions from the crude oil refining aspect of the energy conversion sector, and remove these emissions from all other sectors. This step will make the reported emissions comparable to the earlier PoleStar results for the *Conventional Worlds* scenario.

In Figure 7-7 is a schematic showing the flow of calculations for the renormalization process. The numbers in the schematic relate to the step numbers as outlined above.

Figure 7-7. Methodology for meeting sectoral carbon emissions targets



Indoor Air Pollution and Biomass Fuels

Traditional biomass fuels – wood, charcoal, animal dung and agricultural waste – are widely used in developing countries, particularly for domestic cooking. Rural households generally rely on fuelwood and, as this resource becomes more scarce, they rely on dung and wastes. In some countries, many urban households use charcoal, a compact and transportable fuel with cost advantages over direct use of fuelwood, especially in certain areas where markets are far from forest and other wood resources.

In addition to pressure on wood resources, the production and use of biomass fuels raise other environmental issues, most notably the human health impacts of indoor air pollution. Smith (1987) identifies four major groups of indoor air pollutants contained in the smoke from biomass fuel combustion: carbon monoxide, particulates, polycyclic organic matter, and formaldehyde. These pollutants are associated with a range of health impacts including: respiratory infections in young children; adverse pregnancy outcomes (including low birth weights of babies) for women exposed during pregnancy; chronic lung diseases and associated heart diseases; and cancer.

There is increasing evidence of a correlation between high exposure to pollution and ill health. Smith (1993) describes a number of studies that have found strong relationships between exposure to indoor air pollution and adverse health impacts. However, quantitative assessment of the issue is complicated by the lack of reliable health data, the overlapping

effect of other pollutants such as tobacco smoke and outdoor air pollution, and the lack of proper monitoring of exposure levels. In addition, some studies have failed to find such connections. A study of health effects in low-income urban women in Lusaka, Zambia (Ellegard and Egneus, 1992) failed to find evidence that the health of biomass-fuel users was significantly poorer than those using cleaner fuels (electricity or kerosene). This negative result does not disprove the link between biomass use, indoor pollution and health, but does point to the necessity for local studies (which can correct for possible compounding factors such as smoking and socioeconomic status) and monitoring of exposure. In the particular example of Lusaka, the measured exposure levels were found to be much lower than those in other parts of the world, probably due to site-specific factors such as stove location, ventilation, mode of food preparation and type of housing.

Historically, industrializing countries have undergone an energy transition from traditional fuels to cleaner modern fuels and electricity as incomes rise and populations become more urbanized. This dynamic is seen in the *Market Forces* scenario and in more dramatic form in the *Policy Reform* scenario in the household sector. While we do not explicitly link the scenarios to their associated indoor air pollution human health impacts, it is worth noting what effect each scenario has on levels of traditional biomass use in the developing regions, and thus on expected human health impacts.[31]

Acidification

Small amounts of sulfur are naturally present in the environment through volcanic eruptions, from sea bacteria and other sources (RIVM/UNEP, 1997). When deposited onto soils and lakes, the naturally occurring quantities of sulfur are normally small enough to be beneficial to plants, without causing acidification to soil and water.[32] Ultimately, most sulfur passes into the oceans.

Human economic activity, leading to high emissions of sulfur and nitrogen oxides, can lead to levels of deposition of pollutants so large that they cannot be fully attenuated by the natural geochemical cycle. Acidification can cause a range of environmental impacts including effects on human health, corrosion of materials, reductions in crop yields, loss of fish stocks, and possible forest damage. Until recently, these impacts were largely confined to Europe and North America. It now appears that regional air pollution is a serious and growing problem in many parts of the world, particularly in certain developing countries (SEI-York, 1998).

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[31] Note that in the *Policy Reform* scenario, renewable and carbon-neutral biomass use increases in the industrial sector as an alternative to petrochemical feedstocks, and in the energy conversion sector as a source for creating secondary fuels such as electricity and ethanol, resulting in a net increase in biomass demand in this scenario.

[32] A notable exception is the case of volcanic activity, which can cause high levels of sulfur deposition.

In terms of ecological impacts, the problem of acidification arises when high levels of acid deposition occur in regions where soils, forests and aquatic ecosystems are particularly sensitive to acidification.

Acidification is related to deposition of both sulfur and nitrogen oxides. While emissions of nitrogen oxides (which arise primarily from the combustion of fuels in the energy conversion and transport sectors) are not covered by this analysis, they are thought to be an important contributor to the acidifying load in a number of regions (Brodin and Kuylenstierna, 1992).

It is worth noting two important linkages between acidification and climate change. Firstly, changes in weather patterns stimulated by climate change may change the intensity and distribution of acid deposition; and secondly, emissions of sulfur dioxide, which lead to the accumulation of particles in the upper atmosphere, are thought to partly mask the global warming trends caused by other greenhouse gases. Indeed, differences in sulfur emissions can have a profound effect on warming trends over a period of several decades (Gallopín and Raskin, 2002).

Current Accounts

Estimates of current emissions of sulfur are shown below in Table 7-2. The estimates include emissions from the combustion and conversion of fossil fuels, which in 2005 amounted to about 175 million tonnes of SO_2 (equivalent to approximately 90 tonnes of sulfur)[33]. The combustion of coal for electricity generation and other purposes accounts for approximately 70% of the SO_2 emitted through combustion for energy, the remainder arising primarily from the combustion and refining of oil products. The non-energy related SO_2 emissions from industrial processes, which arise primarily from the smelting of non-ferrous metals (zinc, copper, and lead) plus smaller amounts from the pulp and paper sector, account for roughly 67 % of Industrial emissions, with 38.4 million tonnes of SO_2 in 2005.

Sulfur emissions factors are based on a review of various sulfur emissions inventories for 1990 by Posch et al. (1996) and Kuylenstierna (1998).

[33] Note that sulphur dioxide or SO_2 belongs to a family of sulphur oxide gases, often referred to as SO_x in this and other studies.

Table 7-2. Global emissions of sulfur oxides by sector – 2005

Million tonnes SOx Emissions	Energy sector	Industry combustion	Industry Process	Other combustion	Total
North America	14.1	0.4	8.7	11.2	25.7
Pac OECD	5.6	0.6	9.7	13.4	19.6
Western Europe	5.0	1.4	4.2	6.0	12.3
FSU	4.4	0.2	26.2	28.6	33.2
Eastern Europe	3.0	1.6	1.4	2.4	7.0
Africa	2.2	0.4	1.9	3.4	6.0
China+	1.7	1.1	12.2	13.8	16.6
Latin America	1.3	1.1	0.3	2.1	4.5
Middle East	19.7	9.2	19.4	24.9	53.8
South Asia	4.9	0.4	4.9	7.7	13.0
Southeast Asia	1.6	1.6	0.0	1.5	4.7
World	63.3	18.1	88.9	114.9	196.3

Scenarios

In the *Market Forces* scenario, emissions increase over time from close to 196 million tonnes of SO_2 in 2005 to about 475 million tonnes in 2100. Over this period, emissions from the OECD regions increase only slightly until 2050, due to the widespread adoption of more efficient coal-fired power plants using sulfur emission controls that cut the rate of emissions. The decline of emissions after 2050 in the OECD regions also reflects the slow rate of growth and eventual contraction in the non-ferrous metals sector.[34]

In the non-OECD regions, *Market Forces* scenario sulfur emissions more than triple by 2100. This reflects the increases in coal consumption expected in the scenario, and the assumption of a lower rate of adoption of more efficient power plants using sulfur controls. The scenario also reflects the high levels of growth expected in the industrial sectors of the developing regions. Coupled with the assumption of constant emission factors, this leads to dramatic increases in industrial sector process emissions of sulfur.

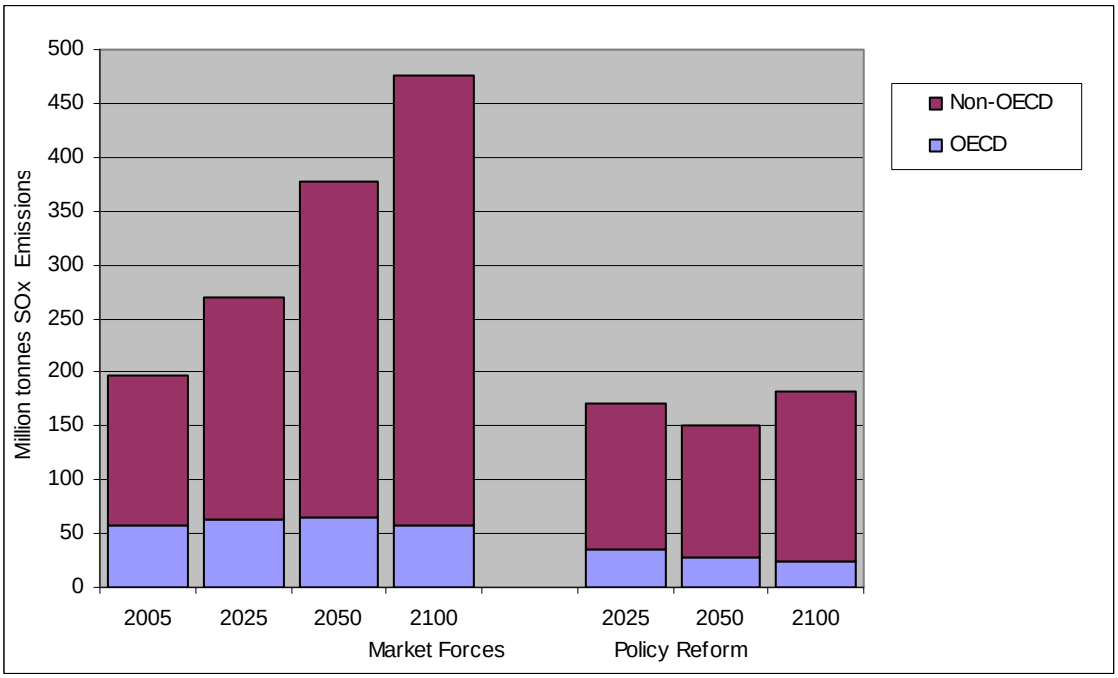
The *Policy Reform* scenario achieves dramatic reductions in sulfur emissions, as shown in Figure 7-8. In part, the scenario reflects the co-benefits of the greenhouse gas mitigation policies that guide the scenario. Those policies require a dramatic shift away

[34] In the *Market Forces* scenario, we assume that emission factors for industrial process emissions and all non-electric sector fuel consumption remain constant over time in each region.

from the combustion of coal towards other less carbon-intensive fuels, at the same time less sulfurous fuels (biomass, renewables and natural gas). The slight increase in sulfur emissions between 2050 and 2100 is due to the increased activity in industrial processes in the non-OECD regions (i.e., copper smelting), which outweighs the decreases in all the other sectors.

In the *Policy Reform* scenario, SO_2 emissions in OECD regions fall dramatically from 58 million tonnes in 2005 to 25 million tonnes in 2100. Fuel-switching policies, when combined with a greater emphasis on demand-side and electricity generation efficiency, dramatically reduce the primary requirements for coal in the OECD regions. Sulfur emissions from the non-OECD regions decrease from 139 million tonnes in 2005 to 123 million tonnes in 2050, in part because of fuel-switching policies and substantial efforts to reduce emission factors (for example reflected in the rapid introduction of sulfur control technologies in the electricity generation sector). This is followed in the non-OECD regions by an increase to 156 million tonnes SO_2 in 2100, due to the increased industrial activity, as explained above.

Figure 7-8. Sulfur emissions by macro-region



Water Pollution

The water pollution analysis provides rough estimates of loadings to water bodies – that is, the amount of the pollutant that enters ground or surface water. Within the water body, pollutants may decompose or be released to the atmosphere in another form. The water "pollutants" considered here are biochemical oxygen demand (BOD) and nitrogen. BOD

is the amount of oxygen that is consumed in the process of breaking down organic matter in waste. The oxygen consumed by oxygen-depleting substances then becomes unavailable for aquatic organisms, making BOD a key indicator of an aquatic system's health. For this reason it is the most widely used measure of organic pollution (Tchobanoglous and Burton, 1991). Nitrogen, the element most commonly applied as fertilizer, has significant impacts on ecosystems and human health. In the form of ammonia, nitrogen depletes oxygen during the nitrification process (contributing to total oxygen demand, often denoted NBOD) and creates nitrates as a byproduct. The increased levels of nitrate in drinking water causes methemoglobinemia ("blue baby" syndrome), which can be lethal to infants under six months, and which has been known to affect children up to age six. In some environments, ammonia can become toxic to aquatic life. Finally, in the same manner that nitrogen enhances crop growth, it can lead to excessive plant growth in rivers and streams resulting in eutrophication and the obstruction of stream flows. The total loadings that are reported in the scenarios are indicative of the stresses placed on aquatic ecosystems and human health from human activities.

BOD loadings are analyzed for domestic water pollution (i.e., pollution from the households and services sectors), industry and agriculture. Nitrogen loadings are estimated for agriculture only, as emissions from livestock wastes and fertilizer use under modern agricultural practices are the main sources of anthropogenic nitrogen (Matthews and Hammond, 1999).

Domestic BOD Loadings

Estimates of BOD loadings are constructed separately for urban and rural areas. Loadings are estimated by multiplying population by an emission factor, and then taking treatment into account. Separate emission factors are used for sewered and unsewered waste. A fraction of sewered urban wastes is assumed to be treated to some degree, while in rural areas it is assumed that the bulk of the population is not connected to central sewer systems, and no waste is treated. BOD emissions are determined by the size of urban and rural populations and by regional GDP per capita, as described below.

Data on BOD loading factors (kg BOD/person) are scarce, but they are known to vary regionally and by sewered and unsewered population. The unsewered BOD generation rate is typically lower than for sewered waste because unsewered loadings remain on-site, where they decay before seeping into the water system. In contrast, the sewered loading is directly piped to its destination (treatment facility or river), with little time to decay in the transfer from source to destination. Values for the United States and representative values for developing countries are shown in Table 7-3.[35] In this analysis,

[35] In theory, figures for BOD represent all of the oxygen that would be consumed by bacteria if a given amount of waste were to be completely degraded. For practical reasons, BOD loading factors are typically reported in terms of 5-day BOD or BOD_5 (the oxygen depletion occurring over 5 days). Where data collected for this analysis were given in terms of BOD_5, the values for untreated waste were converted to BOD assuming that BOD_5 is 83% of BOD (Chapra, 1997).

the United States value is used for OECD regions and the developing countries value is used for non-OECD regions.

Table 7-3. Typical loading rates for untreated domestic sewage

	BOD [BOD_5] (kg/capita/year)	
	Sewered	Unsewered
United States	54.9 [45.5][a]	11.0 [9.1][c]
Developing Countries[b]	23.7 [19.7]	8.3 [6.9]

[a] Chapra (1997). [b] WHO (1982). [c] These values assumes unsewered population contribution 80% less than sewered in industrialized countries, compared to 65% in developing countries, because of higher standards in septic tanks.

In general, not all of the urban population is connected to sewerage and only a portion of the sewered waste is treated. Three levels of treatment currently exist for wastewater, for those areas connected to a treatment plant: primary, which removes 20-30% BOD; secondary, which removes 80-90% BOD; and tertiary, which removes 95% or more BOD (WRI, 1998). Average wastewater treatment levels in three of the regions in this analysis are shown in Table 7-4. The average BOD removed with each degree of treatment (primary, secondary, tertiary) was applied to average wastewater treatment levels in these three regions, to obtain the average percent of BOD removed by region (shown in Table 7-5).

Table 7-4. Wastewater treatment levels in 1995 (selected regions)

	Treatment Shares (%)		
	Primary	Secondary	Tertiary
North America	13	45	42
Western Europe	23	43	34
Eastern Europe	19	74	7

Table 7-5. Average percent of BOD removed during wastewater treatment

	% BOD Removed
North America	81.3
Western Europe	74.9
Eastern Europe	74.5

Figures for the percentage of the urban population connected to sewerage and the percentage of sewered wastewater that is treated are based on data from the Global Urban Observatory (Habitat, 1998), shown in Table 7-6. The percentage of the urban population connected to sewerage and the percentage of wastewater treated increase with income, a pattern observed in average city-level data from the Global Urban Observatory (Habitat, 1998).

Table 7-6. Sewerage connection level and wastewater treatment

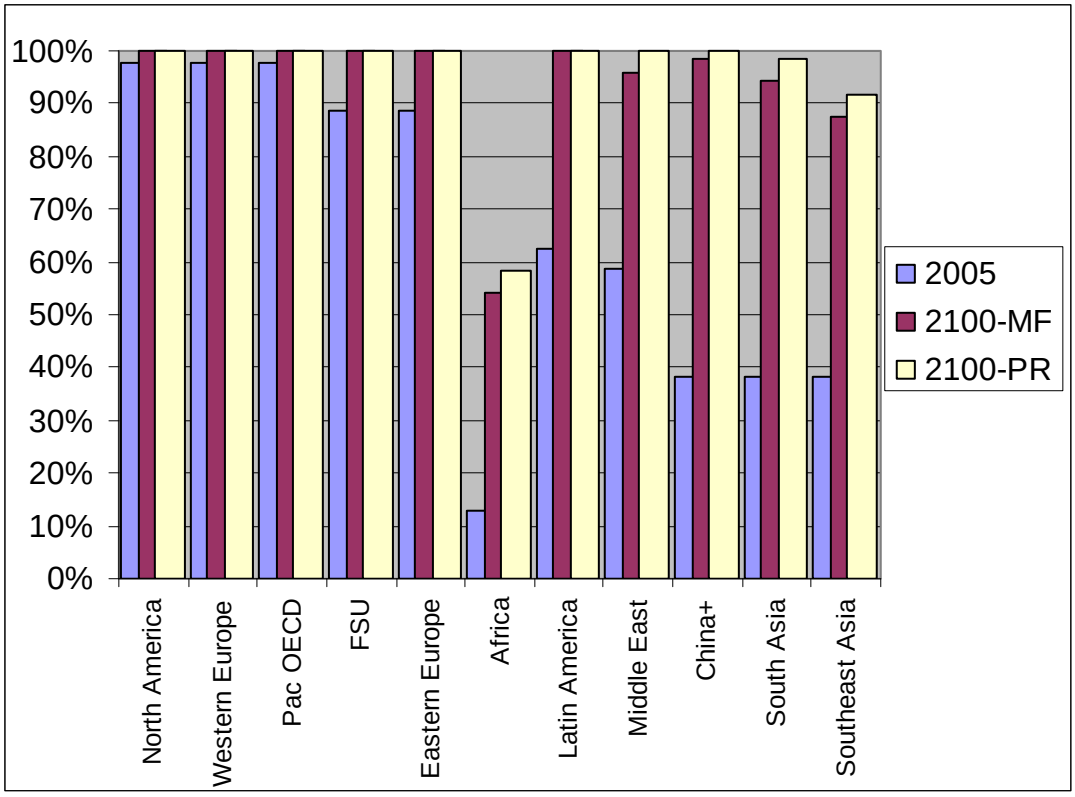
	Household Connection Level	Wastewater Treatement	
Habitat Region	(% urban population connected to sewerage)	(% of total wastewater)	Corresponding region(s) in this study
Industrialized	98	87	North America, Western Europe, Pac OECD
Transitional	89	64	Eastern Europe, FSU
Africa	13	15	Africa
Arab States	59	54	Middle East
Asia Pacific	38	26	South Asia, Southeast Asia, China+
LAC	63	18	Latin America

Source: Global Urban Observatory (Habitat, 1998).

An examination of the patterns showed a rough correspondence between average income and treatment level. Based on the observed patterns, the relationship between treatment level and income assumed in the analysis is as follows: below an income level of around $2,400, it is assumed that only primary treatment is used, in which 25% BOD is removed. Above an income of $7,700 in *Market Forces*, treatment levels are assumed to remain at 80%, close to the current average values for high-income regions in 1995. In *Policy Reform*, above an income of $8,700, treatment levels are assumed to reach 90% by 2050, and 95% by 2100, representing the widespread use of tertiary treatment.

Urban sewerage connection levels in the scenarios are shown in Figure 7-9. The higher income growth rates in developing regions in the *Policy Reform* scenario compared to the *Market Forces* scenario leads to slightly higher connection levels by 2050 in the *Policy Reform* scenario when compared to the *Market Forces* scenario.

Figure 7-9. Urban sewerage connection levels in the scenarios



Livestock Production

Estimates for water pollution from livestock wastes, in the form of nitrogen (N) and biochemical oxygen demand (BOD), are calculated for the current accounts and the scenarios. The analysis is based on a rapid pollution assessment methodology developed by the World Health Organization (WHO, 1982). Using estimated feed energy requirements per head of stock and emission factors per head for different kinds of livestock (Table 7-7), loading factors per unit of feed energy intake are estimated for the base year using data on livestock populations and milk production from the FAOSTAT database (FAO, 2007a), and the loading factors listed in Table 7-7.

The figures for livestock loadings should be taken with some caution. It is possible to manage livestock waste so that the amount of nitrogen eventually entering water bodies

is reduced. However, data on treatment are poor and treatment is not considered in this analysis. Loading factors are applied to livestock in feedlots only, on the assumption that wastes from free-ranging livestock are sufficiently well-distributed that they serve primarily to fertilize the grasslands on which the livestock feed. In contrast to the agricultural sector, abatement and management are taken into account for the household and industrial sectors. Consequently, in the results, agricultural loadings are reported separately from those of other sectors.

Table 7-7. BOD and N loading factors

	Pollutant loadings (kg/head/year)	
	BOD [BOD_5]	N
Beef cattle	301.2 [250.0]	80.3
Milk cattle*	6.4 [5.3]	-
Sheep	44.1 [36.6]	8.4
Hogs	34.2 [28.4]	8.4
Poultry (broilers)	1.7 [1.4]	0.5

* Milk BOD units are kg/ton of milk/year. Source: WHO (1982)

Estimated BOD emissions are the sum of BOD associated with the organic matter in the wastes, as well as oxygen consumed in the oxidation of nitrogen (NBOD). The loading for NBOD is calculated from the nitrogen loading using the relationship:

$$\text{NBOD (ktonnes)} = 4.57 \times \text{N (ktonnes)}.$$

In using this formula, it is assumed that the nitrogen loading factors reported in Table 7-7 represent all oxidizable nitrogen in the waste, in the form of organic nitrogen compounds and ammonia.

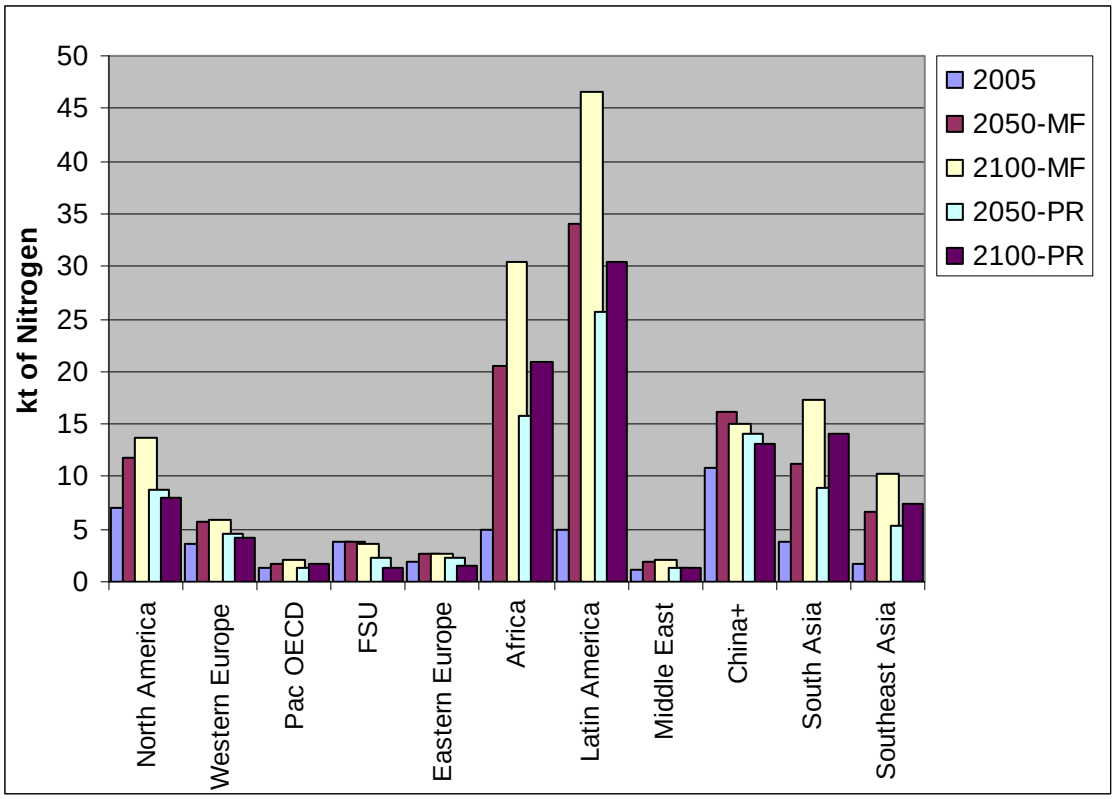
Fertilizer

Nitrogen applied as fertilizer to crops can follow different paths. The goal of applying the fertilizer is that the nitrogen will be taken up by the plant and incorporated in the biomass. However, not all of the nitrogen can be taken up. Some is released to the atmosphere, some remains in the soil, and some enters groundwater or surface water. Following the IPCC guidelines (IPCC/OECD/IEA, 1996), we assume that 30% of the nitrogen applied is lost to leaching and runoff. Note that this value can vary over a broad range, from as little as 10% to as much as 80% (IPCC/OECD/IEA, 1996).

As only manufactured nitrogen fertilizer is tracked in the scenario (see Chapter 4, page 188), loadings from the use of other nitrogen sources, such as manure, are not included in the total. Nitrogen in manufactured fertilizers is typically in the form of ammonium or

nitrate salts. Since nitrate is already oxidized, it does not contribute to oxygen demand. For this analysis it is assumed that fertilizers do not contribute to oxygen demand, in contrast to the nitrogen contained in livestock wastes. Figure 7-10 shows the amount of manufactured nitrogen fertilizer applied in each region in both scenarios.

Figure 7-10. Manufactured nitrogen fertilizer application in the scenarios



Industrial BOD Loadings

Estimation of biochemical oxygen demand (BOD) pollution contributed by manufacturing is based on a study by the World Bank's Development Research Group (Hettige et al., 2000), which examined cross-country data from 12 countries, including both developing and industrialized countries.[36] Consistent with the approach of Hettige et al., pollution generation is expressed as the product of an activity level – industrial value added for the industrial sector – and an intensity. An abatement factor is applied to the total generation to estimate the final load:

[36] The study of Hettige et al. (2000) is based on factory-level data collected on industrial water pollution from national and regional environmental protection agencies in Brazil, China, Finland, India, Indonesia, Korea, Mexico, Netherlands, Philippines, Sri Lanka, Taiwan, Thailand and the U.S.

$$\text{Total Industrial Pollution} = \text{Industrial Value Added} \times \text{Pollution Intensity} \times \left(1 - \frac{\%\ \text{Abatement}}{100}\right) \quad (7\text{-}1)$$

The data of Hettige et al. (2000) suggest that aggregate manufacturing intensities decline steadily from around 5.5 kg/million $/day at an annual income level of $500 per capita to around 4.0 kg/million $/day at an income level of $5,000 per capita and remain relatively steady, showing only a slight increase for incomes above that level. For this analysis, in both scenarios it is assumed that aggregate BOD intensities are 5.5 kg/million $/day for GDP/capita below $500, 4.0 kg/million $/day for GDP/capita above $5,000 and decline steadily for GDP/capita between $500 and $5,000. Abatement levels are also assumed to vary with income, following the tabulated values reported in Hettige et al. (2000).

Results

Water pollutant loadings in the scenarios are shown in Table 7-8, Table 7-9, and Table 7-10 below.

Globally, agricultural BOD loadings (Table 7-8) from livestock increase by a factor of 5.5 between 2005 and 2100 in the *Market Forces* scenario, while nitrogen loadings more than triple the 2005 levels. In the *Policy Reform* scenario, nitrogen loadings from agriculture in 2100 are almost 30% below the corresponding level under the *Market Forces* scenario. BOD loadings in the *Policy Reform* scenario in 2100 are about 20% lower than under *Market Forces* assumptions, but still increase compared to the 2005 value due to increased use of feedlots to compensate for land constraints. These increases of BOD due to feedlots could be offset to some degree by storing animal wastes and then applying them as fertilizer. Due to limited information about the extent of this practice in the base year, it has not been incorporated in the scenarios. However, the values shown on the table indicate the additional pressures that can arise under the *Policy Reform* scenario assumptions regarding livestock production. The efforts required to ameliorate the problem will be correspondingly greater compared to the *Market Forces* scenario.

The figures shown in Table 7-9 for domestic and Table 7-10 for industrial BOD loadings incorporate scenarios for treatment levels, as described above. With the higher income growth rates in non-OECD regions in the *Policy Reform* scenario compared to the *Market Forces* scenario, the degree of wastewater treatment and the number of people connected to sewerage both increase, leading to lower BOD loadings by 2100 in the *Policy Reform* scenario compared to the *Market Forces* scenario. Domestic loadings in 2100 under *Policy Reform* assumptions are 21% lower than the corresponding level in the *Market Forces* scenario, while industrial loadings are only about 2% lower, due to increased industrial activity in the non-ECD regions.

Table 7-8. Agricultural water pollutant loadings

ktonnes	BOD						
		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	31.0	42.4	53.0	64.3	41.6	50.8	58.1
Western Europe	17.3	23.9	28.2	30.1	24.4	29.0	31.7
Pac OECD	4.0	6.8	7.2	11.4	7.3	8.4	13.6
FSU	10.3	7.4	7.4	8.0	7.4	7.2	7.3
Eastern Europe	7.2	11.0	13.8	14.0	11.3	14.4	11.1
Africa	8.4	38.9	88.0	158.3	44.8	89.3	139.3
China+	21.5	122.2	227.6	321.9	105.1	167.3	197.2
Latin America	3.8	5.7	8.0	10.3	5.4	6.8	8.0
Middle East	46.8	75.1	92.2	95.3	72.1	82.2	81.2
South Asia	1.9	18.6	45.8	103.1	22.0	50.6	92.9
Southeast Asia	5.9	17.1	33.0	58.1	17.6	30.2	41.6
World	158.2	369.1	604.2	874.7	359.0	536.0	681.9

ktonnes	Nitrogen						
		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	7.0	9.5	11.7	13.6	8.3	8.7	8.0
Western Europe	3.7	4.9	5.6	5.9	4.5	4.6	4.2
Pac OECD	1.3	1.6	1.6	2.1	1.5	1.4	1.7
FSU	3.8	3.8	3.7	3.7	3.0	2.2	1.3
Eastern Europe	2.0	2.3	2.7	2.6	2.1	2.2	1.4
Africa	5.0	11.8	20.6	30.4	10.7	15.7	20.8
China+	5.0	19.4	34.1	46.6	16.5	25.7	30.5
Latin America	1.1	1.5	1.8	2.1	1.2	1.4	1.3
Middle East	10.8	14.6	16.2	14.9	13.3	14.0	13.1
South Asia	3.9	7.2	11.2	17.3	6.3	8.9	14.1
Southeast Asia	1.6	4.0	6.7	10.2	3.6	5.4	7.4
World	45.1	80.5	116.0	149.3	71.0	90.1	103.9

Table 7-9. Domestic BOD loadings

ktonnes	Domestic						
		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	3.3	4.1	4.9	5.1	3.3	2.6	1.5
Western Europe	4.1	4.4	4.5	4.0	3.6	2.6	1.4
Pac OECD	2.0	2.1	2.1	2.1	1.8	1.3	0.8
FSU	1.5	1.7	2.1	2.6	1.5	1.4	1.1
Eastern Europe	1.0	1.2	1.8	1.6	1.1	1.1	0.5
Africa	7.3	10.6	14.7	18.4	10.4	13.7	14.5
China+	2.6	3.1	3.6	4.5	2.9	2.7	1.5
Latin America	1.4	2.2	3.6	5.5	2.1	2.8	2.4
Middle East	10.9	10.8	10.6	12.1	10.3	8.5	5.1
South Asia	11.5	14.9	15.1	19.7	14.7	13.2	12.8
Southeast Asia	3.5	3.8	4.0	5.3	3.7	3.3	2.4
World	49.0	58.9	67.0	81.0	55.3	53.1	44.1

Table 7-10. Industrial BOD loadings

ktonnes	Industrial						
		Market Forces			Policy Reform		
	2005	2025	2050	2100	2025	2050	2100
North America	0.21	0.29	0.37	0.49	0.28	0.35	0.43
Western Europe	0.24	0.29	0.32	0.35	0.28	0.30	0.31
Pac OECD	0.13	0.14	0.15	0.18	0.14	0.14	0.16
FSU	0.11	0.09	0.10	0.09	0.10	0.10	0.15
Eastern Europe	0.06	0.06	0.07	0.08	0.07	0.08	0.12
Africa	0.37	0.48	0.68	0.65	0.48	0.61	0.68
China+	0.19	0.24	0.28	0.23	0.23	0.30	0.35
Latin America	0.10	0.14	0.20	0.17	0.13	0.20	0.27
Middle East	0.65	0.68	0.60	0.53	0.68	0.63	0.82
South Asia	0.46	0.53	0.58	0.54	0.53	0.59	0.59
Southeast Asia	0.20	0.23	0.21	0.17	0.23	0.22	0.26
World	2.73	3.18	3.56	3.46	3.13	3.52	4.15

Solid Waste

Depending on the method, solid waste disposal can produce air pollution from combustion (incineration) or decomposition (landfill methane). Additionally, the disposal of landfilled waste requires land. While the total area under landfills is very small, landfills must reconcile the necessity of being accessible to municipal areas, while also overcoming objections from those living close to the landfill. Landfills are implicated in water pollution and emissions of methane, a potent greenhouse gas. As an alternative to final disposal, waste can be recycled, reducing requirements for primary materials, while relieving pressure on land resources and avoiding air pollution. Also, incinerated wastes, while they may contribute unwanted atmospheric emissions, can be used to generate energy in the form of electricity and heat.

In the analysis, waste generation is estimated for urban areas for all regions, and for OECD and transitional regions where data are available, for rural areas as well. Both energy from incineration and methane emissions from landfills are considered.

Current Accounts

Waste Generation

In the base year, waste generation rates in OECD regions and some transitional countries are based on data given in OECD (1997; 1999; 2008). Waste generation data from many regions is given by the IPCC 2006 Greenhouse Gas Guidelines on Waste (IPCC, 2006). In the remaining regions, waste generation rates in rural areas (and in transitional regions for urban areas as well) are based on the default regional generation rates given in Doorn and Barlaz (1995).

Treatment

For the OECD regions, waste processing fractions (landfill, recycling, incineration and other) are estimated using data from OECD (1997; 1999; 2008) and from the IPCC (2006). For other regions the processing fractions are based on the regional aggregate figures in the Global Urban Indicators Database (Habitat, 1998), which provides city-level data and regional averages. Processing fractions are applied to the total population in high-income OECD and transitional regions, and to the urban population in developing regions.

Waste incineration based energy generation is estimated for OECD regions and FSU and Eastern Europe from IEA statistics (IEA, 2006b). Incineration fractions are based on OECD data (OECD, 1997; 1999; 2008) and IPCC (2006). Note that incineration provides only a very small contribution to total energy requirements in these regions, but may be a sizeable component of biomass-based energy generation.

Emissions

Air emissions from solid waste disposal can arise from incineration or as methane generated during the decomposition of buried waste. This analysis focuses on methane emissions, as landfills are an important source of methane emissions today, contributing 10% of total global emissions in 1994 (Stern and Kaufman, 1998).

Methane emissions from landfills arises from the decomposition of organic matter in waste by microorganisms, in the absence of oxygen (*anaerobic* decomposition). If oxygen is present (*aerobic* decomposition), then the end product of the decomposition is carbon dioxide. Thus, methane is generated only when waste is buried relatively deeply, as it generally is in industrialized countries. In developing countries, particularly in rural areas, wastes are often discarded in shallow pits, where it decomposes aerobically. For this reason, emissions from rural developing areas are not included in the municipal solid waste analysis.

Based on the analytical approach in SEI's *Greenhouse Gas Scenario System* (SEI, 1993), emissions per tonne of waste are separated into three factors – the fraction of the waste that is organic and potentially decomposable (the decomposable organic content, or DOC); the fraction of the decomposable waste that is gasified; and the fraction of the gas produced that is methane – and then scaled by the ratio of the molecular weight of methane to that of carbon:

$$\text{tonne } CH_4/\text{tonne waste} \equiv \tfrac{16}{12} \times \text{DOC} \times \text{Gasified fraction} \times CH_4 \text{ fraction}. \qquad (7\text{-}2)$$

In all regions, based on figures from SEI (1993), the gasified fraction is set to 80%, and the methane fraction to 50%. However, the DOC factors differ significantly between different regions. Based on the IPCC data (2006), the degradable organic content of waste in all non-OECD regions is set to between 14 and 18%, a relatively low value that takes into account the fact that much organic matter is recycled by individuals. The fractions for OECD regions are set to values between 19% and 21%, due in large part to the sizeable contribution of paper to the total waste stream.

A certain portion of total methane emissions is recovered. Recovery rates are set based on values in Doorn and Barlaz (1995). For most regions, recovery rates are below 5% of total emissions. Only two regions – Western Europe, with an average recovery rate of 18%, and North America, with a recovery rate of 12% – exceed a rate of 5%.

Scenarios

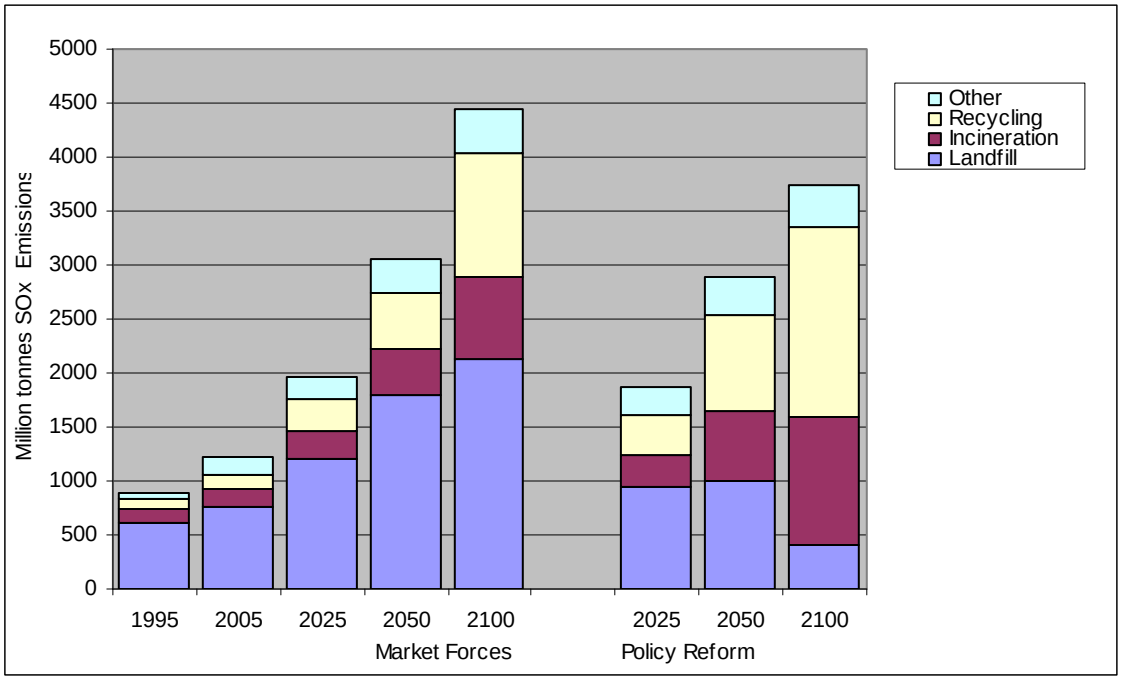
Waste Generation

Continuing developments seen over the past decade in the scenario, high-income OECD generation rates are assumed to increase at a slightly lower rate than GDP, while other regions converge toward the average rate in high-income OECD regions as incomes increase.

Treatment

In the *Market Forces* scenario, changes in recycling rates in the OECD regions are set to increase slightly by 2100, with North America and Western Europe reaching 30% recycling and Pacific OECD reaching 25%. Recycling rates in the non-OECD regions, which are very low compared to OECD levels, rise gradually over the course of the scenario using the convergence methodology (See Annex 1). As the average GDP/capita of the region approaches the average OECD income in 2005, the share of waste processed by recycling approaches the North American share in 2050. The *Policy Reform* scenario sees higher rates of recycling (up to 55% in some regions in 2100) in all regions compared to the *Market Forces* scenario, while landfill rates decline. Generation and treatment levels in the scenarios are shown in Figure 7-11.

Figure 7-11. Solid waste generation and treatment



In both scenarios it is assumed that energy from incineration increases significantly in all regions, but more so in the *Policy Reform* scenario. Generation of electricity and heat from waste incineration makes a small contribution to total energy requirements in all regions. In the *Market Forces* scenario, energy from incineration increases from 108 PJ in 2005 to 888 PJ by 2100, although it remains a very small fraction of total energy requirements. In the *Policy Reform* scenario, generation of heat and electricity from incineration total around 1516 PJ by 2100. The figure is larger in the *Policy Reform* scenario compared to *Market Forces* because starting in 2025, non-OECD regions begin using incineration for energy production, as their energy extraction rates for Electricity and Heat approach and reach OECD levels by 2050.

Emissions

For estimating methane emissions, degradable organic content (DOC) factors in all regions converge gradually toward the base year value for North America. This convergence reflects the increasing importance of paper (which has a high degradable organic content) in the waste streams of all regions. Methane recovery in North America and Western Europe increases to 60% by 2025 to 2050, and to 70% in 2100, based on anticipated developments in the U.S.. These reductions are reasonably strong, and the same level of reduction is assumed in both scenarios. Methane recovery in the Pacific OECD region is negligible in the base year, and is assumed to reach 40% by 2025, reaching 60% by 2050, and 70% by 2100.

In the *Market Forces* scenario, recovery rates in all other regions are assumed to reach 20% by 2025, based on the assumptions in Tellus Institute (1998), and then 30% by 2050, and 50% by 2100. Under *Policy Reform*, higher levels of recovery are assumed of 30% by 2025, 60% by 2050, and 70% by 2100. In the *Market Forces* scenario, methane released from landfills grows from close to 65 million tonnes of methane in 2005 to 111 million tonnes in 2050, a factor of roughly 1.7 times, followed by a decrease in 2100 to about 99 million tonnes corresponding to the demographic transition and lower rates of waste generation. In the *Policy Reform* scenario there is a decrease in released methane, due to higher recycling rates and increased capture for energy production. Methane release decreases by over 80% over the scenario period, to close to 12 million tonnes by 2100.

Toxic Waste

A wide variety of toxic and hazardous substances is used in the manufacture of industrial products. Nearly 100,000 industrial chemicals are now in commercial use worldwide, and this figure is increasing by 500 to 1000 each year. Some of these chemicals may not present significant threats to human health or to the environment, while others are known to represent specific toxicological and ecotoxicological impacts. However, there is insufficient scientific information even for a partial health assessment for about 90% of them (NAS, 1984). Toxic wastes pose particular threats in the environment on account of their toxicity, persistence, and tendency to “bioaccumulate” in living organisms, and through the food chain (Jackson and Taylor, 1992; Dethlefson et al., 1993).

The material and chemical flows underlying the modern industrial economy are immensely complicated and are not well-tracked and understood. Nevertheless, it is important to develop estimates of existing levels of emission of toxic and hazardous substances into the environment, to project trends and to explore alternative scenarios for keeping emissions within acceptable risk levels.

With this aim in mind, the World Bank has devised an “Industrial Pollution Projection System” based on U.S. data, which provides lower bound toxics “emission factors” for many industries expressed as emissions per unit of value added in each industrial

subsector (Hettige et al., 1994). These factors have been updated and adapted for use with the value added data used in this analysis (expressed in purchasing power parity units).

The *Market Forces* scenario analysis of toxic wastes is an update and expansion of an earlier report (Raskin et al., 1996). Some of the text in this chapter is adapted from that report.

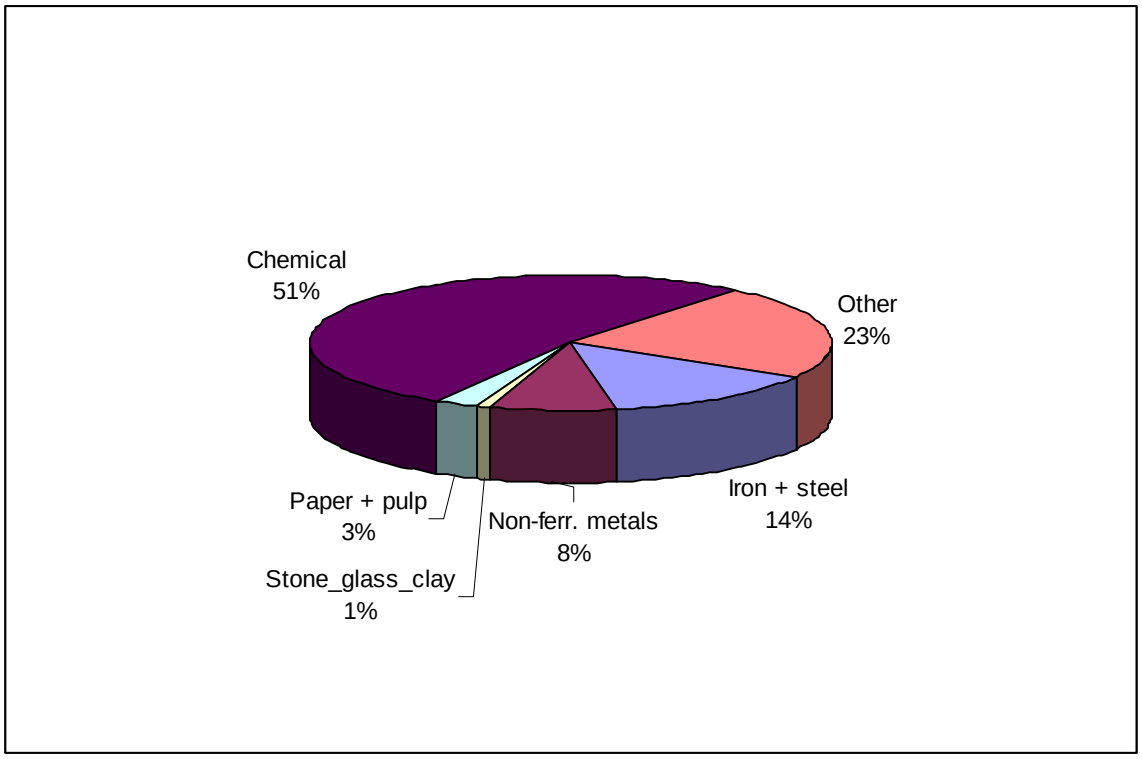
Current Accounts

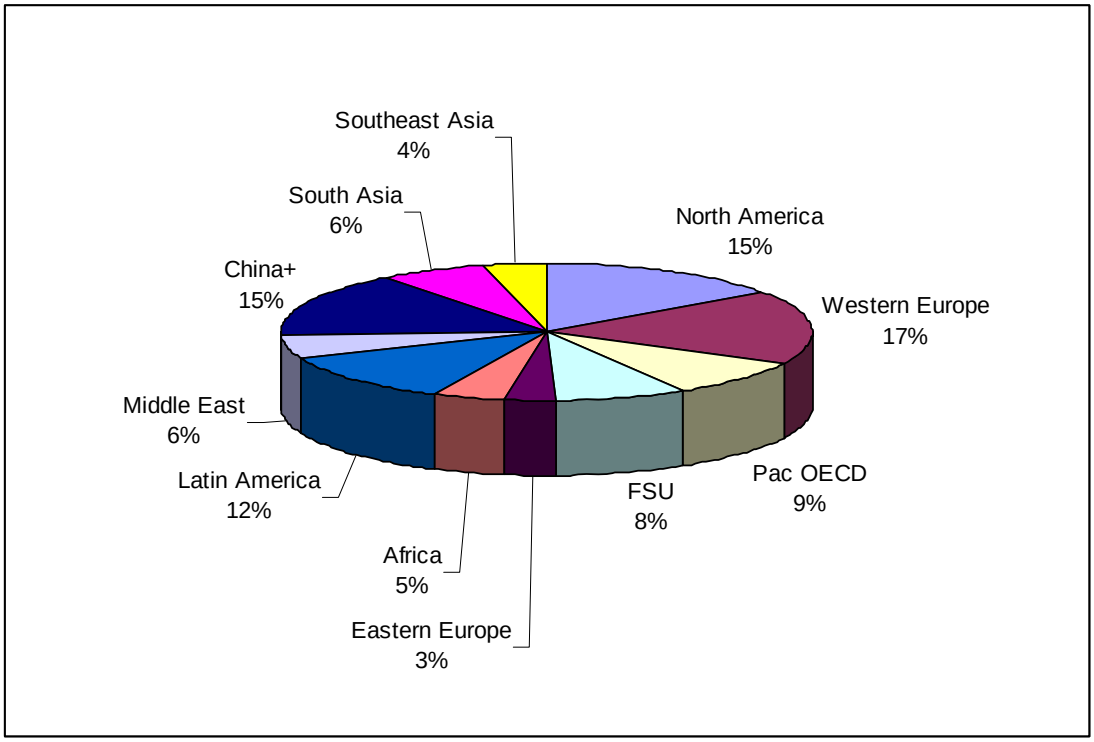
Applying the emission factors to industrial sector value added current accounts yields total emissions of approximately 118 million tonnes in 2005. Figure 7-12 shows how this is broken down by region and industrial subsector. The chemicals industry has the largest sectoral share (51%) with metals industries also significant. The regional picture is dominated by Western Europe, North America, China and Latin America, which account for 59% of all toxic releases.

These estimates should be regarded as indicative only. A number of limitations concerning the quality of the data and the applicability of the accounting methodology need to be highlighted. In the first place, the data have been drawn from a single country (the U.S.) and the degree of validity of extrapolation on a global basis is not clear, particularly since the factors are based on monetary measures of industrial activity rather than a more accurate physical measure (e.g., tonnes of output by industrial subsector). Although the pattern of technological development in other OECD regions may not be vastly dissimilar to the U.S. example, the extension of these emission factors to less developed economies may introduce significant inaccuracies. In general, the effect will be to underestimate actual emissions in less developed regions, because technological efficiencies and environmental controls are likely to be inferior (Jackson and MacGillivray, 1995).

Figure 7-12. Current Accounts Toxic Waste Emissions -- 2005

Total Emissions = 47 million tonnes



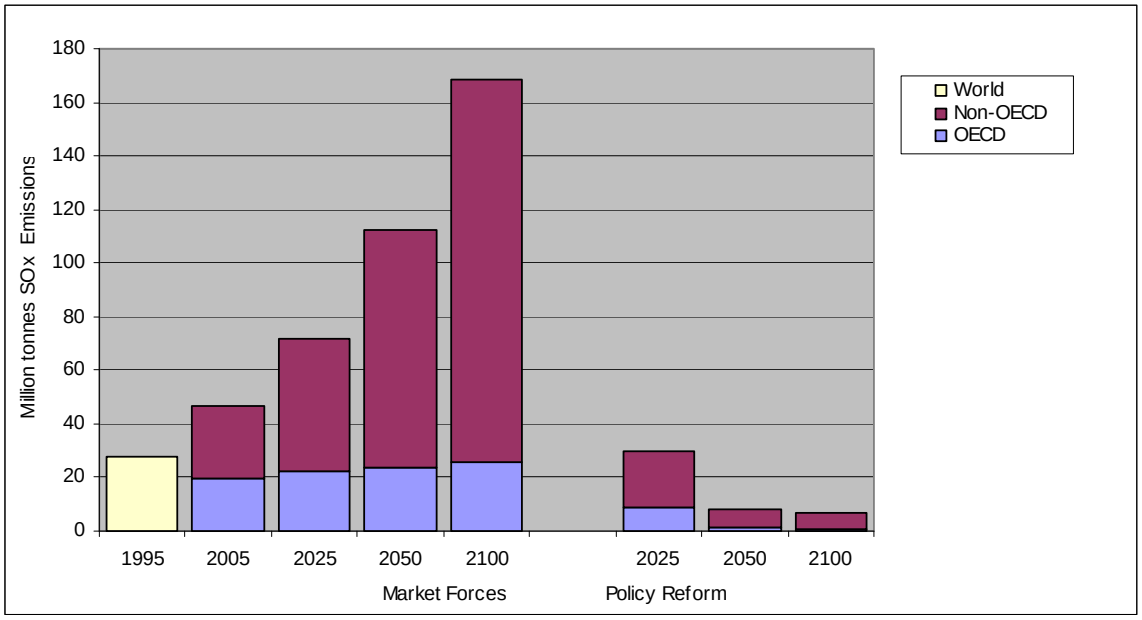


Scenarios

The *Market Forces* and *Policy Reform* scenarios examine how toxic waste emissions might evolve over time. In the *Market Forces* scenario, emission factors per unit of value added are assumed to remain constant, while in the *Policy Reform* scenario, emissions are projected in two phases. Firstly, total emissions in OECD regions are assumed to decrease to 40% of 2005 levels by 2025, to 7% of 2005 levels by 2050, and to 4% of 2005 levels by 2100. Secondly, the emission factors implied by this level of decrease are applied also to non-OECD regions, and the results used to calculate overall levels of emissions. This is an ambitious target, but one in line with the general eco-efficiency assumptions of the scenario.

The results for each scenario are shown in Figure 7-13. In the *Market Forces* scenario, emissions increase dramatically, especially in the developing regions, to a level that is likely to be unacceptable. The sectoral composition of this burden is similar to the current allocation. The chemicals sector is still important, as are the metals sectors. However, a greater proportion of the burden now comes from "other" sectors – an effect consistent with the reduction in material intensity of conventional materials, such as iron and steel, which is assumed in the scenario. In the *Policy Reform* scenario, dramatic reductions are achieved as a result of the stringent emissions targets set in the scenario.

Figure 7-13. Lower bound toxic emissions scenarios



8 A Great Transition Scenario

Overview

The *Great Transition* (GT) scenario is elaborated in detail in the publication, *Great Transition: The Promise and Lure of the Times Ahead* (Raskin et al., 2002), as well as the GTI Paper Series, available online at http://gtinitiative.org/resources/paperseries.html. The present discussion will focus on the approach followed in developing the newly updated quantitative illustration of the *Great Transition* scenario. Detailed quantitative outputs of the *Great Transition* scenario are available on the web at http://tellus.org/programs/integratedscenarios.html. In this section, we begin with a discussion of the general methodological approach to generating the scenario assumptions.

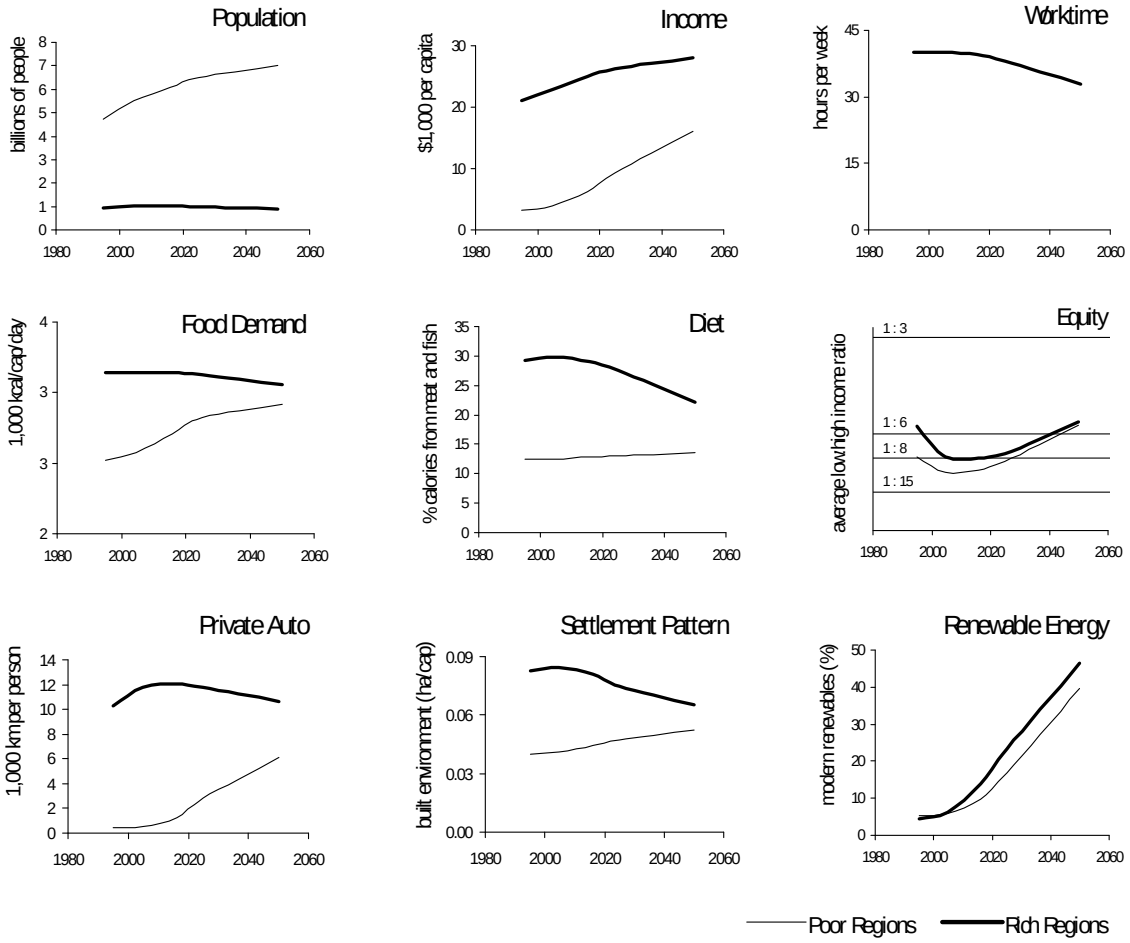
While there will always be differences between regions due to different climates and other natural endowments, and due to persistent cultural differences, nevertheless, the equity considerations of the *Great Transition* scenario prompt a vision of the future in which all regions move toward similar patterns of consumption and resource use. The qualitative differences between regions are characterized by specifying a mix of the three theoretical regional archetypes of Agoria, Ecodemia and Arcadia (Raskin, 2006) in the year 2100.

Global convergence, to varying degrees, also underlies the *Market Forces* and *Policy Reform* scenarios. However, two features differentiate convergence in the *Great Transition* scenario from that in the other two scenarios. First, the convergence should happen more rapidly and completely. Second, in the *Great Transition* scenario it is the characteristics of the final state that are specified in 2100 for each archetype. In contrast, under *Market Forces* the fact of various converging trends are most important, while in the *Policy Reform* scenario the achievement of certain social and environmental targets are the goal. These targets are specified for 2050 and 2100, well before substantial regional convergence has been achieved.

The strategy followed for the *Great Transition* scenario is to identify key elements of an *asymptotic state* that all regions approach. It is assumed that all regions actually reach that state by 2100 in the *Great Transition* scenario, whereas in 2025 conditions are very close to those of the *Policy Reform* scenario. Values for 2050 are interpolated between those for 2025 and 2100. This chapter focuses mainly on describing the quantitative characteristics of the asymptotic *GT* state. Results for major indicators in the *Great Transition* scenario are compared to those of the *Market Forces* and *Policy Reform* scenarios on the results website (http://tellus.org/programs/integratedscenarios.html).

In this chapter, in contrast to the rest of the report, regions will sometimes be classified as either *rich* (the OECD regions) or *poor* (the non-OECD regions). These distinctions apply in the base year, and for much of the scenario, but are erased as the asymptotic state is approached. Patterns of change in key indicators for these two regional groupings are shown in Figure 8-1.

Figure 8-1. Indicators for the *Great Transition* scenario



Source: Raskin et al. (2001).

The Asymptotic State

The asymptotic state of the *Great Transition* scenario represents what the world could approximately look like in terms of economic, social and environmental descriptors. These, while theoretically discussed as an asymptote, are set in our scenario to be met exactly in the year 2100. These states are specified for each of the three theoretical regional archetypes, Agoria, Ecodemia, and Arcadia, in order to outline three distinct

types of GT living. However, since all of our 11 geographical regions are a mix of these archetypes, these asymptotic states are blended accordingly, as shown in Table 8-1.

Table 8-1. Regional Mix of Archetypes in 2100

	Agoria	Ecodemia	Arcadia
North America	75%	5%	20%
Western Europe	60%	20%	20%
Pac OECD	60%	20%	20%
FSU	65%	25%	10%
Eastern Europe	65%	25%	10%
Africa	30%	10%	60%
Latin America	25%	50%	25%
Middle East	25%	25%	50%
China+	20%	40%	40%
South Asia	30%	20%	50%
Southeast Asia	30%	20%	50%

The convergence to these asymptotic states of the *Great Transition* scenario occur at the same rate for each region, as shown in Table 8-2. The main characteristics of the asymptotic state are shown in Table 8-3 below. The values chosen are based on a variety of criteria, as discussed below.

Table 8-2. Convergence toward *Great Transition* asymptotic states

Region	2005	2025	2050	2100
North America	0%	10%	50%	100%
Western Europe	0%	10%	50%	100%
Pac OECD	0%	10%	50%	100%
FSU	0%	10%	50%	100%
Eastern Europe	0%	10%	50%	100%
Africa	0%	10%	50%	100%
Latin America	0%	10%	50%	100%
Middle East	0%	10%	50%	100%
China+	0%	10%	50%	100%
South Asia	0%	10%	50%	100%
Southeast Asia	0%	10%	50%	100%

Note: The remainder of the state in each year is the *Policy Reform* scenario state for each region.

Table 8-3. Characteristics of GT asymptotic state (theoretically reached in 2100)

Variable		Agoria	Ecodemia	Arcadia	Units
Macro					
Income	GDP per capita	35,000	30,000	25,000	$/cap (2005 PPP)
Income inequality	High 20%/ Low 20%	4.5	3.5	3.0	
Sector Share of GDP	Industry	10%	10%	10%	
	Services	86%	86%	86%	
	Agriculture	2%	2%	2%	
	Other/Energy	2%	2%	2%	
Households					
Energy intensity	Electric Appliances	2	1.75	1.5	GJ/cap
	Heat/Other	5	4.5	4	
Fuel choice		electric & renew			
Water intensity		45	45	45	m3/cap
Passenger Travel					
Average distance by mode	Private road	4,000	3,000	2,000	pass-km/cap
	Public road	6,000	4,000	3,000	pass-km/cap
	Rail	0	500	1,000	pass-km/cap
	Air	8,000	6,500	5,000	pass-km/cap
Fuel choice	Road	hydrogen	hydrogen	hydrogen	
	Rail	electric	electric	electric	
	Air	biofuel	biofuel	biofuel	
Energy intensities	Varies by mode	various	various	various	

Variable		Agoria	Ecodemia	Arcadia	Units
Freight Transport					
	Freight intensity	0.4	0.4	0.3	tonne-km/PPP $ GDP
Fuel choice	Road	hydrogen	hydrogen	hydrogen	
	Rail	electric	electric	electric	
	Air & water	biofuel	biofuel	biofuel	
Energy intensities	Varies by mode	various	various	various	
Services					
	Energy intensity	0.15	0.14	0.12	MJ/$ value added
	Fuel choice	electric	electric	electric	
Industry					
Energy intensities	Iron and steel	3.2	3.2	3.2	MJ/$ value added
	Non-ferrous metals	6.0	6.0	6.0	MJ/$ value added
	Stone, glass and clay	3.0	3.0	3.5	MJ/$ value added
	Paper and pulp	1.5	1.5	1.5	MJ/$ value added
	Chemical-Energy	1.3	1.3	1.4	MJ/$ value added
	Chemical-Feedstocks and Other-Non Energy	Same as Policy Reform			MJ/$ value added
	Other	0.7	0.7	0.8	MJ/$ value added
Water intensity	varies by subsector	Based on Best Practice Technology			
	Fuel choice	Based on Policy Reform			

Variable		Agoria	Ecodemia	Arcadia	Units
Energy Conversion					
Efficiencies	Elec Gen - Coal	0.6	0.6	0.6	
	Oil	0.6	0.6	0.6	
	Nat Gas	0.6	0.6	0.6	
	Biomass	0.55	0.55	0.55	
	Nuclear	0.33	0.33	0.33	
	Renewables	1	1	1	
	Dist Heat -All Fuels	0.9	0.9	0.9	
	Oil Refining -All Fuels	0.97	0.97	0.97	
	Alcohol Prod - All Fuels	0.7	0.7	0.7	
	H2 Prod - All Fuels	1	1	1	
	Fuel choice	renewables, including biomass fuel			
	Water intensity	Same as Policy Reform			
Agriculture					
	Daily food consumption	3100	3000	2900	kcal/cap/day
	Fraction of calories from animals	0.2	0.15	0.1	
	Water intensity	Various based on maximum irrigation technology improvement			
	Energy intensity	1.4	1.3	1.2	MJ/$ value added
Land and Forestry					
	Built environment per capita	0.04	0.03	0.05	ha/cap

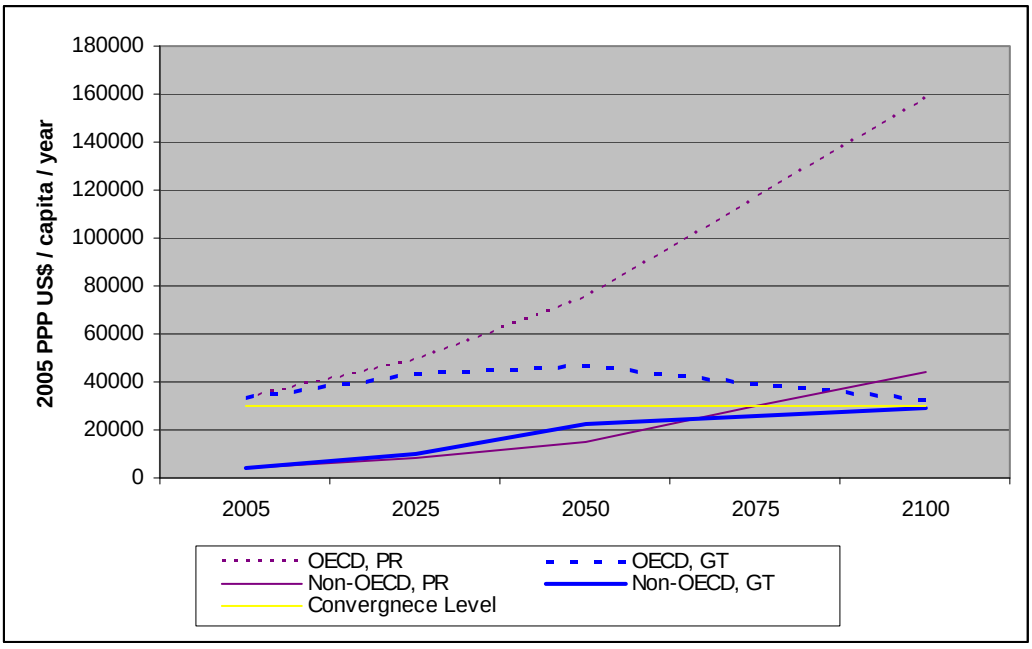
Economics and Demographics

Populations are set between the low and mid-range UN projections in all regions. By 2050, global population in the *Great Transition* scenario is less than that of the *Market Forces* scenario by one billion people, and by 2100, by two billion people.

Income Assumptions

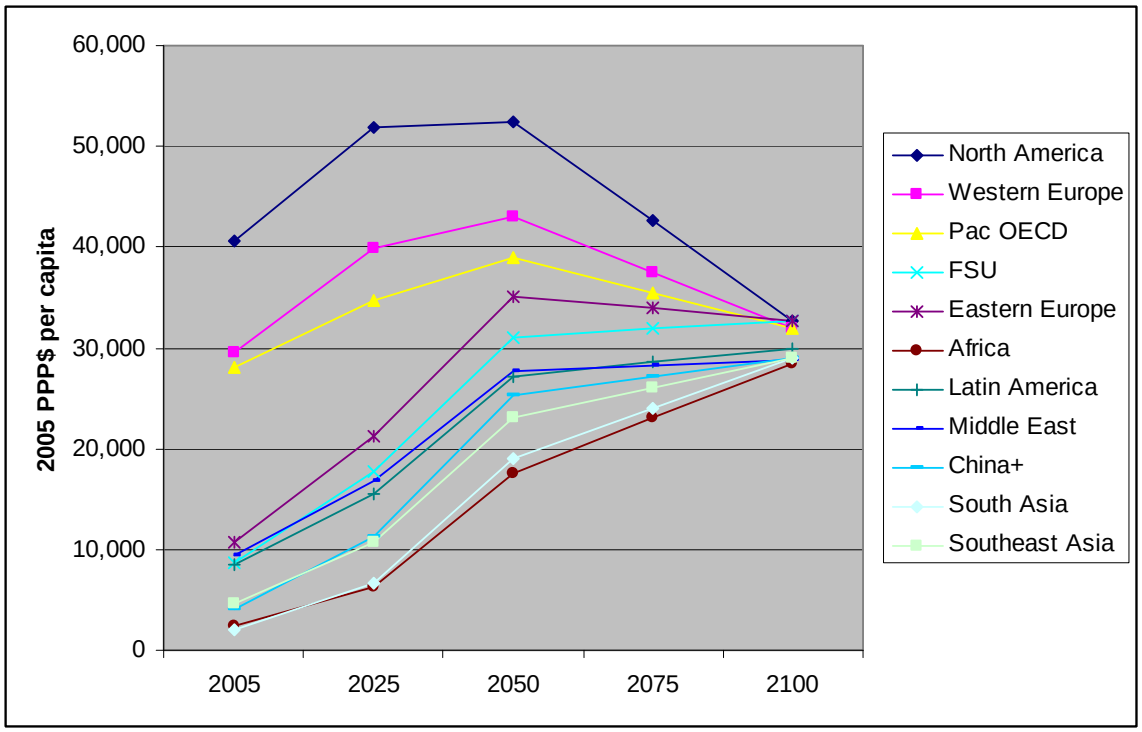
The pattern of change in regional income per capita differs dramatically between the *Conventional Worlds* scenarios (*Market Forces* and *Policy Reform*), and the *Great Transition* scenario (see Figure 8-2). In the *Great Transition* scenario, the global average income per capita in 2100 is lower, and the spread in regional income per capita among the regions is greatly reduced (See Figure 8-3). In North America, the region with the highest current (i.e., 2005) income per capita, the differences are most dramatic. Rather than rising well into the "six-digit level" as in the *Conventional Worlds*, income in North America peaks in 2050 in the *Great Transition* scenario at about 50 percent above its current level. It then declines to roughly half the 2050 level in 2100. The pattern of change in the other two regions with high current incomes—Western Europe and the Pacific OECD region—is similar.

Figure 8-2. Macro-regional incomes in *Great Transition* and *Policy Reform*



The purpose of this section is to explain the pattern of change in income assumed for North America in the *Great Transition* scenario, and to discuss the levels of consumption that are compatible with it. First, a simple labor productivity framework is utilized to explain how the incomes in 2100 arise. Next, differences in the determinants of income in the framework—productivity and work time—are discussed, and related to important choices that workers can make —particularly the quality vs. quantity of work. Finally, the justification for the shape of the *Great Transition scenario's* income path for OECD regions—rising to 2050 and then falling—is addressed.

Figure 8-3. GDP per capita in the *Great Transition* scenario

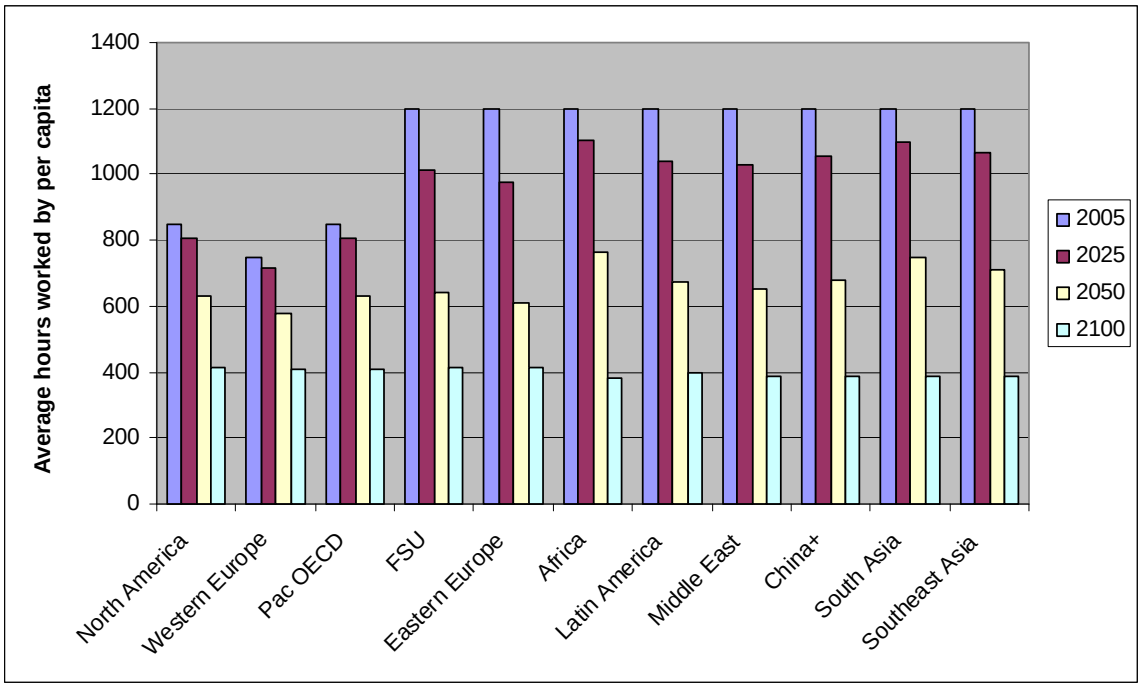


Explaining the Income Difference

In 2005, per capita income in North America was about $41,000. In 2100 it is assumed to be about $193,000 in the *Policy Reform* scenario and even higher in the *Market Forces* scenario, but only about $33,000 in the *Great Transition* scenario. To explain the basis for this difference it is useful to break income down into two constituents: productivity measured by GDP generated per hour worked, and work time measured by hours worked per capita per year. Work time can be further broken down into the hours worked in a typical work week, the weeks worked per year by a full-time employee (FTE), and the number of full-time employees per capita. The last component (FTE per capita) captures long-term trends, such as the increase in the share of women in the work force in the developed regions over the last half century, which affects the number of workers compared to the size of the population.

However, it is average work time per capita that provides the primary explanation for the differences in income. When one thinks about differences between regions with respect to work time, the tendency is to focus on the length of the work week. For example, the fact that in France, the typical work week is shorter than that in the U.S., is well known. As it turns out, this difference is small, about 3 hours, or 8 percent. However, there are also about 12 percent fewer work weeks per year in France, and about 4 percent fewer FTEs per capita, so the work time per capita in France is about 22 percent less than in the U.S. As a result, while French productivity is only 2 percent less than the U.S., French income per capita is about 24 percent lower. Figure 8-4 shows the assumptions on annual hours worked by each FTE in the *Great Transition* scenario.

Figure 8-4. Average annual hours worked per capita in the *Great Transition*



The *Great Transition* and the *Conventional Worlds* scenarios stress differing trends in work time. Historically, in Western Europe and North America work time has fallen. Beginning in about 1970, however, the fall stopped in North America, but not in Europe. We assume that in the *Conventional Worlds* scenarios work time in North America remains constant, as it has recently. In the GT scenario we assume it falls as it had done in the past, and as it has continued to do in Western Europe. It reaches 50 percent of its current magnitude in 2100, a figure (-0.7% per year) consistent with the historical, longer-term downward trend. However, the *Great Transition* scenario does not specify exactly how work time per capita will be reduced. However, it is relatively easy to specify a plausible set of assumptions such as the following:

- Work hours per week reduced from the current 40 to 30 through adoption of the 6-hour day.

- Typical weeks worked per year reduced from 46 to 40, roughly the current level in Western Europe.

Together these two changes would reduce work time per year to 65 percent of current levels. A continuation of a variety of other historical trends—early retirement to pursue non-work interests, more college and graduate school retraining time, more leave time for child or elder care, etc.—could easily account for the remainder (- 15%). In sum, changes which in the aggregate produce a 50 percent reduction in work time are consistent with current policy trends, such as France's 35-hour work week, laws mandating minimum vacation levels in Europe, and policies that mandate family leave and make advanced education and retraining more available.

In the *GT* world substantial gains in productivity are also assumed. In the current low-income regions, the rates of growth are dramatic. However, for the high-income regions the rate of growth of productivity growth assumed is very modest. For example, in the *Policy Reform* scenario for North America the productivity growth rate assumed is only 1.65 percent per year, roughly the low end of historical experience. In the MF scenario the rate is higher, in line with historical experience. In contrast, the rate of productivity growth for North America assumed in the *Great Transition* scenario—60 percent between 2005 and 2100, or about .5 percent per year—is very low by historical standards. This is justified by assuming that capital investment is targeted to developing countries. Yet, because current productivity rates in North America are high, the gain in productivity is still massive. The absolute gain is roughly twice the size of the output per hour that the U.S. had in the early 1950s when it became the first "Affluent Society". Indeed, productivity in the U.S. did not reach a level equal to the absolute gain assumed in the *Great Transition* scenario until roughly 1973, the end of the post-war "golden era" of economic growth.

Values and Choices

In 2100 the income per capita assumed for North America is at roughly at the same level affluent level as France today. In the *Great Transition*, there is simply a decision made to take a reduction in work time, rather than "more stuff".

The *Great Transition* scenario differs from the *Conventional Worlds* scenarios in large part because it is shaped by value changes that stress well-being, solidarity, and environmental concerns. Individual actions and government policies are assumed to reflect these values to an increasing extent over time. These values have clear economic consequences. Environmental concerns motivate a reduction in global average income compared to living in *Conventional Worlds*, resulting in lessened environmental impacts. Solidarity, and particularly a desire to reduce hunger in developing areas, supports a regional pattern of income change with declines in the currently high income regions to provide "space" for income growth in the others, given land and other global natural

resource constraints. It is the fit, then, between the assumed income decline in the three high-income regions, and the pursuit of well-being in those regions, that stands in need of explanation.

Our claim is that the reduction in work time assumed for the developed regions is consistent with an informed pursuit of well-being, as well as with clearly stated public preferences. Further, the choice of economic outputs, occupations, and government policies in the *GT* world is likely to significantly moderate productivity growth.

Is it reasonable that, in the regions which currently enjoy high incomes, reductions in work time would be part of an informed pursuit of well-being? Research on the determinants of well-being shows that the answer is "yes." In studies that rate the sense of well-being experienced during a wide range of day-to-day activities, working and commuting rank next to last and last respectively. Reduced work time provides more time for family, friends, civic activities, and/or exercise, all of which have been shown to contribute more to well-being than foregone income subtracts.

The lower rate of growth in productivity in the *Great Transition* in high-income regions is, then, the result of the *GT* values, particularly the sense of solidarity, which leads to a preference for investment and growth in the low-income regions. In addition, the pursuit of well-being has a variety of effects, many of which are likely to reduce productivity:

- Security, provided by a strong social safety net, is a key source of well-being. The medical, educational, and social services that contribute to that safety net have low productivity.

- A focus on producing quality not quantity in food, clothing, shelter, and other goods and services is consistent with a sense of well-being in work. However, it will also often reduce productivity.

In these instances, the reduction in productivity is a good, not a bad, development because it is consistent with the informed pursuit of well-being. Finally, in the *Great Transition* world, consistent with Amartya Sen's view of self-determination as a key aspect of the pursuit of well-being, greater social input into investment decisions will also likely make the investment process less "efficient" (i.e., slower), thus reducing the pace of productivity growth.

Work and Consumption

GT values together with accompanying government policies are likely to produce a rather different pattern of consumption from that seen in the *Conventional Worlds*. The global convergence in income, reduction in income inequality in all regions, and environmental concern about global transport prevent the sourcing of low-cost goods and services from outside the region. The result is an economy in which all sectors—agriculture, industry, and services—will focus on quality not quantity in their output.

Equipment and structures are usually what is in mind when quality vs. quantity is discussed. Today however, real GDP, and so, income in the U.S. is about 56 percent services. Income in the North American *GT* world of 2100 is likely to break down in a roughly similar fashion—services will account for the bulk of it. Current practice in the service sector depends on the availability of labor for low-wage, low-skill jobs in service areas such as retailing and health care. In these areas the "tight" high-wage *GT* labor market in 2100 will force a shift to more skilled production. Thus, for example, eldercare facilities staffed largely by low-skilled/low-wage employees might be replaced by greater care in the home by relatives and friends who have more free time due to less work time. Their efforts would be guided by social service/medical workers skilled in setting up and maintaining home care. When considering the plausibility of this particular development it is useful to know that recent experimental research by psychologists has shown that the contribution to well-being of the family and friends who help is more substantial and enduring than that obtained from more self-centered activities.

In a *GT* world shaped by the values of well-being, solidarity, and environmental concern, and an economy with tight labor markets and a preference for quality goods and services, in many cases less will truly be more. Here the most obvious example is transportation. In the U.S. today transportation accounts for roughly 10 percent of real GDP, and, thus, income. Yet, the internalization of environmental externalities associated with travel is likely to raise its cost in a *GT* world. More importantly, travel is often a loss for those pursuing well-being. As noted earlier, commuting is the only common activity that ranks below work based on its immediate impact on one's sense of well-being. In the *Great Transition* world options such as "telecommuting" are likely to substantially reduce expenditures on travel. Settlement patterns seen today in "smart growth" plans—denser housing, mixed-use development, proximity to public transit—will also contribute. Synergies, such as greater opportunities for home elder care created by changing settlement patterns, will be an important part of the picture. Synergies will also raise the quality of the travel that does take place. For example, long stays away from home will be feasible given the reduction in weeks per year of work. Even longer trips, for study or service abroad, will be made possible by the reduction in work time, beyond that due to reduced hours per week and weeks per year. The shift just described, reducing frequent bad travel such as commuting, and increasing good travel, is a change from quantity to quality, as well as a key example in which "less is more".

Up and Down

In the *Great Transition* scenario, as noted above, income in the three high-income regions rises from current levels through 2050 and then falls, producing a modest net decline (See Figure 8-3). This pattern reflects the gradual adoption of *GT* values, as well as the associated changes in government policies and social norms over time. As values change, the focus is assumed to shift from ever greater material affluence to the pursuit of well-being. This, in turn, creates a strengthening preference for reductions in annual hours of work per capita. However, while the transition to the *Great Transition* scenario is values driven, in order for people to be comfortable acting on their changing values,

policies and economic arrangements which greatly disadvantage those who work less have to be reduced, as well.

Technology Factors

In most cases, it is assumed that the technological advancement in the *Policy Reform* scenario is as good as it could get by 2100. Thus, the *Great Transition* scenario, by default, uses the same technology parameters as the *Policy Reform* scenario, unless otherwise noted in the table of asymptotic states (Table 8-3). The differences in energy and water intensities that are chosen, therefore, do not reflect a difference in technology, per se, but rather a change in the values and habits of the future society that impact how the relevant technology is used. Thus, people will travel less, use or waste less water, etc., in a *GT* world.

Energy

Energy intensities and transport activity

For most sectors (industry, services, agriculture and transport), energy intensities in the asymptotic state are reduced to only about one-half the 2050 values in *Policy Reform* for Western Europe, given the relatively low levels of energy intensity already attained in that region by 2050, and taking into account likely improvements over today's technologies and consumption patterns. For energy conversion, future efficiencies are set to the "next generation" efficiencies that are introduced over the course of the *Policy Reform* scenario.

For households, energy requirements are split into a base requirement, which differs slightly by regional archetype, and a requirement for space heating, which also is set to vary by regional archetype . These two components are added together to give Household Energy Intensities.

More precisely, space heating is set with reference to the estimated numbers of heating-degree days in the temperate regions, shown in Table 8-4. As shown in Table 8-5, in 1995 the lowest energy intensity for space heating among the industrialized regions (per square meter of floor space and per degree day) was in Japan. For the asymptotic state, heat requirements are set for each archetype to a value that might encompass the variety of climates that are represented. Realistically, however, a colder climate may result in higher heating requirements, and a warmer climate may require less heating, but we only aim to get at the overall global average through the setting of this regional archetype average asymptotic state.

Table 8-4. Regional and national heating degree-days

Region	Heating Degree-Days	Representative Values
North America	2,500	U.S.: 2,500
Western Europe	2,750	Estimate for 6 European countries (Lazarus et al., 1993): 2,760
China	1,500	Beijing: 2,909; Taipei: 114
Transitional	4,600	Estimate for FSU of 4,600 (Lazarus et al., 1993)
Japan	1,750	Tokyo: 1,742

Table 8-5. Energy intensities for space heating, circa 1995

Region	Est. Useful Energy Requirement (GJ/cap)	Useful Energy Intensity (KJ/sq m /degree day)	Residential Floor Area/cap (sq m/cap)
North America	14.4	105	55
Western Europe	12.4	125	36
Japan	3.2	60	30

Notes: Figures are based on IEA (1997c). "Useful energy" is efficiency-corrected for different fuels (liquids and gases, 66% efficient, solids 55%).

For transport activity levels, freight activity intensities in the asymptotic state (given in tonne-km/$GDP) are set to low levels roughly consistent to one-half or less those of Pacific OECD in 2005, depending on the mode.

Fuel shares

Fuels are entirely renewable in all sectors in the asymptotic state, consistent with the goal of environmental sustainability that underlies the *Great Transition* scenario. The choice of fuels depends on the sector, as shown in Table 8-3.

For the industrial sector, fuel shares in the scenario largely follow those of the *Policy Reform* scenario out to 2050.

Water

Water intensities in the asymptotic state are based on "best practice" intensities assumed in the *Policy Reform* scenario.

Potential efficiency improvements in agriculture are set to equal the *Policy Reform* assumptions in all regions, which is a break from the previous version of Polestar scenarios, because it is believed that the technology in *Policy Reform* will maximize all efficiencies. Additionally, in the *Great Transition* scenario we no longer have the "crop-

per-drop" factor increase more rapidly with yields than in either the *Market Forces* or *Policy Reform* scenarios.

Agriculture and Land

Dietary patterns are based on those for Japan today, which has the lowest calorie consumption per capita of all the industrialized countries, and a low level of meat consumption. A caloric intake of 2,900 to 3,100 kcalories/capita/day is assumed for the asymptotic states of the three archetypes. These values are close to the 1995 level in Japan, and is also the "best practice" level of consumption for high-income countries estimated by Bender (1997). The fraction of meat in diets in the asymptotic state (10% - 20%) is less than the total in Japan, where in 1995 9% of dietary calories are derived from fish, and 19% from other animal products. The asymptotic value is low for OECD regions, but is consistent with the goal of low-impact consumption in the *Great Transition* scenario.

Lower levels of meat consumption reduce the pressure of livestock on land resources. Additionally, there is a modest shift toward greater use of mixed farming systems. Using crop by-products as feed, and manure as fertilizer, mixed farming systems reduce requirements both for feed concentrates and grazing land, relative to the *Market Forces* and *Policy Reform* scenarios.

The area of the built environment per capita in the asymptotic state is slightly below the 2050 *Policy Reform* value for Western Europe. The value is consistent with the preference for relatively compact settlement patterns, combined with relative affluence, that characterize the asymptotic state of the *Great Transition*.

Recycling in the Great Transition is set to the same value in 2100 as in the *Policy Reform* scenario, at 80% of all paper and pulp needs.

These assumptions lead to a reduction in agricultural land and an increase in natural forest area in the *Great Transition* scenario, as shown in Table 8-6.

Table 8-6. Land-use change in the *Great Transition* scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
OECD		3094						3094		
	Built Env	80	3%	(20)				61	2%	-0.4
	Cropland	380	12%	6	(32)			354	11%	-0.6
	Grazing and Pasture	724	23%	14	33	(63)		707	23%	-0.4
	Natural Forest	958	31%	0	0	(13)	(20)	925	30%	-0.7
	Plantation	39	1%	0	0	0	33	72	2%	0.7
	Protected (non-forest)	292	9%	0	0	0	0	292	9%	0.0
	All Other	621	20%	0	(1)	77	(13)	683	22%	1.4
Non-OECD		9928						9928		
	Built Env	226	2%	110				336	3%	2.5
	Cropland	1163	12%	(113)	(46)			1004	10%	-3.5
	Grazing and Pasture	2627	26%	2	117	(508)		2237	23%	-8.7
	Natural Forest	2994	30%	0	(7)	8	(74)	2921	29%	-1.6
	Plantation	63	1%	0	0	0	111	174	2%	2.5
	Protected (non-forest)	935	9%	0	0	0	0	935	9%	0.0
	All Other	1921	19%	0	(63)	500	(37)	2320	23%	8.9

Table 8-6 Continued. Land-use change in the *Great Transition* scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
World		13022						13022		
	Built Env	306	2%	91				397	3%	2.0
	Cropland	1542	12%	(107)	(78)			1358	10%	-4.1
	Grazing and Pasture	3351	26%	16	149	(572)		2944	23%	-9.0
	Natural Forest	3952	30%	0	(7)	(5)	(93)	3846	30%	-2.4
	Plantation	102	1%	0	0	0	144	246	2%	3.2
	Protected (non-forest)	1227	9%	0	0	0	0	1227	9%	0.0
	All Other	2541	20%	0	(64)	577	(50)	3004	23%	10.3

9 A Fortress World Scenario

Overview

The *Fortress World* scenario presents a world in which the stresses engendered by *Market Forces* overwhelm the capacity of either the market system itself or of the few *Policy Reforms* that are implemented. In order to prevent a complete collapse, an elite imposes authoritarian rule on the majority, and manages critical resources. In the end, a measure of stability is reached, but at the cost of extreme social polarization. Detailed outputs for the scenario are available online at http://tellus.org/programs/integratedscenarios.html.

The strategy used in developing the *Fortress World* scenario is to define something similar to an asymptotic state to be reached in 2100, as done in the *Great Transition* (see Section 8, p. 291). This asymptotic state includes a certain mix of two regional archetypes for each of the 11 geographic regions in the analysis. This state will be reached gradually, as a blending of the *Market Forces* parameters with the parameters of the new *Fortress World* asymptotic state.

Assumptions

Methodologically, in order to study the development of such a world within a quantitative scenario, the global population is separated into "rich" and "poor," where the proportion of the population that is rich and poor differs by region. The proportions of rich and poor regional archetypes are set to reach a specified mix by 2100, as shown in Table 9-1 below.

As the scenario progresses, the rich population in all regions follows a trajectory similar to that of the industrialized regions under *Market Forces*, while the poor population tends toward extreme absolute and relative levels of poverty. The two archetypes of "Rich" regions and "Poor" regions are defined by taking some of the parameters directly from the *Market Forces* scenario. Specifically, the asymptotic values set for a variety of parameters in 2100 are a blend of 2050 *Market Forces* values, with the North America value representing the rich portion, and *Africa* representing the poor. This scenario represents global convergence between regions in some ways, and social divergence within regions. But the convergence is partial: only the world's elites live in a truly connected, globalized world.

Table 9-1. Regional mix of archetypes in 2100

	Rich	Poor
North America	40%	60%
Western Europe	35%	65%
Pac OECD	30%	70%
FSU	20%	80%
Eastern Europe	20%	80%
Africa	5%	95%
Latin America	20%	80%
Middle East	20%	80%
China+	20%	80%
South Asia	10%	90%
Southeast Asia	10%	90%

Table 9-2. Convergence toward *Fortress World* asymptotic states

Percent of the *FW* state mixed with the *Market Forces* state				
Region	2005	2025	2050	2100
North America	0%	10%	50%	100%
Western Europe	0%	10%	50%	100%
Pac OECD	0%	10%	50%	100%
FSU	0%	10%	50%	100%
Eastern Europe	0%	10%	50%	100%
Africa	0%	10%	50%	100%
Latin America	0%	10%	50%	100%
Middle East	0%	10%	50%	100%
China+	0%	10%	50%	100%
South Asia	0%	10%	50%	100%
Southeast Asia	0%	10%	50%	100%

In general, all parameters that were defined for the *Great Transition* scenario in Table 8-3 (See Chapter 8) are set in the *Fortress World* scenario by taking the *Market Forces* values for North America and Africa in 2050, as discussed above. The comparable values for the "rich" and "poor" regions are shown in Table 9-3 below. Where an asymptotic value is not set for a particular parameter, the default is to equal the values used in the *Market Forces* scenario. All other exceptions will be discussed in this section below.

Table 9-3. Characteristics of FW asymptotic state (reached in 2100)

Variable		Rich	Poor	Units
Macro				
Income	GDP per capita	90,000	5,000	$/cap (2005 PPP)
Income inequality	Hunger	0.7	15.7	% of pop
Sector Share of GDP	Industry	calculated by Ind VA per cap		
	Services	remainder		
	Agriculture	calculated by Agr VA per cap		
	Other/Energy	Base year value		
Agr Value Added per Cap by Sector	Agriculture	487	405	$/cap (2005 PPP)
Ind Value Added/Cap by Sector	Iron and steel	311	84	$/cap (2005 PPP)
	Non-ferrous metals	86	15	$/cap (2005 PPP)
	Stone, glass and clay	234	51	$/cap (2005 PPP)
	Paper and pulp	692	99	$/cap (2005 PPP)
	Chemical-Energy	1557	279	$/cap (2005 PPP)
	Other	8635	1328	$/cap (2005 PPP)
Households				
Energy intensity	Total	38.9	12.9	GJ/cap
	Heat/Other	12	4	
Fuel choice		various	various	
Water intensity		165	33	m3/cap
Connection to Sewerage		100	33	%
Wastewater Treatment		100	33	% of urban wastewater treated
BOD Removed in water treatment		80	61	%

Table 9-3 Continued. Characteristics of FW asymptotic state (reached in 2100)

Passenger Travel				
Average distance by mode	Private road	32,314	1,172	pass-km/cap
	Public road	1,701	1,724	pass-km/cap
	Rail - Fossil	45	8	pass-km/cap
	Rail - Electric	176	26	
	Air	11,239	364	pass-km/cap
Fuel choice	Road	various	various	
	Rail	various	various	
	Air	various	various	
Energy intensities	Varies by mode	various	various	
Freight Transport				
Freight Intensity	Road	0.15	0.09	tonne-km/PPP$ GDP
	Rail - non-Electric	0.19	0.06	tonne-km/PPP$ GDP
	Rail - Electric	0.00	0.01	tonne-km/PPP$ GDP
	Water	0.51	0.70	tonne-km/PPP$ GDP
Fuel choice	Road	various	various	
	Rail	various	various	
	Air & water	various	various	
Energy intensities	Varies by mode	various	various	

Table 9-3 Continued. Characteristics of FW asymptotic state (reached in 2100)

Services				
	Energy intensity	0.4	0.5	MJ/$ value added
	Fuel choice	various	various	
Industry				
Energy intensities	Iron and steel	6.0	8.4	MJ/$ value added
	Non-ferrous metals	15.9	16.7	MJ/$ value added
	Stone, glass and clay	8.0	4.9	MJ/$ value added
	Paper and pulp	7.8	1.1	MJ/$ value added
	Chemical-Energy	4.0	1.0	MJ/$ value added
	Chemical-Feedstocks and Other-Non Energy			MJ/$ value added
	Other	1.7	4.5	MJ/$ value added
Water intensity	varies by subsector	various	various	
	Fuel choice	various	various	
Energy Conversion				
Efficiencies	Elec Gen - Coal	0.37	0.41	
	Oil	0.42	0.41	
	Nat Gas	0.44	0.46	
	Biomass	0.31	0.31	
	Nuclear	0.33	0.33	
	Renewables	1	1	
	Dist Heat -All Fuels	0.9	0.9	
	Oil Refining -All Fuels	0.95	0.95	
	Alcohol Prod -All Fuels	0.7	0.7	
	H2 Prod - All Fuels	0.8	0.8	
	Fuel choice	Various		
	Water intensity	Various		

Table 9-3 Continued. Characteristics of FW asymptotic state (reached in 2100)

Agriculture			
Daily food consumption	3,636	2,816	kcal/cap/day
Fraction of calories from animals	0.29	0.09	
Water intensity	Various based on maximum irrigation technology improvement		
Energy intensity	4.3	1.1	MJ/$ value added
Land and Forestry			
Built environment per capita	0.14	0.07	ha/cap

Economics and Demographics

Population projections in all regions are based on the UN medium variant (UN, 2006a), but are increasingly higher in each scenario year. In 2025, *Fortress World* populations are 2% higher than the UN medium variant population projections, in 2050 they are 5% higher, and by 2100 they are 10% higher.

The income of the rich populations in each region are set approximately equal in 2100 the *Market Forces* North America value in 2050, or $90,000 US PPP per capita. In the poor populations, the incomes are set approximately equal in 2100 the *Market Forces* Africa value in 2050, or $5,000 US PPP per capita. The resulting income trajectories are shown in Figure 9-1.

These assumptions lead to changes in average income that are sometimes surprising. Figure 9-2 shows how the *Fortress World* and *Market Forces* OECD and non-OECD average incomes compare throughout the scenario period. The assumption of convergence in the *Fortress World* scenario leads to a much more equitable distribution of income between non-OECD and OECD regions when taken as a whole, with the ratio of average non-OECD income to average OECD income reaching 0.43 in 2100, which is nearly as high as the *Policy Reform* result of 0.45, and nearly twice the value of the *Market Forces* result of 0.23. However, when comparing the rich to the poor within each region, the true depth of inequity in the *Fortress World* scenario becomes apparent.

Figure 9-1. GDP per capita in the *Fortress World* scenario

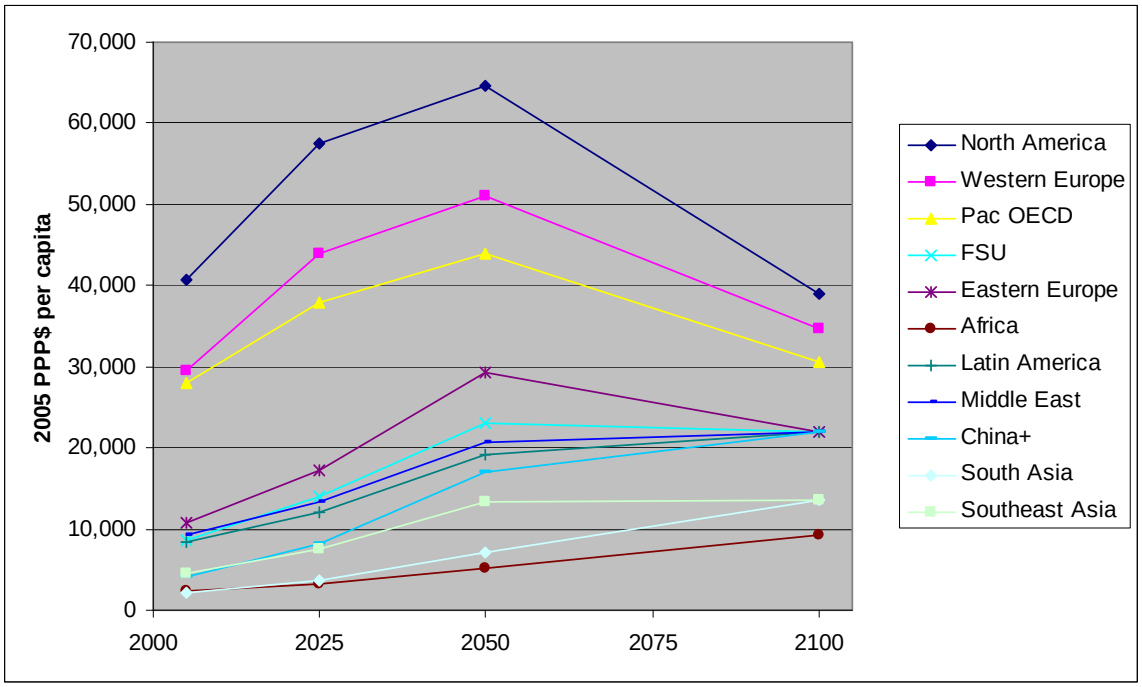
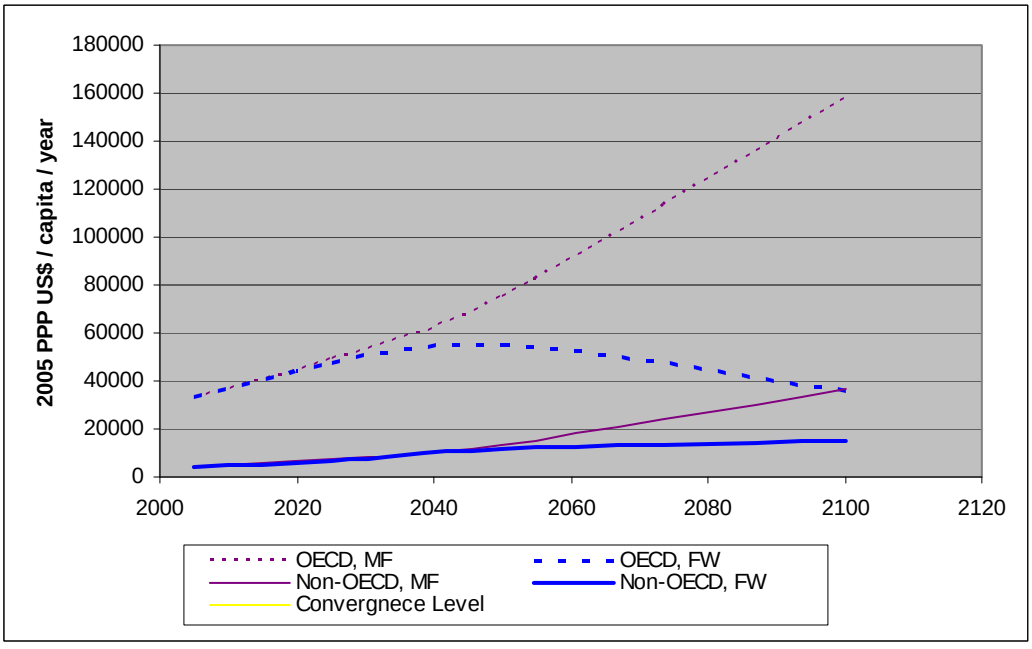


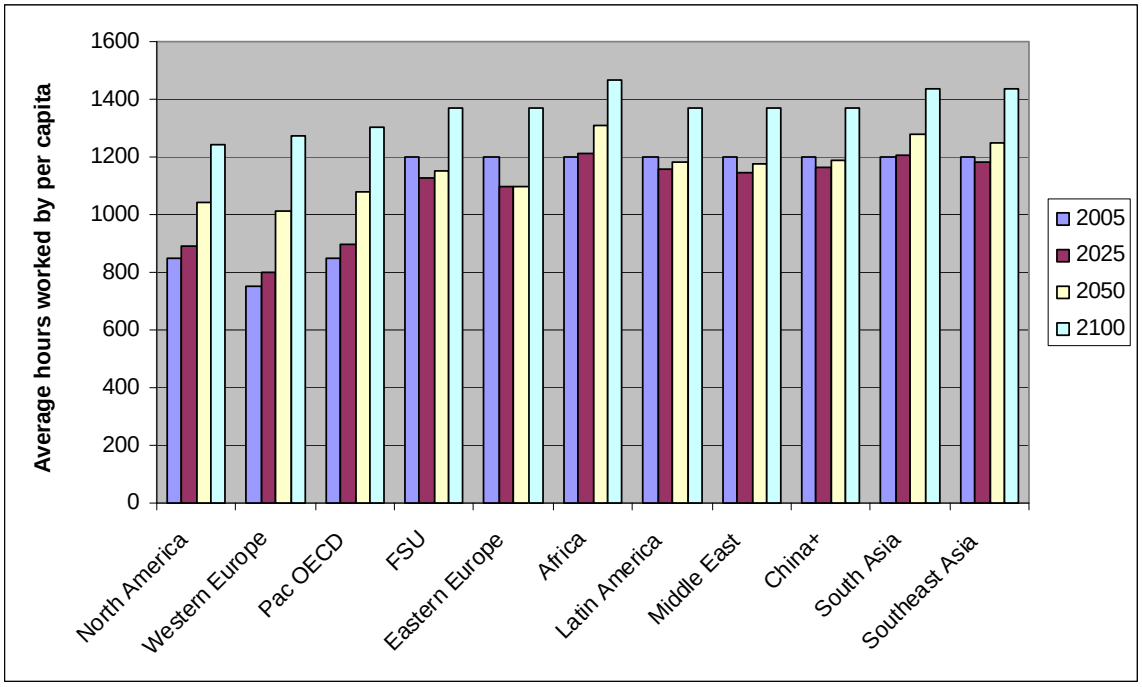
Figure 9-2. Macro-regional incomes in *Market Forces* and *Fortress World*



Work and Consumption

The average hours worked per capita are calculated using the same methodology as the rest of the *Fortress World* scenario. The poor population, however, are set to a value that is greater than Africa in *Market Forces* 2050, to a level of 1500 hours per capita per year, to represent the increased need for work, such as scavenging for food, water, and other resources, that a *Fortress World* may require from many of the poor. The results of this are shown in the following graph.

Figure 9-3. Average annual hours worked per capita in *Fortress World*



Energy and Water Use

In the sectors detailed in Table 9-3, the remaining usage intensities for the poor and rich populations are set according to the method described in detail above. The same methodology is applied to passenger transport usage patterns. Note that these usage patterns in the *Fortress World* scenario often lead to a sharp decline in average energy or water intensity. However, this is not a reflection of increasing efficiency, but of deepening poverty.

In other sectors, economic output is usually the driver of energy use. For the sectors of the economy in the *Fortress World* scenario, shifts in activity are already accounted for by the economic growth assumptions and the distribution of output. Intensities in these sectors are, therefore, given by the same methodology as for the *Market Forces* scenario.

Agriculture and Land

Diets in the rich and poor populations diverge from one another, even as they converge separately within the poor and rich populations. Amongst the rich, caloric intake converges over the scenario to the pattern seen in North America in the base year of 2005, closing 75% of the base-year gap by 2050. The poor also converge, but toward the much lower level of caloric intake in Latin America. The pattern for Latin America is chosen, because as average incomes in the poor population change in the scenario, they tend toward the average income in Latin America today.

Crop yields are set to the *Market Forces* rate. The rate of cropland abandonment is the same as in the *Market Forces* scenario, as degraded and marginal land that would have been abandoned under *Market Forces* conditions continues to be used. Yields increase on average, as the elite control productive cropland and engage in agricultural trade. Livestock production sees a retreat from industrial practices, with a greater use of informal feed sources and a significant expansion in grazing land, with much slower growth in purchased feed. Increases in livestock productivity are set to the same values as in the *Market Forces* scenario.

Growth in the built environment, driven by large population increases and increasing sprawl, causes the area of natural forest to drop significantly.

The resulting land-use change is shown below in Table 9-4.

Table 9-4. Land-use change in the *Fortress World* scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
OECD		3094						3094		
	Built Env	80	3%	29				109	4%	0.6
	Cropland	380	12%	(9)	80			451	15%	1.6
	Grazing and Pasture	724	23%	(20)	(84)	88		708	23%	-0.4
	Natural Forest	958	31%	0	0	(96)	(98)	764	25%	-4.3
	Plantation	39	1%	0	0	0	116	155	5%	2.6
	Protected (non-forest)	292	9%	0	0	0	0	292	9%	0.0
	All Other	621	20%	0	4	8	(17)	615	20%	-0.1
Non-OECD		9928						9928		
	Built Env	226	2%	340				565	6%	7.6
	Cropland	1163	12%	(191)	145			1117	11%	-1.0
	Grazing and Pasture	2627	26%	(138)	(235)	(160)		2095	21%	-11.8
	Natural Forest	2994	30%	(6)	(6)	(235)	(229)	2520	25%	-10.5
	Plantation	63	1%	0	0	0	262	325	3%	5.8
	Protected (non-forest)	935	9%	0	0	0	0	935	9%	0.0
	All Other	1921	19%	(6)	96	394	(34)	2371	24%	10.0

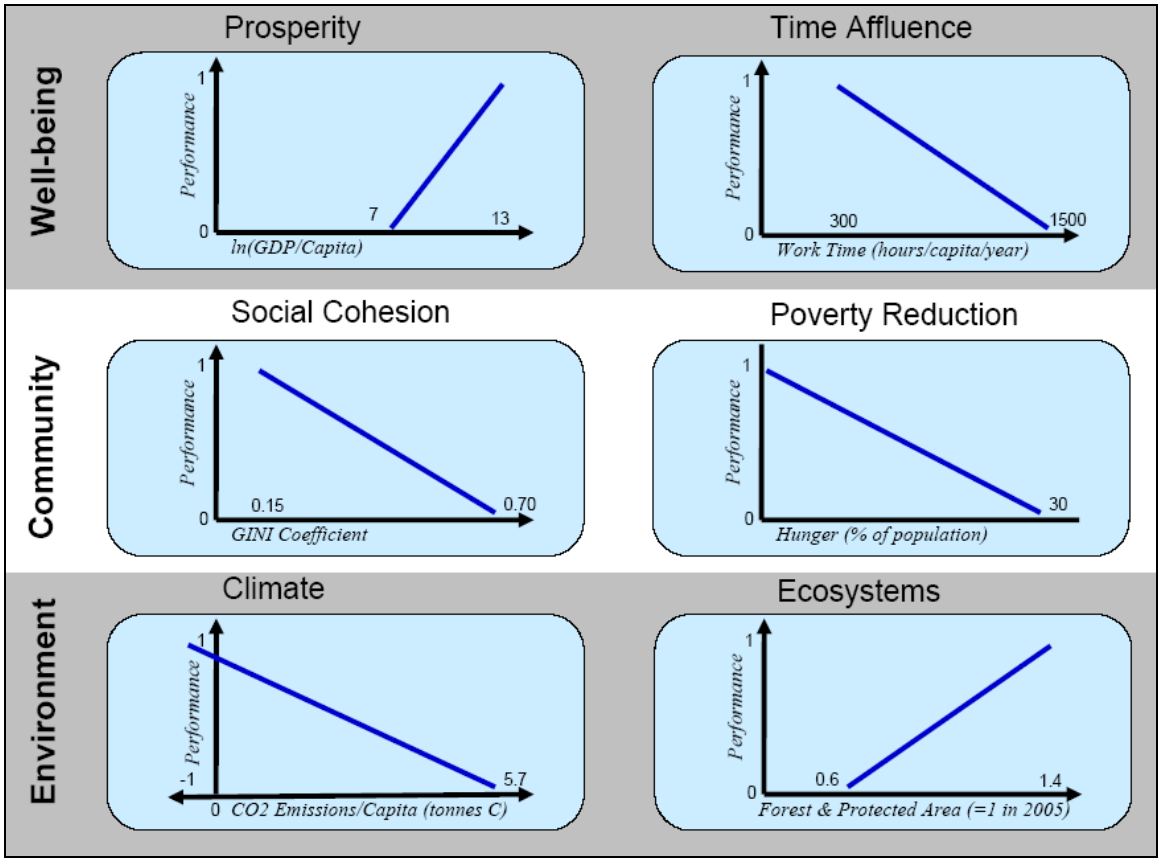
Table 9-4 Continued. Land-use change in the *Fortress World* scenario

Area in Mha				Increase(decrease) in conversions to (from)						
Region	Land Use	Area in 2005	Share of Area in 2005	Built Env	Cropland	Grazing Land & Pasture	Forest	Area in 2050	Share of Area in 2050	Avg Rate of Change (Mha/yr)
World		13022						13022		
	Built Env	306	2%	369				675	5%	8.2
	Cropland	1542	12%	(200)	225			1568	12%	0.6
	Grazing and Pasture	3351	26%	(158)	(319)	(71)		2803	22%	-12.2
	Natural Forest	3952	30%	(6)	(6)	(331)	(327)	3283	25%	-14.9
	Plantation	102	1%	0	0	0	378	480	4%	8.4
	Protected (non-forest)	1227	9%	0	0	0	0	1227	9%	0.0
	All Other	2541	20%	(6)	100	402	(51)	2986	23%	9.9

10 Quality of Development Index

The Quality of Development Index (QDI) is a comprehensive metric of development that incorporates economic, social, and environmental components. The structure of the QDI is indicated in the graphic in Figure 10-1. It consists of the three sub-indices at the left of the graphic: Well-being, Community, and Environment. Each of these sub-indices is composed of two additional indicators as shown in the corresponding row.

Figure 10-1. Quality of Development Index (QDI) components



Methodology

Using standard index development procedures,[37] each of the six indicators runs along a *performance* (P) scale from zero to one (the y-axis) as a metric variable (M) runs along the x-axis between lower (L) and upper (U) limits. For each indicator, P takes the following vales when an increase in M is associated with progress in development:

$$P = \begin{cases} 0 & \text{when } M < L \\ (M-L)/(U-L) & \text{when } L \leq M \leq U \\ 1 & \text{when } M > U \end{cases}$$

and the following values when an increase in M is associated with a deterioration in development:

$$P = \begin{cases} 1 & \text{when } M < L \\ (M-U)/(L-U) & \text{when } L \leq M \leq U \\ 0 & \text{when } M > U \end{cases}$$

We calculate the value of each P for each region. The sub-indices are then computed as weighted averages of the component indicators. Finally, the QDI is computed as a weighted average of the three sub-indices. For the basic scenario runs, indicators are given equal weights (50%) to form the sub-indices and the sub-indices are given equal weights (33.3%) to form the QDI. The weights may be altered by the user to create new indices or test for sensitivity. Global values are computed by population-weighting regional values, except for the global Ecosystem indicator where the ratio of total world forest and protected land area to the base year values are used.

Table 10-1 below summarizes the procedures and assumptions used to develop the QDI. The first two columns list the sub-indices and their component indicators. The third identifies the metrics. The final two columns provide the lower and upper bounds (i.e., the values of L and U) used in the rescaling. For all but the first metric, increases in the metrics correspond to deterioration, not progress in development.

[37] For an illustration of the calculation of the Human Development Index, see (UNDP, 2003) p. 341.

Table 10-1. Structure of the QDI

Sub-index	**Indicator**	**Metrics**	**Boundaries***	
			Lower	**Upper**
Well-being	Prosperity	Ln (GDP/Capita)	7	13
	Time Affluence	Work Time	300	1500
Community	Social Cohesion	Gini Coefficient	0.15	0.7
	Poverty Reduction	% Hungry	0	30
Environment	Climate	CO_2/Capita	-1	5.7
	Ecosystems	Forest & Protected Land	0.6	1.4

*Units are shown on graphic on page 2.

Metrics are chosen to reflect the aspect of development with which they are associated.

Four of the six metrics (work time, percentage of the population below the hunger level, CO_2 emissions per capita, and the area of forest and protected land) provide transparent and straightforward driving variable for, respectively, time affluence, poverty reduction, climate, and ecosystem health. The GDP per capita, measured in purchasing power parity (PPP) dollars per capita, is the standard measure of income in macroeconomics. Use of its logarithm reflects the well-known diminishing impact of gains in income on well-being (see, e.g., the HDI).

The Gini coefficient as a metric for Social Cohesion is less transparent. As explained earlier in this report, the Gini is a commonly used variable to measure the extent to which the actual distribution of income deviates from equality. Income distribution depends on policy choices to aid the poor through social assistance and social security mechanisms (such as health care) and to pay for such aid in part through progressive taxation which reduces the share of income going to the rich. Such policy choices reflect social cohesion, that is a balancing of the interests of rich and poor by the electorate as a whole. Observations of this type, as well as various other analyses, have led development economists such as Easterly to identify the Gini coefficient as an “indirect measure” for social cohesion (Easterly, 2006). Further evidence on the linkage between income distribution and social cohesion has been provided by Wilkinson among others (Wilkenson, 1997).

Turning to the values of the metrics, GDP per capita, Gini coefficients, population below the hunger line, CO_2 per capita, and the area of forest and protected land are discussed elsewhere in this report. However, the variable we call Work Time requires explanation.

Worktime

Work Time is defined as the average number of hours worked per person across the whole population. Work Time is related to two other variables: GDP per capita and productivity (i.e., GDP per hour). As so defined, income equals productivity times work time.

Some of the literature on work time focuses on a different variables: hours per week and weeks per year worked by a "full-time equivalent" (FTE) worker under typical local conditions. In the U.S., for example, a 40-hour work week for 46 weeks per year is typical. However, this is not the full story. In any population, there are many above or below working age. Among those of working age, some work part time and others not at all. Participation (i.e., FTE per capita) is generally only 50 percent or less. It is the combined effect of work week, weeks per year, and participation that determines the contribution of work time to income.

Development of work time proceeds in three steps:

- Base year (i.e., 2005) values are specified. To avoid anomalous results the values for the current low-income (i.e., non-OECD) regions are adjusted.
- For the *Conventional Worlds* scenarios (MF and PR), future values are specified based on constant work time for the OECD regions and convergence for the others.
- For the Great Transition, values for 2100 for the three regional types are specified. Regional values for 2100 are based on the mix of types assumed for each region. Finally, values for 2025 and 2050 are developed by interpolation.

Base year data is available for the OECD regions (Conference Board, 2008). However, for many low-income countries, including India and China, no historical data on work time is available. Historic trends show that dramatic increases in work time accompany rapid urbanization and industrialization (Madison, 2001, p.354). Data suggesting low levels of work time in some developing countries may fail to record long hours of work in subsistence agriculture as well as rural under- and unemployment. To correct for this anomaly, base year work time in the non-OECD regions is set at a reference value of 1200 hours per year, a level consistent with values for Japan in the 1960s and '70s, and

Singapore and South Korea since the 1990s which reflect rapid urbanization and industrialization. This approach is similar to that used in long-term macroeconomic analysis in which output at "full capacity", rather than at actual levels, is considered. For the three high-income regions—North America, Western Europe, and Pacific OECD—there is no need for such an adjustment. Base year values are set, based on recent historical data, at 850, 750, and 850 hours per year, respectively.

Future values of work time in the *Conventional Worlds* scenarios, where global competition and the dogged pursuit of economic growth are assumed, remain at base year values in the OECD regions. Based on experience over the last 50 years, this is a mid-range assumption, bracketed by declines in Western Europe and modest increases in the U.S., Canada, and Australia. For the remaining regions, work time is determined by convergence: work time moves toward the average OECD-wide level as income converges to the OECD base year level.

In the *GT*, there is an assumed cultural emphasis on time affluence rather than material affluence. Consistent with historical experience over the last 100 years in Western Europe, a fall of roughly 50 percent by 2100 is assumed. The specific values—Agoria at 425, Ecodemia at 400, and Arcadia at 360—are consistent with the differing scenario narratives across these archetypal regions. To produce regional values for 2100, these are weighted by the mix of these archetypal regions assumed for each geographic region. Values for other years are determined by the usual weighting of the mix of *Policy Reform* scenario values and *GT* 2100 values (e.g., GT at 10 percent in 2025 and 50 percent in 2050).

The *Fortress World* scenario employs a similar methodology as the *GT* scenario described above. For the *Fortress World*, each geographical region is made up of the assumed 'rich' and 'poor' areas. To define the work time scenario for the *Fortress World*, the 2100 geographic regional values are set as a particular blend of the rich population's work time of 850 average hours worked per capita and the poor population's 1500 hours. This results in an increase for all regions from the base year work time levels, ranging from 20 to 50% increase by 2100, depending on the mix of rich and poor in the geographical region. Values for the other scenario years are determined by the usual weighting of the *Market Forces* scenario values and the *Fortress World* 2100 values (e.g., *Fortress World* at 10 percent in 2025 and 50 percent in 2050).

Table 10-2. Worktime by scenario

Average number of hours worked per capita		Market Forces		Policy Reform		Fortress World		Great Transition	
	2005	2050	2100	2050	2100	2050	2100	2050	2100
North America	850	850	850	850	850	1045	1240	630	411
Western Europe	750	750	750	750	750	1011	1273	579	407
Pac OECD	850	850	850	850	850	1078	1305	629	407
FSU	1200	931	814	871	814	1151	1370	642	412
Eastern Europe	1200	821	814	811	814	1095	1370	611	412
Africa	1200	1155	1032	1144	990	1311	1468	764	384
Latin America	1200	998	814	948	814	1184	1370	672	396
Middle East	1200	975	814	919	814	1173	1370	653	386
China+	1200	1002	814	964	814	1186	1370	677	389
South Asia	1200	1128	894	1113	823	1281	1435	750	388
Southeast Asia	1200	1059	814	1029	814	1247	1435	708	388

The reductions in work time assumed in the GT are substantial. However, they are part of a reasonable, internally consistent picture of the economy for 2100. All three regions have labor productivity 60 to 80 percent higher than that in the U.S. today. “Progress” continues but at a slower rate than in the *Conventional Worlds*. As one moves from Arcadia to Ecodemia and then to Agoria, productivity in 2100 rises modestly, consistent with the scenario narratives for the three archetypes where Arcadia has the least and Agoria the most emphasis on material consumption. For North America the work time in 2100 of 411 hours per year is a substantial drop from the base year value of 850. This could be achieved by shifting to a 3-day, 7-hour-day work week and increasing the “weeks off” per year to current Western European levels. In a GT world nearly 100 years from now these shifts are plausible.

Results

The Quality of Development Index, and all of the discussed metrics and sub-indices, are calculated and displayed in the Indicators module of the model. The QDI results for each scenario are shown below in Figure 10-2, Figure 10-3, Figure 10-4, and Figure 10-5.

In the base year, 2005, QDI values range from the lowest in Africa at 0.37 to the highest in Western Europe at 0.64. The results show that in *Market Forces*, the quality of development decreases slightly in the OECD regions, while non-OECD countries improve generally by 2100 towards the OECD quality of development, resulting in 2100

with a QDI range of 0.49 to 0.59. *Fortress World* shows steady decline in all regions, reaching a QDI value of between 0.28 and 0.45 by 2100. In the *Policy Reform* scenario, there is a slight increase in the OECD regions' quality of development, and a stronger convergence from the non-OECD regions to the OECD level of development. The range of QDI values for the *Policy Reform* scenario by 2100 reach between 0.60 to 0.72. However this scenario does not show nearly as much improvement as the *Great Transition* scenario, where by 2100 all regions have reached a QDI of between 0.77 and 0.87, and the improvement comes sooner in the scenario.

In Figure 10-6, the global-level Quality of Development Index is shown, and the resulting behavior of the index follows the logic of the four scenarios, with *Great Transition* leading to the greatest improvement, followed by the *Policy Reform* scenario with a slower increase in the QDI. The *Market Forces* global QDI is close to level, but decreases slightly over the course of the scenario, and the *Fortress World* results shows a steady decline of the QDI, as would be expected.

Figure 10-2. QDI in *Market Forces*

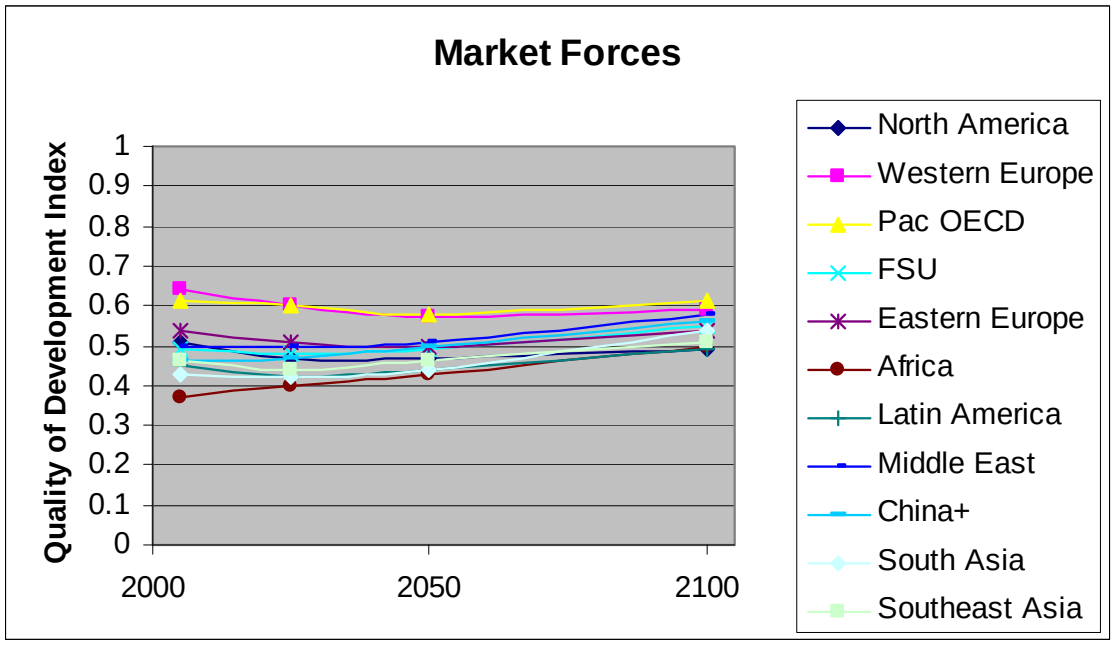


Figure 10-3. QDI in *Policy Reform*

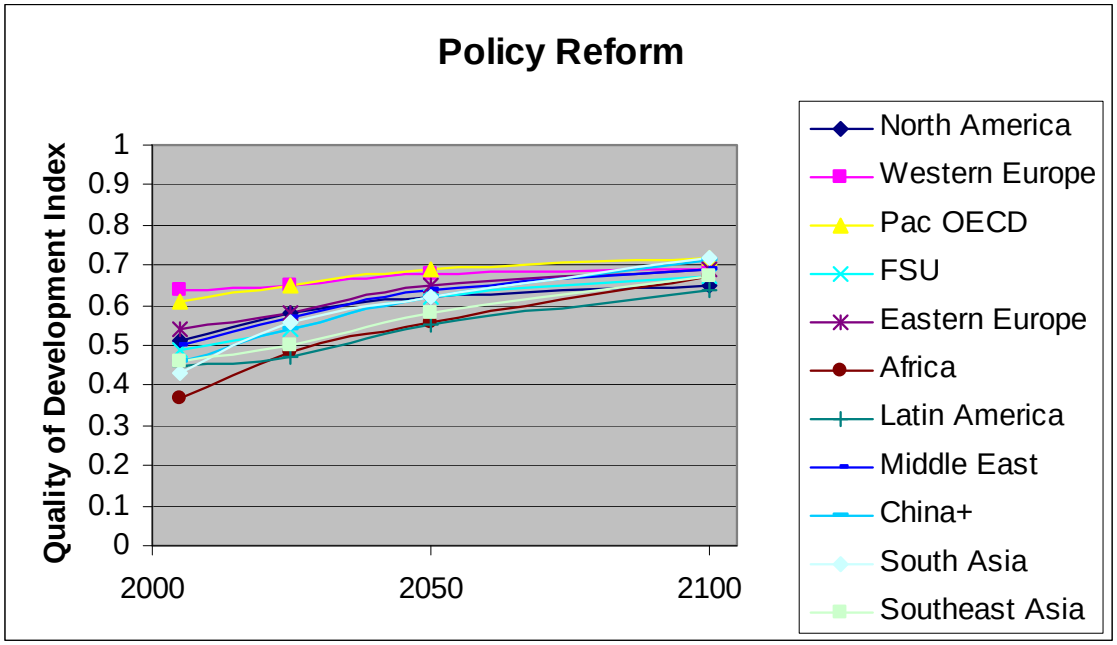


Figure 10-4. QDI in *Great Transition*

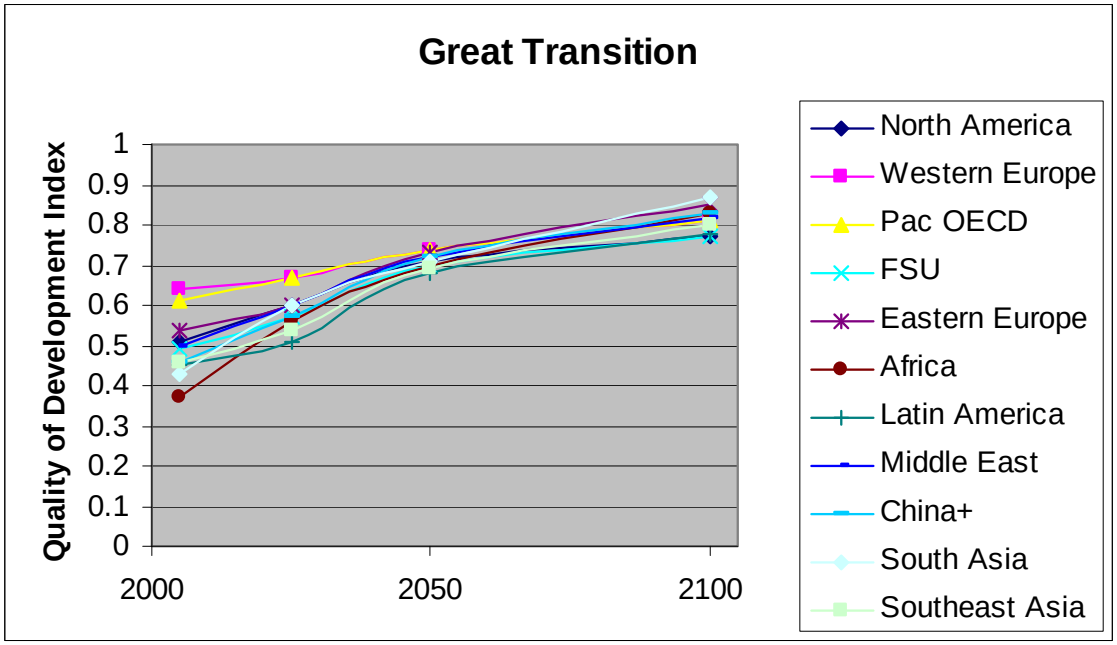


Figure 10-5. QDI in *Fortress World*

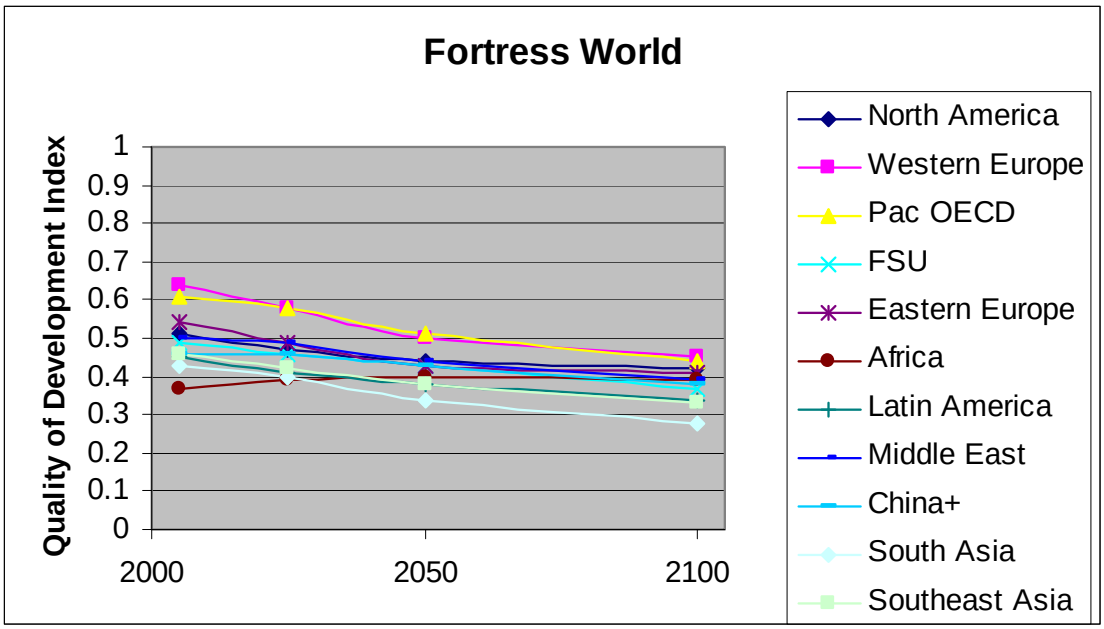
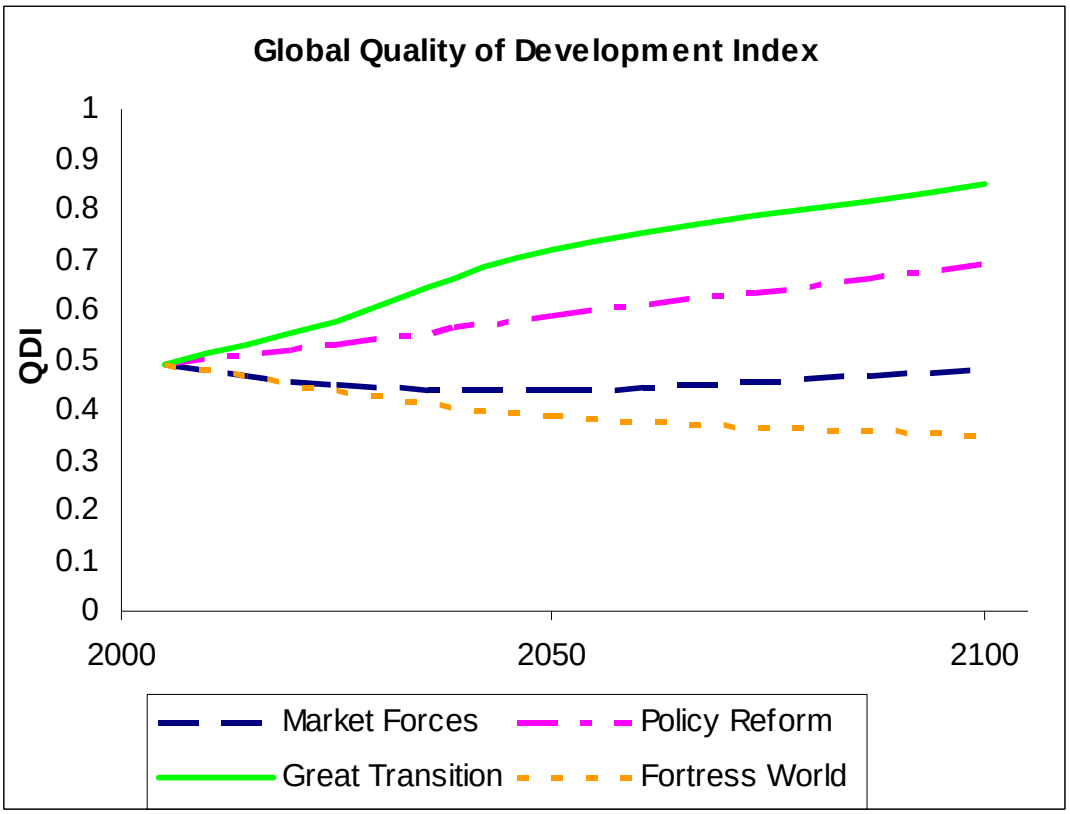


Figure 10-6. Global QDI



Annex

Annex 1. The Convergence Algorithm

A central feature of the *Conventional Worlds* scenarios is the gradual convergence of regional consumption patterns. To aid in the development of the scenarios, in several instances we used a *convergence algorithm*, which reflects the basic features of convergence.

The algorithm is based on the idea that, in the course of economic development, the structure of economies, certain activity levels (such as travel patterns) and intensities in non-OECD regions converge toward those of the highly industrialized societies with increasing GDP/capita. However, the non-OECD regions are not expected to recapitulate the history of the OECD regions; rather, they are expected to move more quickly along the development path, through technological "leapfrogging," as they take advantage of improved technologies and materials use that were not available earlier.

In mathematical terms, the algorithm used in the scenarios to reflect this behavior can be expressed as:

$$V_{r,2025} = V_{r,2005} + \left(V_{OECD,2025} - V_{r,2005}\right) \times \left(\frac{i_{r,2025} - i_{r,2005}}{i_{OECD,2005} - i_{r,2005}} \right) \quad \text{(A-1)}$$

and

$$V_{r,2050} = V_{r,2025} + \left(V_{OECD,2050} - V_{r,2025}\right) \times \left(\frac{i_{r,2050} - i_{r,2025}}{i_{OECD,2005} - i_{r,2025}} \right) \quad \text{(A-2)}$$

and

$$V_{r,2100} = V_{r,2050} + \left(V_{OECD,2100} - V_{r,2050}\right) \times \left(\frac{i_{r,2100} - i_{r,2050}}{i_{OECD,2005} - i_{r,2050}} \right) \quad \text{(A-3)}$$

where $V_{r,y}$ is the value of the value added share, activity level or intensity in region *r* in year *y*; $V_{\mathrm{OECD},y}$ is the average OECD value in year *y*; $i_{r,y}$ is the income (GDP/capita) in region *r* in year *y*; and $i_{\mathrm{OECD},y}$ is the corresponding average OECD value, or in some cases, the corresponding value of one of the OECD regions.[38]

The formulas produce a basic pattern of convergence, in that the regional value in the scenario year (2025, 2050, or 2100) approaches that of the OECD in the scenario year as the regional income increases; the linear dependence on income is chosen for simplicity. Moreover, the formulas reproduce the basic pattern of technological leapfrogging, because the regional value converges to the OECD value as the regional GDP/capita approaches that of the OECD in the *base year*, rather than the scenario year, arriving at the OECD level at a lower income than in the OECD. Table A-3 shows the convergence factors calculated in the scenarios

Table A-1: Scenario convergence factors

	Market Forces			*Policy Reform*		
Non-OECD Region	2025	2050	2100	2025	2050	2100
FSU	0.25	0.69	2.25	0.30	0.84	2.80
Eastern Europe	0.33	0.97	3.37	0.41	1.19	4.19
Africa	0.04	0.11	0.43	0.05	0.14	0.54
Latin America	0.17	0.52	1.64	0.22	0.65	2.07
Middle East	0.20	0.58	1.74	0.25	0.72	2.20
China+	0.16	0.51	2.08	0.18	0.60	2.55
South Asia	0.05	0.19	0.79	0.07	0.22	0.98
Southeast Asia	0.12	0.36	1.37	0.14	0.44	1.70

Notes:

1. In any given column, the convergence factor is the following ratio:

$$\left(\frac{i_{r,\,futureyear} - i_{r,2005}}{i_{OECD,2005} - i_{r,2005}} \right)$$

2. A scenario convergence factor greater than 1 represents the fact that the income of that region has surpassed the OECD average income in the base year. This means that full convergence has occurred. Thus, in 2100 where many values are far greater than a 1, those regions have reached the OECD-average value of whatever variable was converging.

[38] Note that in some cases, as noted in the text, the non-OECD regions are set to converge to a particular OECD region, most often Western Europe which often has lifestyle patterns thought to a be more likely future development in the non-OECD regions.

Annex 2. Sensitivity Analyses of Hunger Line Use

This Annex provides the sensitivity analysis that was presented with the previous version of these Technical Notes (Kemp-Benedict, et al., 2002).

In the *Market Forces* scenario, changes in the level of hunger follow from the model described above, as well as scenario assumptions about key variables. In this section, we explore the sensitivity of the *Market Forces* scenario results to some of the model parameters and assumptions. In addition, we ask how the model performs when applied to historical data.[39]

Sensitivity to Base Year Gini Coefficients

Data on income distribution are relatively scarce. In order to get the fullest coverage possible for each region, we expanded the set of Gini coefficients using two procedures. First, as explained in the previous section, we used the most recent results of surveys carried out between 1985 and 1995. Second, although Gini coefficients from income surveys were used when they were available, in several cases it was necessary to use Gini coefficients estimated from expenditure surveys. The scenario hunger estimates could potentially be sensitive to either of these procedures. Data limitations prevented us from testing the sensitivity to the first procedure – the use of data from multiple years. We present the results of sensitivity studies of the second procedure.

According to Deininger and Squire (1996), expenditure survey Gini coefficients tend to be lower than ones estimated from income surveys by about 6.6 percentage points, a difference which could affect the estimated hunger levels. To test the sensitivity of the *Market Forces* scenario result to the inclusion of Gini coefficients from different types of surveys, all expenditure survey Gini coefficients were increased by 6.6 percentage points. This produces slightly lower global average values for *national equity* (population-weighted average low/high ratios) in 1995. Under *Market Forces* scenario assumptions, hunger in 2050 is 7% higher with the adjusted Gini coefficients than with the unadjusted coefficients. The basic conclusion of persistent poverty in the *Market Forces* scenario remains unchanged.

Dependence of the Hunger Line on Average Income

A key element in determining hunger levels in the scenarios is the hunger line, as shown in Equation (2-10). Different assumptions about the way hunger lines change in the scenarios could have a significant effect on the estimated hunger levels. The reasonableness of the method for projecting hunger lines used for this study is tested

[39] Note that the analysis in this section was applied to an earlier study, *Bending the Curve* (Raskin et al., 1998). However, it is not expected that the conclusions would change significantly using the figures in this study.

here: by studying the sensitivity of the *Market Forces* scenario result to different values for the regression parameters in Figure 2-7 on page 27, and by applying the methodology to historical data.

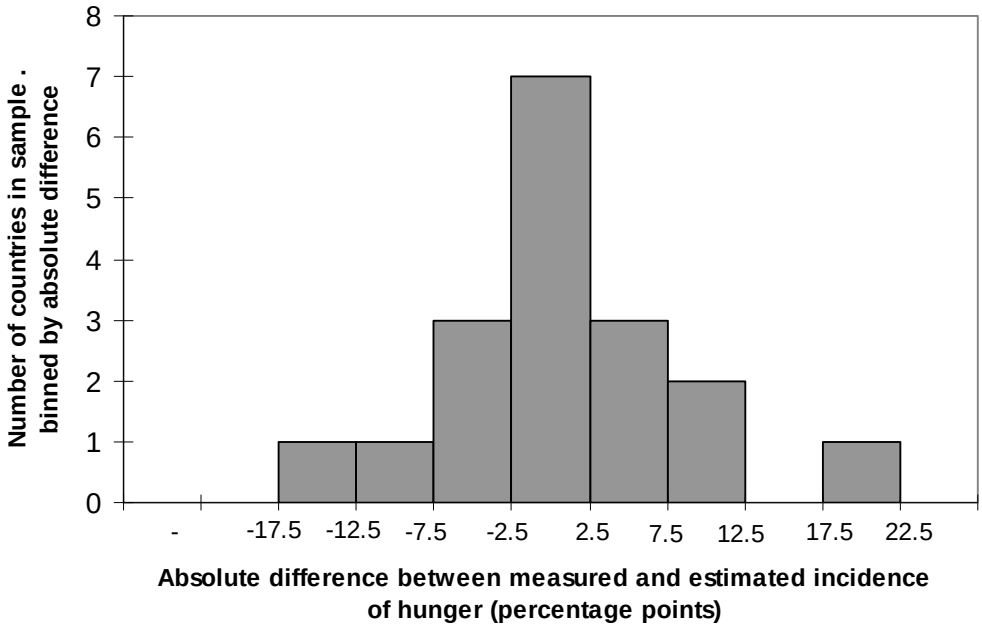
The parameters in the regression line shown in Figure 2-7 have standard errors associated with them, reflecting the degree of scatter around the regression line. The standard error for the slope is 16% of its value, or 0.02. Adding this to the slope, hunger in 2050 is 14% higher under *Market Forces* scenario assumptions. Subtracting the standard error from the slope, hunger in 2050 is 13% lower. The quantitative value for the hunger level is therefore somewhat sensitive to changes in this parameter, in that a given percent change in the slope leads to roughly the same percent change in the level of hunger in 2050. However, the qualitative picture of widespread poverty persisting into the next half-century remains the same, when the slope is varied within its standard error. The sensitivity to the intercept is much less than the sensitivity to the slope. Adding or subtracting the standard error of $66 for the intercept to its value of $480 leads to only a 1% change in the estimated hunger level in 2050 in the *Market Forces* scenario.

Comparison to Historic Data

For a few countries, historical data are available for hunger, income distribution and GDP per capita adjusted for purchasing power parity: FAO estimates of the incidence of hunger are available for 1969-71 and 1990-92 (FAO, 1997a); the income distribution data set of Deininger and Squire (1996) contains values for multiple years for some countries, and for some countries Gini coefficients estimated from the same type of survey are available for years close to 1970 and 1991; finally, historical values for GDP_{PPP} per capita are available for many countries (WRI, 1996). Using these data it is possible to apply the methodology described in the previous section to a 1970 base year, to construct estimated hunger levels for 1991. We performed this calculation for 18 countries. The difference between the estimated and measured incidence of hunger in 1991, as a percentage of the population, are shown in Figure A-2. Generally, the methodology performed well. For 13 of the 18 countries, or over 70% of the sample, the estimated value is within plus or minus 7.5 percentage points of the measured value. Furthermore, the symmetry of the distribution in Figure A-2 below suggests that there is no inherent bias toward high or low values. For all but two of the countries the estimated value is within 10 percentage points of the measured value. For two of the countries (Bangladesh and the Philippines) the approach used for this study did very poorly in explaining historical patterns, with the difference between the estimated and measured values exceeding 10 percentage points.[40] In the case of Bangladesh the methodology led to an underestimate of the actual hunger level, while for the Philippines it led to an overestimate.

[40] Note that large discrepancies between the estimated and measured incidence of hunger could result from several possible causes: failure of the model, errors in the data, or historical policy interventions (for example, a targeted food aid program introduced between 1970 and 1991).

Figure A-2. Hunger methodology applied to historical data



Changing U.S. Gini Coefficient Trends

In the *Market Forces* scenario, the Gini coefficient in the United States rises at half its historical rate of increase, while Gini coefficients for the other countries move gradually toward the U.S. pattern. The assumption of global convergence is fundamental to the *Conventional Worlds* story, but certainly other assumptions could have been made about the course the U.S. Gini coefficient follows in the scenario. This would be problematic if global hunger levels in the *Market Forces* scenario are sensitive to small changes in the rate of increase of the U.S. Gini coefficient. However, they are not very sensitive: increasing or decreasing the U.S. rate by 10% leads to an increase or decrease of about 5% in global hunger levels in 2050. The basic conclusion of the *Market Forces* scenario, that hunger is unlikely to decrease significantly over the next 50 years, is unaffected by the changes.

References

Alexandratos, N. (ed.) 1995. World Agriculture: Towards 2010. Chichester, U.K.: John Wiley and Sons.

Asia Pacific Research Centre (APERC). 2006. "APEC Energy Demand and Supply Outlook 2006". Japan: Asia Pacific Research Centre. Available from http://www.ieej.or.jp/aperc/2006pdf/Outlook2006/Whole_Report.pdf

Bénabou, R. 1996. "Inequality and Growth". C.V. Star Center for Applied Economics, New York University. Economic Research Reports RR# 96-22. New York: New York University.

Bender, Jim. 1994. *Future Harvest: Pesticide-Free Farming*. Lincoln: University of Nebraska Press.

Bender, William H. 1994. "An End Use Analysis of Global Food Requirements." *Food Policy* 19(4), pp. 381-395.

Bender, William H. 1997. "How Much Food Will We Need in the 21st Century?" *Environment* 39(2), pp. 7-11, 27-28.

British Petroleum (BP). 2007. *BP Statistical Review of World Energy*. London: British Petroleum Company. Updated version available from http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

Brodin, Y-W, and J. C. I. Kuylenstierna. 1992. "Acidification and Critical Loads in Nordic Countries: A Background," *Ambio* 21, pp.332-338.

Brown, L. R., C. Flavin, H. French, J. Abramowitz, C. Bright, G. Gardner, A. McGinn, M. Renner, D. Roodman and L. Starke. 1997. *State of the World: A Worldwatch Institute Report on Progress Toward a Sustainable Society*. New York: W.W. Norton and Company.

Bumb, B. L. and C. A. Baanante. 1996. *The Role of Fertilizer in Sustaining Food Security and Protecting the Environment to 2020*. Washington, D.C.: IFPRI. Food, Agriculture and the Environment Discussion Paper 17.

Central Intelligence Agency (CIA). 2007. *The World Factbook 2007*. Washington, D.C.: Central Intelligence Agency. Available from https://www.cia.gov/library/publications/the-world-factbook/; INTERNET.

Chapra, S. 1997. *Surface Water-Quality Modeling*. McGraw-Hill Companies, Inc.

Conference Board, The, and Groningen Growth and Development Centre (Conference Board). 2008. Total Economy Database. September 2008. Available from http://www.conference-board.org/economics/

Conway, G. 1997. *The Doubly Green Revolution: Food for All in the 21st Century*. London: Penguin Books.

Council for Agricultural Science and Technology (CAST). 1999. *Animal Agriculture and Global Food Supply*. Ames, IA: CAST. Available from: http://www.cast-science.org/.

Crosson, P. and J. R. Anderson. 1992. *Resources and Global Food Prospects: Supply and Demand for Cereals to 2030*. Washington, D.C.: The World Bank. World Bank Technical Paper Number 184.

de Haan, C., H. Steinfeld, H. Blackburn. 1996. *Livestock & the Environment: Finding a Balance*. Suffolk: WRENmdedia. Available from: http://www.fao.org; INTERNET.

Deininger, K. and L. Squire. 1996. "A New Data Set Measuring Income Inequality," *The World Bank Economic Review* 10(3), pp. 565-591.

Dethlefson, V., T. Jackson, and P. Taylor. 1993. "The Precautionary Principle," in *Clean Production Strategies: Developing Preventive Environmental Maintenance in the Industrial Economy*, T. Jackson (ed.). Boca Raton, Florida: Lewis Publishers.

Doorn, M.R.J. and M. A. Barlaz. 1995. *Estimate of Global Methane Emissions from Landfills and Open Dumps*. Prepared for U.S. Environmental Protection Agency, Office of Research and Development. Washington, D.C.: U.S. Environmental Protection Agency. EPA-600/R-95-019.

Durning, A. B. and H. B. Brough. 1991. *Taking Stock : Animal Farming and the Environment*. Washington, D.C.: Worldwatch Institute. Worldwatch Paper 103.

Easterly, William. 2006. "Social Cohesion, Institutions, and Growth. Center for Global Development." Working Paper Number 94, August 2006.

Ellegard, A. and H. Egneus. 1992. *Health Effects of Charcoal and Woodfuel Use in Low-Income Households in Lusaka, Zambia*. Stockholm: Stockholm Environment Institute. Report.

Elliot, R. N. 1994. *Electricity Consumption and the Potential for Electric Energy Savings in the Manufacturing Sector*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Energy Innovations. 1997. *Energy Innovations: A Prosperous Path to a Clean Environment*. Washington, D.C.: Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists. Available from http://go.ucsusa.org/publications/report.cfm?publicationID=141

Evans, L.T. 1998. *Feeding the Ten Billion: Plants and Population Growth*. Cambridge: Cambridge University Press.

Fischer, Günther. 1993. Personal communication.

FAO (Food and Agriculture Organization of the United Nations). 1995. *Irrigation in Africa*. Rome: FAO.

_____. 1996. *Sixth World Food Survey*. Rome: Food and Agricultural Organization.

_____. 1997a. *Mapping Undernutrition* (poster). Rome: Food and Agricultural Organization.

_____. 1997b. *State of the World's Forests 1997*. Rome: Food and Agriculture Organization.

_____. 1998a. *Asia-Pacific Forestry Toward 2010: Report of the Asia-Pacific Forestry Sector Outlook Study*. FAO Asia-Pacific Forestry Commission. Available from: http://www.fao.org/forestry/; INTERNET.

_____. 1998b. *Global Fibre Supply Model*. FAO Forestry Department, Forest Products Division, Wood and Non-Wood Products Utlization Branch. Available from: http://www.fao.org/forestry/; INTERNET.

_____. 1999a. *State of Food and Agriculture 1999*. Rome: Food and Agriculture Organization of the United Nations.

_____. 1999a. *FAOSTAT 98 CD-ROM*. Rome: Food and Agriculture Organization of the United Nations.

_____. 1999b. *State of the World's Forests 1999*. Rome: Food and Agriculture Organization.

_____. 2000a. *Agriculture: Towards 2015/30, Technical Interim Report, April 2000*. Rome: Food and Agriculture Organization of the United Nations.

_____. 2000b. *The Global Outlook for Future Wood Supply from Forest Plantations*. Rome: FAO. Global Forest Products Outlook Study Working Paper GFPOS/WP/03.

_____. 2006a. *Agriculture: Towards 2030/2050: Interim report, June 2006.* Rome: Food and Agriculture Organization of the United Nations.

_____. 2006b. *Global Forest Resource Assessment 2005: Progress towards sustainable forest management (FRA 2005)*. Rome: Food and Agriculture Organization of the United Nations.

_____. 2007a. *FAOSTAT Online Database.* Rome: Food and Agriculture Organization. Available from: http://faostat.fao.org/default.aspx; INTERNET.

_____. 2007b. *Food Security Statistics.* Rome: Food and Agriculture Organization. Available from http://www.fao.org/es/ess/faostat/foodsecurity/index_en.htm; INTERNET.

_____. 2007c. *Animal Feed Resources Information System*. Rome: Food and Agriculture Organization Feed Resources Group. Accessed October 2007. Available from: http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/afris/default1.htm ; INTERNET.

_____. 2007d. *Country Pasture Profiles.* Rome: Food and Agriculture Organization Crop and Grassland Service. Accessed December 2007. Available from: http://www.fao.org/ag/AGP/AGPC/doc/pasture/forage.htm; INTERNET.

_____. 2007e. *AQUASTAT Database*. Rome: FAO. Available from http://www.fao.org/nr/water/aquastat/main/index.stm; INTERNET.

_____. 2007f. *State of the World's Forests 2007*. Rome: FAO. Available from http://www.fao.org/docrep/009/a0773e/a0773e00.HTM.

_____. 2008a. FAOSTAT Online Database. Rome: Food and Agriculture Organization. Available from: http://faostat.fao.org/default.aspx; INTERNET.

_____. 2008b. FishStat Online Data. Rome: Food and Agriculture Organization. Available from: http://www.fao.org/fishery; INTERNET.

Food and Agriculture Organization of the United Nations/International Institute for Applied Systems Analysis (FAO/IIASA). 2000.*Global Agro-ecological Zones*. Available from: http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm; INTERNET.

Forest Resources Assessment 1990 Project (FRA). 1996. *Forest Resources Assessment 1990: Survey of Tropical Forest Cover and Study of Change Processes*. Rome: FAO.

Galaty, J. G. and D. L. Johnson. 1990. "Introduction: Pastoral Systems in Global Perspective," *in* J. L. Galaty and D. L. Johnson, Eds. *The World of Pastoralism: Herding Systems in Comparative Perspective*. New York: The Guilford Press.

Gallopín, G. A. Hammond, P. Raskin and R. Swart 1997. *Branch Points: Global Scenarios and Human Choice*. Stockholm, Sweden: Stockholm Environment Institute. PoleStar Series Report No. 7.

Gallopín, G. and P. Raskin. 2002. *Global Sustainability: Bending the Curve*. London: Routledge.

Gleick, P. 1992. "Environmental Consequences of Hydroelectric Developments: The Role of Facility Size and Type," *Energy* (17), pp. 737-747.

_____ (ed.) . 1993. *Water in Crisis: A Guide to the World's Fresh Water Resources*. New York: Oxford University Press.

_____. 1998. *The World's Water 1998-1999: The Biennial Report on Freshwater Resources*. Washington, D.C.: Island Press.

Gleick, P. H., P. Loh, S. V. Gomez and J. Morrison. 1995. *California Water 2020: A Sustainable Vision*. Oakland, California: Pacific Institute for Studies in Development, Environment, and Security.

Global Resource Information Database/United Nations Environment Program (GRID/UNEP). 1991. *Global Assessment of Human Induced Soil Degradation (GLASOD): Global Digital Database*. Nairobi: GRID.

Greenland, D. J. and B. N. Okigbo. 1983. "Crop Production Under Shifting Cultivation and Maintenance of Soil Fertility," in *Symposium on Potential Productivity of Field Crops Under Different Environments*. Los Baños, Phillipines: International Rice Research Institute.

Greenpeace and European Renewable Energy Council (EREC). 2007. "energy [r]evolution: A sustainable Global energy outlook." Utrecht: Greenpeace and EREC.

Greenpeace and European Renewable Energy Council (EREC). 2008. "energy [r]evolution: A sustainable Global energy outlook (Update)." Utrecht: Greenpeace and EREC.

Grigg, D. 1995. *An Introduction to Agricultural Geography, 2nd Edition*. London: Routledge.

Habitat (United Nations Center for Human Settlements). 1998. The Global Urban Observatory. *Global Urban Indicators Database*. Habitat: Nairobi. http://www.urbanobservatory.org/.

Hansen, J., Mki. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos. 2008. "Target Atmospheric CO_2: Where Should Humanity Aim?" *Open Atmos. Sci. J.*, **2**, 217-231, doi:10.2174/1874282300802010217.

Heaps, C., E. Kemp-Benedict and P. Raskin. 1998. *Conventional Worlds: Technical Descripition of "Bending the Curve" Scenarios*. Boston: Stockholm Environment Institute-Boston.

Heaps, C., M. Lazarus, P. Raskin, and D. von Hippel. 1993. "Considerations in Energy Planning Models for Wood Energy Planning," in *Wood Energy Development: Planning, Policies and Strategies.* Vol II, Proceedings of the Expert Consultation on Data Assessment and Analysis for Wood Energy Planning. Bangkok: FAO.

Hettige, H. M. Mani, and D. Wheeler. 2000. "Industrial Pollution in Economic Development: the Environmental Kuznets Curve Revisited". *Journal of Development Economics*. vol. 62, pp. 445-476.

Hettige, H., P. Martin, M. Singh and D. Wheeler. 1994. *The Industrial Pollution Projection System*. Washington, D.C.: The World Bank.

Hexem, R. W. and E. O. Heady. 1978. *Water Production Functions for Irrigated Agriculture*. Ames, Iowa: The Iowa State University Press.

Homewood, K. M. and W. A. Rogers. 1991. *Maasailand Ecology: Pastoralist Development and Wildlife Conservation in Ngorongoro, Tanzania*. Cambridge: Cambridge University Press.

Houghton, R. A. and J. L. Hackler. 1995. *Continental Scale Estimates of the Biotic Carbon Flux from Land Cover Change: 1850 to 1980*. Carbon Dioxide Information Analysis Center. NDP-050. Available from http://cdiac.esd.ornl.gov; INTERNET.

Hubbert, M. K. 1956. "Nuclear energy and the fossil fuels"; *American Petroleum Institute Drilling & Production Practice Proceedings, Spring Meeting*, San Antonio, Texas, 7-25.

Hudson, N. 1992. *Land Husbandry*. Ithaca, N.Y.: Cornell University Press.

Humphreys, L.R. 1991. *Tropical Pasture Utilization*. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2000. *Land Use, Land-Use Change, and Forestry*. Robert T. Watson, Ian R. Noble, Bert Bolin, N.H. Ravindranath, David J. Verardo, David J. Dokken, Eds. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 2. S Eggleston, L Buendia, K. Miwa, T Ngara and K Tanabe, Eds. Hayama, Japan: Institute for Global Environmental Strategies (IPES).

_____. 2007. *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.)]. Geneva, Switzerland: IPCC.

Intergovernmental Panel on Climate Change/Organization for Economic Cooperation and Development/International Energy Agency (IPCC/OECD/IEA). 1996. Re*vised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 3. JT Houghton, LG Meira Filho, B Lim, K Treanton, I Mamaty, Y Bonduki, DJ Griggs and BA Callender, Eds. Bracknell: UK Meteorological Office.

International Energy Agency (IEA). 1997. *Indicators of Energy Use and Efficiency: Understanding the Link Between Energy and Human Activity*. Paris: OECD/IEA.

_____. 2006a. *Energy Balances of Non-OECD Countries, 1971-2004* (electronic distribution). Paris: OECD.

_____. 2006b. *Energy Statistics of OECD Countries, 1971-2004* (electronic distribution). Paris: OECD.

International Energy Agency and World Business Council on Sustainable Development (IEA/WBCSD). 2004a. *IEA/SMP Model Documentation and Reference Case Projection.*

_____. 2004b. *SMP Transport Spreadsheet Model.*

International Food Policy Research Institute (IFPRI). 1999. *Livestock to 2020: The Next Food Revolution.* Washington, D.C.: IFPRI

_____. 2001. *2020 Global Food Outlook:TTrends, Alternatives and Choices.* Washington, D.C.: IFPRI

International Institute for Applied Systems Analysis (IIASA). 2006. IIASA *Greenhouse Gas Initiative Version 1.0.9.* Online Database. Laxenburg, Austria: IIASA. Available from: http://www.iiasa.ac.at/web-apps/ggi/GgiDb/dsd?Action=htmlpage&page=countries.

International Rice Research Institute (IRRI). 1999. IRRI RiceWeb: *Geography of Production.* Country reports available from: http://www.riceweb.org/geography.htm; INTERNET

Jackson, T. and A. MacGillivray. 1995. *Accounting for Toxic Emissions from the Global Economy: the Case of Cadmium*. Stockholm: Stockholm Environment Institute. PoleStar Series Report No. 6.

Jackson, T. and P. Taylor. 1992. "The Precautionary Principle and the Prevention of Marine Pollution," *Journal of Chemistry and Ecology* 7, pp. 123-134.

Kemp-Benedict, E., Heaps, C., and P. Raskin. 2002. *Global Scenario Group Futures: Technical Notes, PoleStar series report no. 9*. Boston: Stockholm Environment Institute-Boston.

Krishnamoorthy, Ch. 1983. "Low Input Cropping Systems," in *Symposium on Potential Productivity of Field Crops Under Different Environments*. Los Baños, Phillipines: International Rice Research Institute.

Kuylenstierna, J. 1998. Personal communication.

Lægreid, M., O.C. Bøckman and O. Kaarstad. 1999. *Agriculture, Fertilizers & the Environment*. Wallingford, U.K.: CABI Publishing, in association with Norsk Hydro ASA.

Lalonde, L.-G. and T. Sukigara. 1997. LDPS^2 User's Guide. Rome: Food and Agriculture Organization, Animal Production and Health Division. Report and model available from: http://www.fao.org/ag/aga/lspa/ldps2/default.htm; INTERNET.

Lazarus, M., L. Greber, J. Hall, C. Bartels, S. Bernow, E. Hansen, P. Raskin and D. Von Hippel. 1993. *Towards a Fossil Free Energy Future: The Next Energy Transition*. Amsterdam: Greenpeace International.

Leach, G. 1995. *Global Land & Food in the 21st Century: Trends & Issues for Sustainability*. Stockholm: Stockholm Environment Institute. PoleStar Series Report No. 5.

Leach, G. and P. Mearns. 1988. *Beyond the Woodfuel Crisis: People, Land and Trees in Africa*. London: Earthscan.

Lenssen, N. 1992. *Empowering Development: The New Energy Equation*. Washington, D.C.: Worldwatch Institute. Worldwatch Paper 111.

Lonergan, S. and D. Brooks. 1994. *Watershed: The Role of Fresh Water in the Israeli-Palestinian Conflict*. Ottawa: International Development Research Centre.

Luyten, J. C. 1995. *Sustainable World Food Production and Environment*. DLO Research Institute for Agrobiology and Soil Fertility. AB-DLO Report 37.

Mackenzie J. J. 1996. *Oil as a Finite Resource: When is Global Production Likely to Peak?* World Resources Institute. On-line resource paper. Available from http://www.wri.org/wri/climate/finitoil; INTERNET.

Madison, A. 2001. "The World Economy: A Millennial Perspective." Paris: Development Center of the Organisation for Economic Co-operation and Development.

Maheshwari, M. L. 1995. "Rangeland Nutritional Resource for Livestock in India," in *Range Management in Arid Zones: Proceedings of the Second International Conference on Range Management in the Arabian Gulf*, ed. S. A. S. Omar, M. A. Razzaque and F. Alsdirawi. London: Kegan Paul, International.

Masters, C., D. Root and E. Attanasi. 1990. "World Oil and Gas Resources – Future Production Realities," *Annual Review of Energy* 15, p. 23.

Matthews, E. and A. Hammond. 1999. *Critical Consumption Trends and Implications: Degrading Earth's Ecosystems*. Washington, D.C.: World Resources Institute.

Meyer, W.B. and B.L. Turner (eds.). 1994. *Changes in Land Use and Land Cover: A Global Perspective*. First published 1994, reprinted 1998 Cambridge: Cambridge University Press.

Misri, B.K. 1999. *Country Pasture/Forage Resource Profiles: India*. Available from http://www.fao.org; INTERNET.

Munslow, B., Y. Katerere, A. Ferf and P. O'Keefe. 1988. *The Fuelwood Trap: A Study of the SADCC Region*. London: Earthscan.

Nakicenovic, N. 2007. "CO2 emissions pathways compared to long-term CO2 stabilization scenarios in the literature and IPCC AR4." Paper prepared for the IEA Conference on World Energy Outlook 2007, 21 November, 2007, Vienna, Austria.

National Academy of Sciences (NAS). 1984. *Toxicity Testing: Strategies to Determine Needs and Priorities*. Washington, D.C.: National Academy of Sciences.

National Research Council (NRC). 1996. *Nutrient Requirements of Beef Cattle*. 7th Revised Edition. Washington, D.C.: National Academy Press.

OECD (Organisation for Economic Co-operation and Development). 2004. *OECD Environmental Data: Compendium 2004*. Paris: OECD.

_____. 2006. *Water: the Experience in OECD Countries*. Paris: OECD. Available from http://www.oecd.org/dataoecd/18/47/36225960.pdf.

_____. 2008. *OECD Environmental Data Compendium Online Datasets*. Paris: OECD. Updated datasets available from http://www.oecd.org/document/49/0,3343,en_2649_34283_39011377_1_1_1_1,00.html; INTERNET.

_____. 2008. *OECD Environmental Outlook to 2030*. Paris: OECD. Available at *www.oecd.org/environment/outlookto2030*

Organization for Economic Co-operation and Developent and International Energy Agency (OECD/IEA). 2007. *World Energy Outlook 2007: China and India Insights*. Paris: IEA.

O'Keefe, P., P. Raskin and S. Bernow. 1984. *Energy and Development in Kenya: Opportunities and Constraints*. Stockholm: Beijer Institute. Energy, Environment and Development in Africa, vol. 1.

Oldeman, L., R. Hakkeling and W. Sombroek. 1991. *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note*. Second revised edition. Nairobi: United Nations Environment Program.

Pacific Institute. 2007. *The World's Water Data*. Washington, D.C.: Island Press. Available from http://www.worldwater.org/data.html; INTERNET.

_____. 2008. *The World's Water Data*. Washington, D.C.: Island Press. Available from http://www.worldwater.org/data.html; INTERNET.

Penning de Vries, F. W. T., H. van Keulen and J. C. Luyten. 1996. "The Role of Soil Science in Estimating Global Food Security in 2040," in *The Role of Soil Science in Interdisciplinary Research*. Madison, Wisconsin: American Society of Agronomy and Soil Science Society of America. SSSA Special Publication 45.

Pinstrup-Anderson, Per, Rajul Pandya-Lorch and Mark W. Rosegrant. 1997. *The World Food Situation: Recent Developments, Emerging Issues, and Long-Term Prospects*. Washington, D.C.: International Food Policy Research Institute. 2020 Vision Food Policy Report.

Plucknett, D.L., N.J.H. Smith, S. Ozgediz. 1990. *Networking in International Agricultural Research*. Ithaca, NY: Cornell University Press.

Posch, M., J.-P. Hettelingh, J. Alcamo and M. Krol. 1996. "Integrated Scenarios of Acidification and Climate Change in Asia and Europe," *Global Environmental Change* 6(4), pp. 375-394.

Postel, S. 1992. *Last Oasis: Facing Water Scarcity*. New York: W.W. Norton & Company.

Raskin, P. 2006. *The Great Transition Today: A report from the Future.* GTI Paper Series. Boston: Tellus Institute.

Raskin, P., T. Banuri, G. Gallopín, P. Gutman, A. Hammond, R. Kates and R. Swart. 2002. *Great Transition: The Promise and Lure of the Times Ahead*. Boston: Stockholm Environment Institute-Boston. PoleStar Series Report no. 10.

Raskin, P. M. Chadwick, T. Jackson and G. Leach. 1996. *The Sustainability Transition: Beyond Conventional Development.* Stockholm: Stockholm Environment Institute. PoleStar Series Report No. 1.

Raskin, P., G. Gallopín, P. Gutman, A. Hammond, and R. Swart. 1998. *Bending the Curve: Toward Global Sustainability*. Boston: Stockholm Environment Institute-Boston. PoleStar Series Report No. 8.

Raskin, P., P. Gleick, P. Kirshen, G. Pontius and K. Strzepek. 1997. *Water Futures: Assessment of Long-range Patterns and Problems.* Background Document for the SEI/United Nations Comprehensive Assessment of the Freshwater Resources of the World. Stockholm: Stockholm Environment Institute.

Raskin, P., E. Hansen and R. Margolis. 1995. *Water and Sustainability: A Global Outlook.* Stockholm: Stockholm Environment Institute. PoleStar Series Report No. 4.

Raskin, P. and R. Margolis. 1995. *Global Energy in the 21st Century: Patterns, Projections and Problems*. Stockholm: Stockholm Environment Institute. PoleStar Series Report No. 3.

RIVM/UNEP (Netherlands Institute of Public Health and the Environment/United Nations Environment Program). 1997. *The Future of the Global Environment: A Model-based Analysis Supporting UNEP's First Global Environment Outlook.* Bakkes, J. and J. van Woerden (eds.). Bilthoven, The Netherlands: RIVM.

Robinson, J. 1990. "Futures under glass: a recipe for people who hate to predict," *Futures* October 1990.

Ross, M., P. Thimmapuram, R. Fisher, and W. Maciorowski. 1993. *Long-Term Industrial Energy Forecasting (LIEF) Model (18 Sector Version).* Argonne, Illinois: Argonne National Laboratory.

Scherr, S. and S. Yadav. 1996. *Land Degradation in the Developing World: Implications for Food, Agriculture, and the Environment to 2050.* Washington, D.C.: IFPRI.

Schipper, L. and S. Meyers. 1992. *Energy Efficiency and Human Activity: Past Trends, Future Prospects*. Cambridge: Cambridge University Press.

Seckler, D. 1996. *The New Era of Water Resources Management: From "Dry" to "Wet" Water Savings*. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).

Seckler, D., U. Amarasinghe, D., Radhika de Silva and R. Barker. 1998. *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues.* IIMI Research Report 19.

Shiklomanov. 1997. *Assessment of Water Resources and Water Availability of the World*. Geneva: World Meteorological Organization.

_____. 1999. Personal communication.

Smith, K. R. 1987. *Biofuels, Air Pollution, and Health - A Global Review*. New York: Plenum Press.

Smith, K. R. 1993. "Fuel Combustion, Air Pollution Exposure, and Health: The Situation in Developing Countries," *Annual Review of Energy and the Environment* 18, pp.529-66.

Stern, D.I., and R.K. Kaufmann. 1998. "Annual Estimates of Global Anthropogenic Methane Emissions: 1860-1994", in *Trends Online: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., USA.

Stockholm Environment Institute (SEI). 1993. *G2S2: Greenhouse Gas Scenario System.* Database and User Guide. Boston: Stockholm Environment Institute-Boston.

Stockholm Environment Institute-York (SEI-York). 1998. Personal communication.

Strzepek, Kenneth M. and O. Perrin Bowling. 1995. *Global Assessment of the Use of Freshwater Resources for Industrial and Commercial Purposes*. A Study for the United Nations Industrial Development Organization.

Swallow, B.M. 1999. "Impacts of Trypanosomiasis on African Agriculture". Nairobi: International Livestock Research Institute.

Swart, R. 1996. "Security Risks of Global Environmental Changes: Viewpoint," *Global Environmental Change* 3(3), pp. 187-192.

Tchobanoglous, G. and F. Burton (Metcalf & Eddy, Inc.). 1991. *Wastewater Engineering: Treatment, Disposal and Reuse, 3rd Edition*. New York: McGraw Hill, Inc.

Tellus Institute. 1998. *Climate and Employment Benefits from Organic Waste Diversion*. Prepared for the U.S. EPA Office of Solid Waste.

United Nations (UN). 1990. *Industrial Statistics Yearbook*. New York: United Nations.

United Nations (UN), *Department of Economic and Social Affairs*, Population Division. 2004. World Population to 2300. New York: United Nations. Available at http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

_____. 2006a. Population, Resources, Environment and Development: The 2005 Revision. New York: United Nations. Available at: http://www.un.org/esa/population/unpop.htm

_____. 2006b. World Urbanization Prospects: The 2005 Revision. New York: United Nations.

United Nations Development Program (UNDP). 2003. "Technical Note 1", *Human Development Report 2003*. New York: UNDP.

United Nations Industrial Development Organization (UNIDO). 2007. *UNIDO Industrial Statistics Database (online)*. Vienna, Austria: United Nations Industrial Development Organization. Accessed at http://www.unido.org/index.php?id=o3474

United States Department of Agriculture (USDA). 1994. *1992 National Resources Inventory: 1992 NRI Changes in Land Cover/Use Between 1982 and 1992*. Available from: http://www.nhq.nrcs.usda.gov/land/tables/t2211.html; INTERNET.

United States Department of Commerce, Bureau of the Census (USBC). 1992. *Statistical Abstract of the United States*. Washington, D.C.: U.S. Government Publishing Office.

_____. 1995. *Statistical Abstract of the United States.* Washington, D.C.: U.S. Government Publishing Office.

United States Geological Survey/University of Nebraska-Lincoln/Joint Research Centre of the European Commission (USGS/UNL/JRC). 1999. *Global Land Cover Characteristics Database Ver 1.2.* Documentation and data available from: http://edcdaac.usgs.gov/glcc/; INTERNET.

Watson, R. T., M. C. Zonyowera, R. H. Moss, D. J. Dokken (Eds.). 1996. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis.* Cambridge: Cambridge University Press. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

Wilkinson, Richard G. Comment: Income, Inequality, and Social Cohesion. 1997. *American Journal of Public Health*. September 1997, Vol. 87, No. 9, p. 1504-1506.

Willenbrock, J. H. and H. R. Thomas (eds.). 1980. *Planning, Engineering and Construction of Electric Power Generation Facilities*. New York: John Wiley & Sons.

Wirsenius, S. 2000. *Human Use of Land and Organic Materials: Modeling the Turnover of Biomass in the Global Food System*. Thesis. Göteborg, Sweden: Göteborg University.

World Bank. 2007. *World Development Report 2008: Agriculture for Development*. Washington, D.C.: The International Bank for Reconstruction and Development / The World Bank.

_____. 2008a. *Global Purchasing Power Parities and Real Expenditures: 2005 International Comparison Program.* Washington, D.C.: International Bank for Reconstruction and Development/The World Bank.

_____. 2008b. *Global Economic Prospects 2008.* Washington, D.C.: World Bank. Available at http://go.worldbank.org/TC26UFESJ0

_____. 2008c. *World Bank Country Statistics.* Washington, D.C.: World Bank. Accessed September 2008 at http://go.worldbank.org/1SF48T40L0

World Conservation Monitoring Centre (WCMC). 1998. *Global Protected Areas Summary Statistics*. Cambridge: WCMC. Available from: http://www.wcmc.org.uk; INTERNET.

World Energy Council (WEC). 2007. *Survey of Energy Resources, 2007*. London, UK: World Energy Council. Available online from http://www.worldenergy.org/publications/survey_of_energy_resources_2007/default.asp

World Health Organization (WHO). 1982. *Rapid Assessment of Sources of Air, Water, and Land Pollution*. Geneva: World Health Organization. WHO Offset Publication No. 62.

World Resources Institute (WRI). 1992. *World Resources 1992-93, Data Base Diskette*. Washington, D.C.: World Resources Institute.

_____. 1996. *World Resources 1996-97 Database Diskette*. Washington, D.C.: World Resources Institute.

_____. 1998. *World Resources 1998-99.* New York: Oxford University Press.

_____. 2007. *EarthTrends Online Database*. Available at http://earthtrends.wri.org/; INTERNET.