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Greenhouse Gas Emissions in an Equity-, Environment- and Service-Oriented World: An IMAGE-Based Scenario for the 21st Century

BERT DE VRIES, JOHANNES BOLLEN, LEX BOUWMAN, MICHEL DEN ELZEN, MARCO JANSSEN, and ERIC KREILEMAN

ABSTRACT

This article describes a greenhouse gas (GHG) emissions scenario for a world that chooses collectively and effectively to pursue service-oriented economic prosperity while taking into account equity and environmental concerns, but without policies directed at mitigating climate change. After peaking around 2050 at 2.2 times the 1990 level of primary energy use, a number of factors lead to a primary energy use rate at the end of the next century that is only 40% higher than the 1990 rate. Among these factors are a stabilizing (and after 2050,

The authors are with the Bureau of Environmental Assessment (MNV), the Department for Environmental Information Systems (CIM) and the Soil and Groundwater Research Laboratory (LBG) of the National Institute of Public Health and the Environment (RIVM), P.O. Box 1, 3720 BA Bilthoven, The Netherlands.

Dr. BERT DE VRIES has a background in theoretical chemistry and environmental science. He has been project leader of the TARGETS-project and the IMAGE-project and is coordinating the energy module in the IMAGE-model versions.

Drs. JOHANNES BOLLEN is economist and responsible for the WorldScan-scenarios which are input for the IMAGE-model. He is presently working on carbon reduction scenarios and policies with the WorldScan-model in cooperation with economists at the CPB Netherlands Bureau for Economic Policy Analysis.

Dr. IR. LEX BOUWMAN is soil scientist and works on compilations of global inventories of emissions from soils and agriculture, modelling of land use-climate interactions and atmospheric pollution, and scaling of trace gas exchange.

Dr. MICHEL DEN ELZEN has a background in mathematics and has a long experience in integrated assessment modelling and its applications in policy analysis. He is responsible for the emissions module and the atmospheric chemistry module of IMAGE 2 model and for IMAGE-related decision support tools ('scanners').

Dr. MARCO JANSSEN is an economist with extensive experience in integrated modelling. He has worked on the energy module of the IMAGE 2 model and on a variety of multi-agent models. He is currently at the Department of Spatial Economics of the Free University, Amsterdam.

Dr. ERIC KREILEMAN works as applied mathematician. He has experience with integrated modeling of climate change since 1990. Currently he is projectleader of one of the IMAGE projects, Integration and Maintenance.

Address correspondence to Bert de Vries, National Institute for Public Health and the Environment, P.O. Box 1, 3720 BA Bilthoven, The Netherlands: E-mail: <Bert.de.Vries@rivm.nl>.

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declining) population, convergence in economic productivity, dematerialization and technology transfer, and high-tech innovations in energy use and supply. Land use-related emissions show a similar trend. Total CO_2 emissions peak at 12.8 CtC/yr around 2040, after which they start falling off. Other GHG emissions show a similar trend. The resulting CO_2-equivalent concentration continues to rise to about 600 ppmv in 2100. Present understanding of climate change impacts suggest that even in this world of high-tech innovations in resource use in combination with effective global governance and concern about equity and environment issues, climate policy is needed if mankind is to avoid dangerous interference with the climate system.

Introduction

In the past decade, numerous projections of the emissions of GHGs have been published. Among the most well-known are the IS92 scenarios, which were developed for the Intergovernmental Panel on Climate Change (IPCC) [1] and were evaluated in the 1994 IPCC Supplementary Report [2]. The IS92 emission scenarios have been widely used by economic and climate researchers to assess the mitigation costs and environmental consequences of GHG emissions [3]. Although they span a wide range of possible emission trajectories, they had little qualitative, descriptive detail. The coal-based IS92a scenario, in which GHG emissions more than triple over the next 100 years, has received the most attention and been used as a kind of median, "business-as-usual" future. Partly in response, various scenarios have been presented in which energy efficiency innovations and nonfossil supply technologies lead to much lower GHG emissions at similar population and economic growth levels: the Low CO_2 emissions Energy Supply System (LESS) scenario [4],[1] the Shell Planning scenarios [5], the Ecologically Driven scenario of the International Institute of Applied Systems Analysis (IIASA) [6, 7], the Egalitarian scenario of the TARGETS-project [8], and the Great Transformations scenario of the Stockholm Environment Institute (SEI) [9, 10].[2]

This article presents the results of a model-based scenario exercise with the WorldScan-model developed at the Dutch Central Plan Bureau (CPB) and the IMAGE-model developed at the Dutch National Institute of Public Health and the Environment (RIVM).[3] It is an attempt at "computer-aided storytelling": the models are used to explore economic, energy, and land use developments in the direction of global sustainability. As such, it is akin to the low-emission scenarios mentioned above, and contains elements described in the vast literature on sustainable development [11–17]. The scenario exercise was initiated as part of an international and interdisciplinary modeling effort that involved six modeling groups in which a set of 40 emission scenarios have been developed. For further details see the articles by Nakicenovic, and Kram et al. in this issue.

The set of 40 scenarios is divided into four scenario families. The scenario described in this article belongs to one of the four scenario families, one that uses the degree and effectiveness of governance and the degree of citizens' social and environmental concerns as the two preferred characteristics to construct a scenario set. The governance aspect has been strongly linked to globalization trends such as trade liberalization, market-

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[1] Recently published scenarios along these lines are, for example, [44], and [58].

[2] These scenarios are rooted in older visions of an energy-efficient, renewable-energy-based future [59, 60, 61, 62, 15].

[3] The WorldScan model is described in [63], [64] and [65]. The IMAGE 2.0 model is described in [66], the IMAGE 2.1 model in [67]. The Energy-Industry System module in the IMAGE 2.1 model is based on the Targets Image Energy Regional (TIMER) model. Descriptions can be found in [68, 69, 70, 71, 72]. A detailed description of the Terrestrial Environment System (TES) and the Atmospheric Ocean System (AOS) modules in the IMAGE-model can be found in [67].

based mechanisms and instruments, the size of interregional capital flows, and the dissemination of technical innovations. Social and environmental concerns have been related to, for instance, the degree of support for solidarity between the rich and the poor, "green" lifestyles and technologies, and community-oriented experiments toward a more sustainable future. It includes all sorts of regional exchanges and social and environmental concerns, but no global climate policies. We refer to the scenario presented here as the B scenario.[4] This article presents the storyline behind this scenario, describes how it has been implemented in the WorldScan and IMAGE2 models, and presents the main results.

The B Storyline: A Prosperous, Fair, and Green World

Population. Increasing and more equally distributed affluence, supported by policies oriented toward education for women and community-based initiatives, cause a rapid decline in fertility levels: world population drops from 8.7 billion people in 2050 to 7.0 billion in 2100. The potential adverse impacts of population "greying" are overcome by adequate social security arrangements. Human settlements are controlled by promoting compact cities and major transport/communication corridors based on improvement of current infrastructure rather than expansion. Urbanization trends are halted or even reversed as orientation shifts to more decentralized living.

Values. Rising affluence and intercultural exchange cause a growing interest in the non-material aspects of life, which show up in the form of declining working hours, improving community services, a revived interest in spiritual values [18], and the like. Technology development and life-style trends increasingly incorporate the principles of sustainable resource use, partly in response to a growing concern by governments, business and the general public about the threat of social unrest and conflict and about worsening environmental problems [19]. The values associated with the market ideology—competition, consumerism, individualism, and materialism—become less dominant. In some instances, the shift occurs when people begin to understand the side effects of unbridled market power, such as financial dependency, instability, and corruption. In other instances, it happens in response to people's search for more rewarding and meaningful lives, with more emphasis on leisure time, arts and crafts, childcare, interpersonal relationships, and the like.

Governance. The present trends of globalization and liberalization continue, but there is a strong commitment among national and international governments towards sustainable development initiatives [20]. Successful institutional innovations are coupled with bottom-up solutions to problems, which reflect wide success in getting broad-based support within communities. Support for "green parties" in the industrialized regions, and later in the less industrialized regions, increases. A more equitable income distribution, both within and between regions, is increasingly seen as a precondition for sustainable development [21]. A large part of the world's productivity gains are invested in equity, social institutions, and environment protection.

Economy. Economic output in monetary units grows at a somewhat lower rate than in the past 50 years: gross world product increases by a factor of five between 2000 and 2050, as compared with the factor six increase between 1950 and 2000. Per capita Gross Regional Product (GRP) converges among the world regions at a faster

[4] The scenario contains some elements of the B scenario described by Bossel [11] as an alternative to the Business-as-Usual A scenario. However, his B scenario emphasizes the need for decentralization and autarchy in relation to required system properties of stability and resilience.

rate than is the case with the "business-as-usual" expectations of the 1990s. However, it is increasingly recognized that this is a rather poor indicator of well-being, if only because it depends on monetarizing human activities.

While technology and finance remain dominated by multinational firms and banks, people in the developed regions begin a slow but persistent transformation of their economies [22]. A growing number of people begin organizing their own employment and income. Partly in reaction to globalization trends and the perceived side-effects of increasing unemployment and inequity and overexplotiation of the environment, there is increasing support for a citizen's income and Local Exchange Trade Systems, also in less developed regions. Internet becomes the medium par excellence in implementing these social and financial innovations. In the affluent regions, macroeconomic policies become narrower and less relevant; the importance of nongovernmental organizations (NGOs) is on the rise at all levels of society.

The affluent regions develop consistent and effective ways to support sustainable development in the poor regions, technology transfer agreements being one of the instruments. In the ensuring spiral of mutual trust, most less-developed regions manage to control social and economic tensions; corruption gradually vanishes and local conflicts are resolved by negotiation. In this atmosphere of sincerity on both sides, international organizations gain some of the authority and effectiveness their founders had hoped for. As a result, per capita income in the developing countries grows at or near the upper bounds of historical experience. The transition from traditional to modern economic activities throughout the world proceeds faster than it has in the past. Labor productivity continues to rise throughout the 21st century.

The service sectors prosper as activity patterns change toward increased teleworking, Internet-oriented education and info/entertainment, public-transport-oriented travel and tourism, and the like. Educational, legal, childcare, and physical-health- and mental-health-related services make up an increasing part of personal expenditures. All kinds of artistic and hand crafted work have become part of the formal monetary economy, but there may be large regional differences. Much "economic growth" also reflects the [re]distribution of scarce, positional goods such as space, time, and valuable artworks [23].

Business and manufacturing. The "greening" of business gets an unexpected boom. Increasingly, business and government leaders support eco-efficiency initiatives to decouple pollutant release and resource use from economic activity [17]. Capital markets become better informed about environmental performance and respond negatively to adverse environmental incidents caused by firms. This widespread search for more sustainable development paths results in the gradual introduction of subsidy and regulatory reforms, eco-taxes, regulations and standards, and new arrangements for rights and liabilities [24, 30].

Regional specialization and trade are part of the competitive global industry. The pace of technological innovations is high and research and development (R&D) expenses, as a fraction of gross world product, increase. Nanotechnologies become a spearhead in R&D, sparking off a revolution based on development of new materials and an ever-decreasing use of materials per function [25]. Materials recycling becomes a global business because national governments enforce waste-management laws and guarantee decent profitability.

Technology transfer from the industrialized to the less-industrialized regions in the world is accelerated to comply with national and international pollution abatement agreements [26]. Technology transfer is supported by large, regulated capital flows from the rich to the poor regions. In poor rural regions, governments support small-scale, labor-intensive industry, but enforce strict environment regulations. In some regions, the introduction of mechanization and robotization is slowed down to safeguard adequate employment rates.

Mobility, transport, and communications. To solve environmental and congestion problems, there is an active policy to invest in infrastructure: subways in large cities, separate lanes for bicycling and electric buses, etc. This is largely financed from taxes on transport fuels, following the European example. Intercity traffic is increasingly by fast trains, with excellent local transport systems, including car rental. New and efficient methods for freight transport are gradually introduced such as underground pipelines and rail systems. Air traffic is mostly for long-distance intercontinental trips. Although the private car remains the most important passenger transport option, both ownership and mileage saturate in most regions below present-day U.S. levels. Average fuel efficiency increases with a factor five to ten; electric and hybrid ([m]ethanol-based) cars make up an ever larger share of the market as they are appreciated for their convenience and low noise and pollution levels [27, 28].[5] The rapid expansion of telecommunications and information technology gives less-developed regions important leapfrogging opportunities. For instance, sparsely populated regions in Africa and Latin America jump into cellular phone and satellite systems, bypassing material-intensive infrastructure.

Land and food. The leading consumer trend is away from the high-meat-content, western-style diet, initially because of health concerns among the affluent, but later also in land-poor regions as people become aware of its implications. Selective application of biotechnology gradually makes agriculture in many regions less environmentally damaging while maintaining or raising average yields in combination with vastly more efficient irrigation schemes [29]. The use of fertilizer and other agricultural inputs starts declining because farmers are taught to use inputs more selectively or switch to sustainable agriculture practices altogether. Prudently-introduced biotechnology and ecotechnology become key areas for development [30]. Partly for environmental and health reasons, subsistence agriculture and fuelwood use decline. The virtues of locally-grown crops and traditional farming practices are rediscovered. The resulting pressure on land is bearable as population growth diminishes and the demand for meat falls. Within certain boundaries on food self-sufficiency, food trade is large in a safe world. In some regions, production of commercial biofuels becomes large business. Logging of primary forests is restricted to sustainable practices; most wood is produced from plantations following Scandinavian practices. Large forested areas are converted into conservation areas to safeguard biodiversity.

Environment and energy. In response to people's demand for a cleaner environment, governments intensify the monitoring of industrial and traffic emissions and impose more stringent controls. Changing activities, values, and lifestyles, the transition to a service- and information-economy, and the inclusion of the informal economy all contribute to a decline in energy- and material-demand per unit of economic output ("dematerialization," ecological restructuring, "factor ten" etc.).[6] The 10–15 materials which make up 80% of industrial energy demand are produced ever more energy efficiently (see e.g., [31]).

[5] The overall economic activity related to transport (car manufacturing, gasoline, roads, etc.) is growing at lower rates than in Business-as-Usual scenarios—after all, the value added per unit of time when bicycling is small. This is one of the explanations of the lower rate of economic growth in this scenario as compared to the A1 scenario discussed in Kram et al., this issue.

[6] It is still controversial whether a shift to the so-called service sector can actually decouple money and material flows while avoiding a reduction in employment. The private service sector appears to have an overall energy use per worker similar to that of the manufacturing sector; only the public services sector, with inherent saturation tendencies, has a markedly lower energy use per worker [73].

Environmental degradation is, in most regions, gradually reversed as environmental amenities become part of "the good life." Negative side effects of rapid development are anticipated and dealt with effectively; externalities are priced. Subsidies on coal and electricity are gradually abolished [32]. Low-emission technologies and careful management and preservation of land become standard practice. In some regions, concerns about supply security and power shortages stimulate energy efficiency and novel supply options, such as cogeneration and fuel cells, in combination with government tax and subsidy schemes and environmental regulations. The rapid growth of the less-developed economies in tropical regions makes electricity an ever more important energy carrier; innovations in electric power generation significantly reduce the conversion losses [33].

The fossil fuel supply industries experience rather high rates of technological innovation. Learning-by-doing in exploration and exploitation (surface coal mining, oil and gas production) largely offsets cost increases due to depletion and geological/geographical conditions [34]. Technological and cost improvements in energy production from nonfossil options are large, thanks to government support and research, development and demonstration (RD&D) by multinational firms [35, 36, 37]. As conventional oil resources, and later, gas resources, dwindle in availability, these options provide a timely replacement. In combination with other environmental measures, GHG emissions will rise only modestly.

Sustainable development without climate policies? So far, the B scenario has been presented to described sustainable development with a whole set of environmental policies, yet without explicit policies directed a mitigating climate change. As such, it is intended to serve also as one of the baseline scenarios for the assessment of climate change impacts, mitigation and adaptation policies. However, it has been argued that the focus on global sustainable development in the B scenario is inconsistent with such a "no-control" assumption. In our view, however, this argument does not hold. First, much of the reductions in GHG emissions unfold because of developments that are not driven by the climate change issue per se. Energy productivity has been rising continuously over the last century, the replacement of coal by grid-based energy forms (e.g., electricity, gas) started decades ago, and important emission reductions have resulted from the desire for less polluted urban air. Similarly, the recent changes in consumer expenditure patterns and diet, and the installation of wind turbines and development of energy-efficient smart cars are not driven by GHG emission reduction policies. Second, some of the technologies with GHG emission reduction potential are developed for economic or strategic reasons, and for niche markets as part of the autonomous economic dynamics. Examples include the rapid, albeit late, development of cogeneration in Western Europe, the penetration of photovoltaics in rural areas in Africa without a central grid, and the efforts to develop fuel cells. Admittedly, the B scenario presumes that such efforts are successful and not pushed back by cost reductions in fossil-fuel technologies such as clean coal technologies (liquefaction and gasification, for instance).

Third, one should not equate changes in consumer decisions and firm behavior that may partly be influenced by climate change expectations and concerns, with climate change *policy*. The quest for environmental sustainability has led many people in the higher-income regions to make changes in their lifestyle, opting for a lifestyle that is less materialistic, more environmentally responsible, and more equitable. Environment-friendly behavior is part of a broader and, by now, recognized trend, that takes its form in local initiatives to make inner cities car-free, to global actions to rescue the tropical

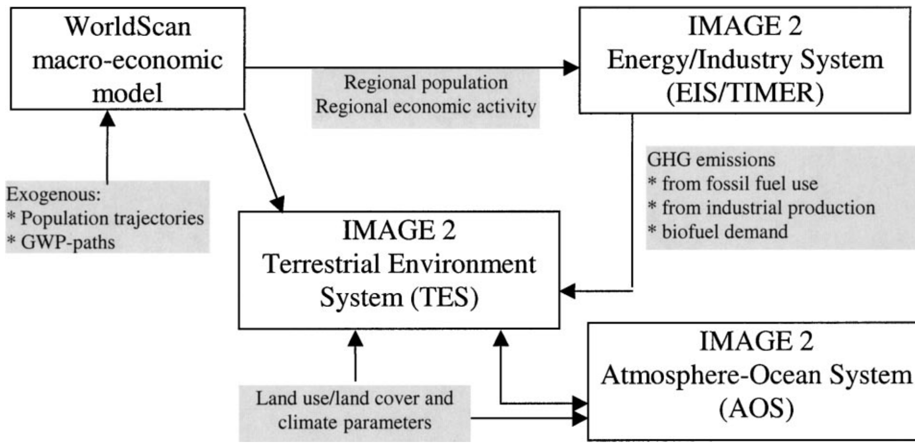

Fig. 1. Scheme showing the models used in constructing the IMAGE B scenario.

forests. These actions are not an explicit part of climate change policies, but have GHG emission reductions as one of their side effects. More in general, it is hard to distinguish climate change policies from public concern about climate change. Supposedly, climate change policy is a delayed response to public concern, but public awareness may change the behavior of millions of consumers and producers long before policies are enacted. Also, the link with R&D activities and policies is all but obvious: technological breakthroughs with important emission-reduction potential may occur totally unrelated to climate change policies, as has happened often in the past. It may be that the actual move toward a B scenario will occur if and only if concerns for more sustainable development paths trigger action in a variety of ways: grassroots actions for sustainability, the "greening " of multinationals, concerns about expected climate change—with all of these possibly reinforced by a serious warning from the climate system itself.

This brings us to a last point: Does it matter for the scenario formulation whether climate change occurs or not? One narrative is that climate change will only cause minor disruptions and that some people in a B future will praise themselves for having contributed to a more sustainable development path, whereas others will find evidence that those in favor of sustainability were over-cautious. If climate change turns out to have major consequences in a B future, it may be that effective global governance is not focused on reducing emissions but instead on adequate monitoring and adaptation with a climate fund organized along equity principles.

Modeling Tools

We used two simulation models: the macroeconomic WorldScan model and an adapted version of the IMAGE 2.1 model. The WorldScan model is a dynamic multi-sector, multi-region, applied general equilibrium model for the world economy. The IMAGE 2.1 model consists of three fully linked systems of models: the Energy-Industry System (EIS), the Terrestrial Environment System (TES), and the Atmosphere-Ocean System (AOS). Figure 1 indicates how the models are linked and used. Demographic developments are exogenous to the economic, energy, and land/food systems. There are only associative connections, such as a unidirectional decline of fertility and an increase of pollution-abatement efforts with an increase in GRP/capita.[7] Feedbacks from the energy, land/food, and climate systems onto the population and economic growth paths, for instance in the form of power shortages due to lack of investment capital or changes in diet or technology in response to climate changes, are absent. In the remainder of this section, we give a brief description of each of the [sub]models.

ECONOMY: WORLDSCAN

The WorldScan model simulates long-run economic growth using a neoclassical growth and trade framework (see Appendix Table A1 for classifications). The law of one price holds, and due to equality of technology and preferences, trade is determined by relative factor endowments. Economic growth is determined by population and total factor productivity growth. Sectoral production is based on Constant-Elasticity-of-Substitution (CES)-technology production functions. In the B scenario relatively smaller due to outflow into the formal, high-productivity sectors, which is itself an engine for economic growth.

The advantage of using WorldScan results as an input for the energy model described in the next paragraph is that the regional sectoral activity levels provide a macroeconomically consistent input. However, no feedbacks from the IMAGE-EIS system into the WorldScan model have been considered, and in this sense, our approach is "partial equilibrium." One may hypothesize, however, that in the B scenario the impact of such feedbacks on GRP is relatively small.[8]

IMAGE 2.1—ENERGY INDUSTRY SYSTEM

The IMAGE-EIS model uses 13 world regions and five economic sectors (see Appendix Table A2 for classifications). Model calibration is based on IEA statistics 1971-1990. Figure 2 gives an overview of the energy model in IMAGE-EIS.[9] In the Energy Demand (ED) submodel, sectoral activity levels (in US$) are translated into demand for energy services ("useful energy": electricity and non-electricity).[10] The next step is to allow for autonomous and price-induced changes in the Useful Energy Intensity (UEI). The Autonomous Energy Efficiency Improvement (AEEI) accounts for autonomous processes of energy productivity increases and for the leapfrogging potential in less-developed regions. The Price-Induced Energy Efficiency Improvement (PIEEI) simulates the process of investing in energy efficiency as a result of rising fuel and electricity prices, which in turn induces a process of learning-by-doing. The result of these two factors is a decrease in the UEI, which is highest in a situation of high activity

[7] In reality, there is a complex interplay between population, economy, and environment (see e.g., [74]). For instance, very skewed income distributions and inefficient and insufficient infrastructure, often in combination with institutional inertia and corruption, may impede economic productivity and growth. The large and rapid changes in age distribution give rise to both "greying" and "greening"; it is unclear how economies will accommodate this. In the future, we hope to use the Population & Health Regional (PopHeR) model to establish such links [75].

[8] The contribution of energy sectors to value added is below 5% for the OECD-economies and below 10–15% for the former Soviet Union, the Middle East and Sub-Saharan Africa. Moreover, in the B scenario, these values become less by 2100 because of the decline in energy intensity.

[9] The model has still several shortcomings, among them that the demand for non-electrical and electrical useful energy are not explicitly related; that the module on Combined-Heat-and-Power (CHP) schemes has only been implemented for Eastern Europe and CIS; and that possibly important technological options like coal liquefaction/gasification and hydrogen from fossil fuels or biofuels is not, or at best, implicitly dealt with.

[10] As an activity indicator for industry we use Industrial Value Added, and for the service sector we use Service Value Added. For transport and other sectors we use GRP; for the residential sector we use Private Consumption. All four are computed in the WorldScan model.

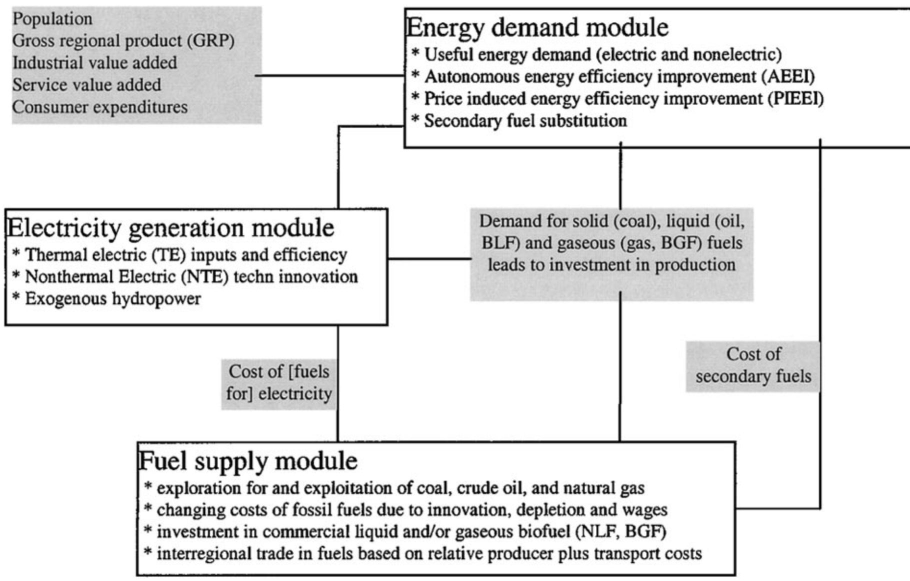

Fig. 2. Overview of the Targets IMage Energy Regional (TIMER) model as part of the IMAGE 2 Energy/Industry System (EIS).

growth, rising fuel and electricity prices, and catching-up. The resulting use of *secondary fuels* and *electricity* is calculated by multiplication with a time-dependent fuel-conversion efficiency, taking exogenous constraints into account. Secondary fuel prices are modified with price-adders to reflect taxes, subsidies, and perceived [dis]advantages. Such "premium factors" reflect nonmarket considerations about security, user convenience, environmental side effects, and lack of infrastructure [39]. It is an operationalization of increasing stringency of environmental standards and measures when people become more affluent, the so-called "environmental Kuznets-curve" [40, 41]. The main output from the ED submodel, then, is the use of solid, liquid and gaseous fuels, and electricity.[11]

The Electric Power Generation (EPG) submodel converts the demand for electricity in the required generating capacity. Hydropower capacity is installed according to an exogenous, time-dependent fraction of the hydropower potential. The remaining capacity is allocated among fossil electric (FE) and nonfossil electric (NFE) based on some unspecified mix of nuclear or renewable sources. The allocation is calculated from the relative generation costs, which for FE depend on fuel-specific investment costs, conversion efficiencies, and fuel prices. For NFE, the relative generation costs depend on specific investment costs, which decline with cumulated production. Generation costs plus additional transmission and distribution make up the electricity price for consumers.

All three Fuel Supply (FS) submodels (solid fuel, liquid fuel, gaseous fuel), are based on a conceptual scheme in which resources are discovered through exploration, produced through exploitation, converted into secondary fuels, and in the final stage, converted into useful energy. The costs, derived from the capital-output ratio, are determined by the simultaneous processes of depletion and learning-by-doing. The latter

[11] In these simulations we removed possible constraints, such as capital unavailability; hence, demand can also be met by supply. In the real world, regional economies may be in disequilibrium, and there can be large unmet demand, which also affects economic performance (see e.g., [76]).

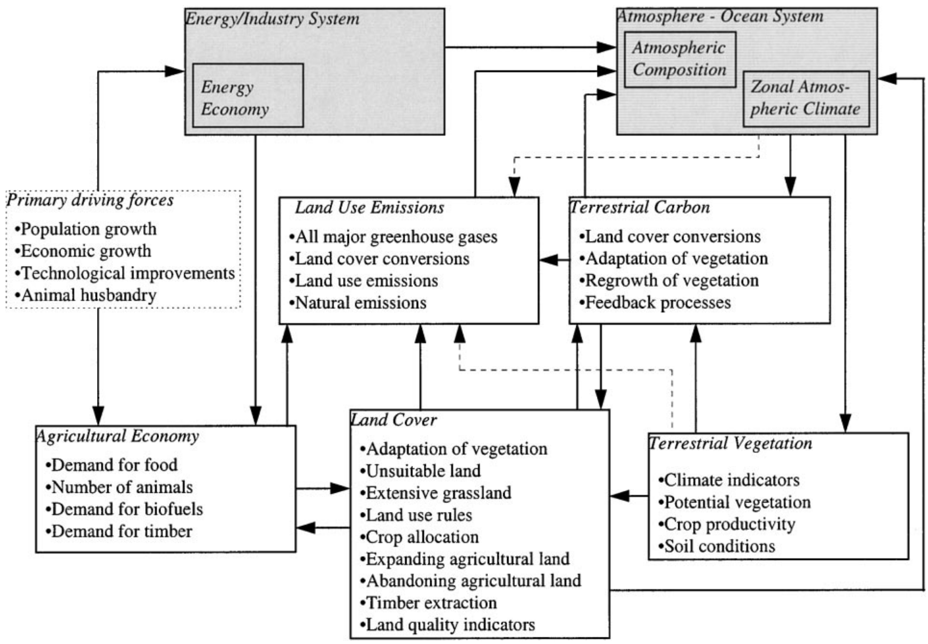

Fig. 3. The structure of the IMAGE 2 Terrestrial Environment System (TES).

is based on loglinear learning, the former on exogenous depletion multipliers. For liquid and gaseous fuels, there is a biomass-derived alternative (bioliquid fuel or BLF, biogaseous fuel or BGF) that penetrates the market once its relative costs make it competitive. Interregional fuel trade is calculated on the basis of relative cost differences and an estimate of transport costs as a function of distance.

The *emissions* of the most important GHG, carbon dioxide (CO_2), are calculated by multiplication of fossil fuel combustion with specific emission coefficients for coal, oil, and gas, and augmented with the GRP-related estimates of emissions from industrial production. The same has been done for sulfur dioxide (SO_2) nitrogen oxides (NO_x), methane (CH_4), nitrous oxide (N_2O), and Volatile Organic Compounds (VOCs). In these cases, the specific emission coefficients are assumed to follow time-paths, which reflect the abatement, measures, and control strategies judged consistent with the storyline. Emissions related to industrial production are calculated from relationships between production and specific emission coefficients.

IMAGE 2—TERRESTRIAL ENVIRONMENT SYSTEM AND ATMOSPHERE-OCEAN SYSTEM

The Terrestrial Environment System (TES; Figure 3) consists of several modules that simulate the dynamics of land cover and land use. The environmental characteristics are realized on a high-resolution grid base (0.5° latitude × 0.5° longitude) and the socioeconomic components for the same 13 world regions as EIS. The model has been calibrated for the period 1971–1990 using statistics of the Food and Agriculture Organisation (FAO). The Agricultural Economy model determines the demand for agricultural and forest products (i.e., land use demand). This demand is calculated from economic and demographic developments and the availability of agricultural and forest resources in each region. Trade between regions is also considered. The Terrestrial Vegetation model calculates the productive potential of available land resources on a grid basis from local (i.e., that of an individual grid cell) climate, terrain, and soil conditions. The Land Cover model links the regional land use demands with the grid-based productive potential. If the available land is insufficient to satisfy the land use demands, the land use-dominated, land cover types (i.e., agricultural land or regrowth forest) expand at the expense of natural vegetation. On the other hand, if the available land exceeds the demand for agricultural produce, agricultural land is abandoned and reverts back to the potential natural vegetation. This could be caused by increasing agricultural productivities, improved climate conditions, or decreased demands.

The resulting land cover changes are used as input to the Terrestrial Carbon model, which simulates the terrestrial carbon fluxes. The carbon uptake is driven by Net Primary Productivity (NPP, plant photosynthesis minus plant respiration), which is adjusted for local climate, soil, CO_2 concentration, altitude, land cover type, and history. NPP is allocated in biomass over the living parts of plant (leaves, branches, stems, and roots), from where a part slowly shifts to the nonliving biomass compartments (litter, humus, and charcoal). This organic matter then decomposes and its CO_2 is released to the atmosphere. The resulting net carbon flux between the atmosphere and biosphere is the Net Ecosystem Productivity (NEP).[12]

The consequences for changing land cover on NPP and NEP is also calculated by the Terrestrial Carbon model. Four major land cover conversions are distinguished: (1) natural vegetation to agricultural land (either cropland or pasture); (2) agricultural land to natural vegetation; (3) forest to “regrowth” forests; and (4) one type of natural vegetation into another. The latter occurs under the influence of climate change. When natural vegetation is converted into agricultural land or “regrowth” forest, part of the carbon in the living biomass is emitted to the atmosphere (through biomass burning, mimicking tropical-deforestation processes); part of it is stored in wood products (some stems and branches are harvested), part of it used as traditional fuelwood; and part moves into nonliving biomass and decomposes. Finally, the Land Use Emissions model simulates the non-CO_2 GHG emissions from land use-related sources.

The objective of the Atmosphere-Ocean System (AOS) of models is to compute climate change, sea level rise, and the build-up of GHGs and sulfate aerosols in the atmosphere. The Atmospheric Composition model computes the atmospheric concentrations of climate-relevant gases and sulfate aerosols based on CO_2 fluxes and other emissions computed by EIS and TES. The atmospheric concentration of CO_2 further depends on the flux of CO_2 between the atmosphere and the ocean. Both the biotic and physical/chemical CO_2 uptake are computed in the Ocean Biosphere and Chemistry model. The final concentrations of GHGs determine changes in radiative forcing. This is calculated in the Zonal Atmospheric Climate model, which is then coupled with the Ocean Climate model in order to compute the Earth’s heat balance. Changes in climate directly result from changes in this balance. Climatic change is calculated by changes in surface temperature and precipitation. Such climatic change directly affects the flux of carbon between the biosphere and atmosphere, the occurrence of sea ice, and several other processes. These interactions and feedbacks are an important feature of IMAGE 2 simulations.

[12] NEP is defined as NPP minus soil respiration. Negative values indicate a net release of CO_2 from the biosphere, while positive values indicate a net uptake of CO_2 by the biosphere. NEP is influenced by land cover, soil, and climatic factors.

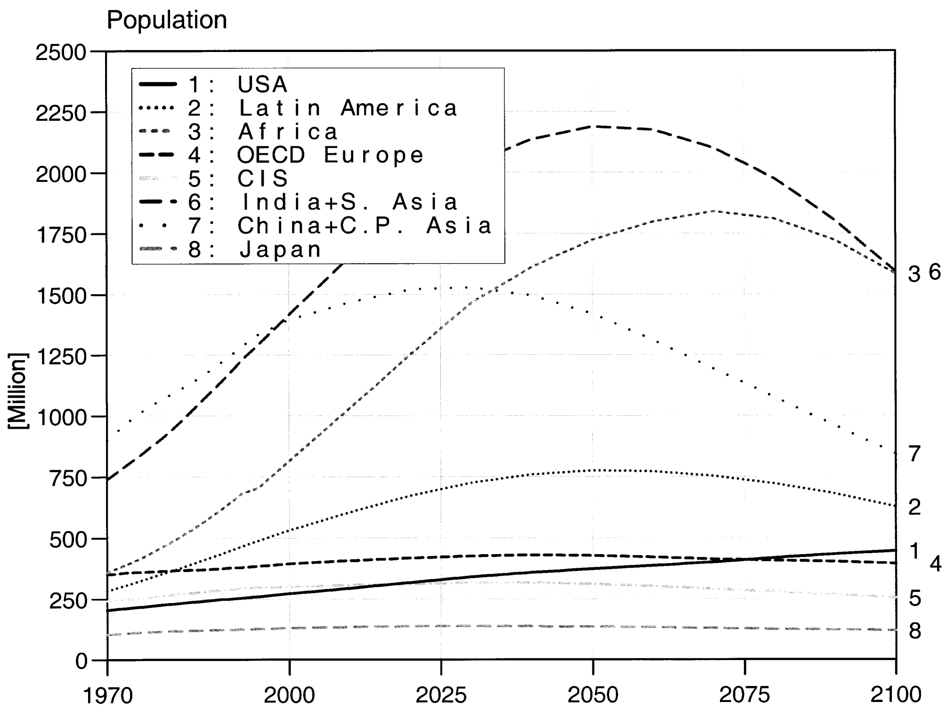

Fig. 4. Population pathways for selected regions in the B scenario.

Model Implementation: From Storyline to Simulation

POPULATION AND ECONOMY

In this section we briefly discuss the key assumptions for the B scenario. For *population*, we use an exogenous trajectory assuming a continuing decline a fertility, which results in a stabilization and then decline in world population by the middle of the next century [42]. Figure 4 shows population paths for the 13 regions.

Economic growth is simulated with the WorldScan model using these regional population projections. Gross world product has been exogenously fixed at a 2100-value of US\$ 330 10^{12} in argument with other groups participating on this modeling effort (see the first article of this issue for further details). Convergence applies to the elements discussed in the Economy: WorldScan. Regional technological parameters move toward the levels of the leader region (either Japan or the United States), regional long-run sectoral consumption shares move toward the level of those in the United States (which implies a gradual decline in the share of manufacturing sectors), and there is convergence toward the educational levels of the Organization for Economic Cooperation and Development (OECD). These convergence processes start in 2010. The leader region grows at some rate and the gap that would occur by 2100 at fixed growth rates is calculated for all regions. The regional parameter settings are then chosen in such a way that a desired closure of the gap occurs, leading to a growth path deviating from the one between 1995–2010.

The first key feature of the B scenario is the convergence of regional technologies, in the form of a stable pathway for the leader region, with the other regions trying to catch-up with this “leader.” Another important element of the B scenario is increasing environmental awareness, which is reflected in the model by the lower value shares of energy-intensive manufacturing sectors. Consequently, the time-path of the value share of the manufacturing sectors will decline to 7.5% of total consumption for all regions, with some regions rapidly moving away from their current consumption share because of the large difference between the current value and that of the United States. The third element in the B narrative is the assumption of steadily rising and converging education levels, resulting in an ongoing move from a low-skilled to a high-skilled labor force.

ENERGY SUPPLY AND DEMAND AND ENERGY-INDUSTRY EMISSIONS

Within the IMAGE-EIS model, assumptions have been made regarding fossil fuel resources, the relation between economic activity levels and useful energy demand, technology characteristics, and fuel prices. Assumptions on the *fossil resource base* come from estimates of ultimately recoverable conventional and unconventional (fossil fuel) resources from Rogner [43]. Ultimate resources assumed to be exploitable are huge: 110,000 EJ for oil and 837,000 EJ for gas. Most estimates include only conventional and a very limited part of unconventional occurrences, and are much smaller: 20,000–30,000 EJ for oil and gas each. For coal resources, we have also used Rogner's [43] estimates. They add up to a total of 262,000 EJ, of which 58,450 EJ belong to the categories proven recoverable (A), additional recoverable (B), and additional identified (C).[13] The capital output ratio (COR) of exploitation is assumed to rise on depleting a resource, but falls with cumulated production due to learning-by-doing.[14] Regional estimates of the size and exploitation costs of conventional and unconventional oil and gas resources of Rogner are used to construct the long-term supply cost curves for oil and gas as of 1971 (shown in Figure 5).[15] Only a part of the resource base is shown in Figure 5: the 22,000 EJ of oil deposits are somewhat higher that most current estimates of conventional oil, whereas the 65,000 EJ of natural gas occurrences include a significant amount of nonconventional resources, which are excluded from most current natural gas resource estimates of 10,000–15,000 EJ. It is assumed that the production cost of coal rises with increasing depth and labor wages. However, the production cost is partly offset by mechanization (in underground mining) and economies of scale (in surface mining). Parameterization is based on independent estimates of the COR as function of depletion (underground) and depth (surface).

Assumptions on the relation between economic growth (in monetary units) and energy use involve required energy services as a function of sectoral activity, fuel substitution and prices, and electric power generation technologies, among others. The regional useful energy intensity (UEI, in GJ/US$) as a function of per capita sectoral activity level was estimated from 1971–1990 International Energy Agency (IEA) data, assuming that at very high per capita activity levels, the UEI approaches a constant GJ/capita isoline. This saturation level in GJ/capita was set exogenously on the basis of past trends and regional differences in climate, population density, and industrial

[13] This is to be compared with the estimates of the World Energy Conference of 21,000 EJ anthracite and bituminous and 10,250 EJ subbituminous and lignite proved recoverable reserves. The WEC-estimate of additional recoverable coal reserves amount to about 17,000 EJ [77].

[14] On every doubling of cumulated output, the COR of exploration and exploitation is assumed to decrease by 5–10%. This reflects technical innovations such as improved geological tracking, use of water or gas injection, and directional drilling (see e.g. [78], [34]).

[15] The assumed learning-by-doing in the order of 5–10% COR-reduction for every doubling of cumulated production, is on top of the modest cost reductions assumed by Rogner and makes the actual production costs lower than the ones in Figure 5.

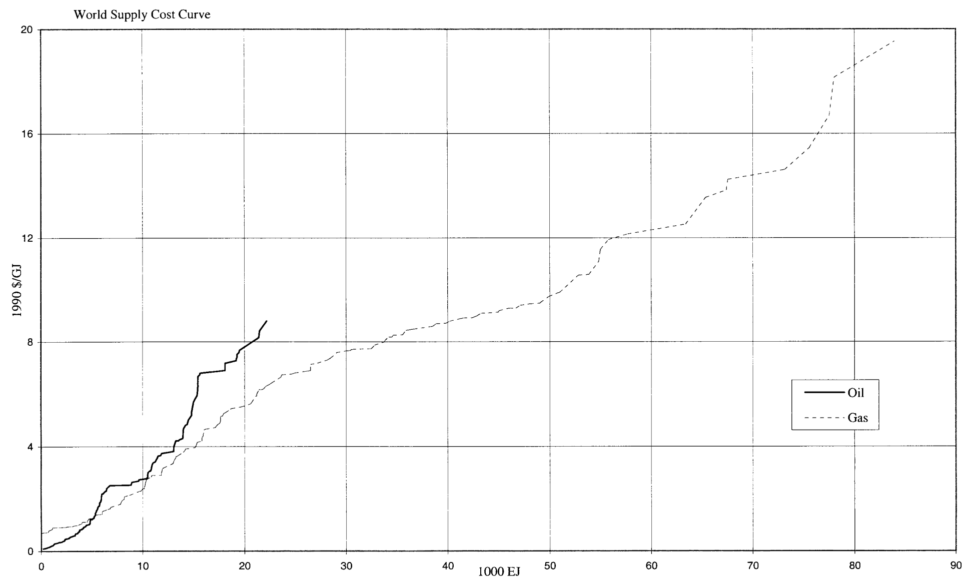

Fig. 5. The long-run supply cost curves for conventional and unconventional oil and gas resources in the B scenario, constructed from regional estimates based on Rogner (1997) [43]. Simulated prices differ because of innovations and transport costs.

characteristics. The resulting development of the UEI corresponds for the industrialized regions with declining income elasticities; in the other regions, it corresponds for most sectors with increasing but later on declining income elasticities. It is also possible to derive the useful energy per capita as a function of per capita sectoral activity level, as is shown by way of example in Figure 6 for the transport sector.[16] This representation allows a link with bottom-up, needs-oriented analyses such as those by Goldemberg et al. [15], Worrell et al. [31], and Sorensen and Meibom [44]. For instance, comparison with regional estimates of "fully satisfied per person delivered energy demand" as estimated by Sorensen and Meibom suggests that there is an improvement potential in the range of 8 (Japan) to 20 (United States) for the transport sector. For industrial use, the potential ranges from 5 (India + South Asia) to 15 former Soviet-Union: Commonwealth of Independent States (CIS), and for the residential and services sector from 10 (India + South Asia) to 60 (Latin America). This potential exists because the UEIs are based on "frozen efficiency" 1971 technology, and they will therefore decrease over time as the result of autonomous and fuel-price driven, energy efficiency improvements (see Figure 2).

The assumptions on these energy efficiency improvements, such as the learning curve determining the AEEI, the steepness of the conservation supply cost curves, the desired payback times, and the fuel taxes and perceived premium values are, as much

[16] This Useful Energy demand represents demand as if the user characteristics (techniques, behavior) had not changed since the base-year 1971. The derived curves represent, of course, only stylized hypotheses. In deriving them from the IEA-data, for some regions—notably CIS, Latin America and the Middle East—no acceptable calibration could be accomplished. This, in combination with the errors in estimates of the regional efficiency, fuel price and trade parameters, explains why simulated regional fuel use in the period 1971–1995 matches the IEA-data for several regions only within about 15%. More research on this topic will be done for the IMAGE 2.2 model.

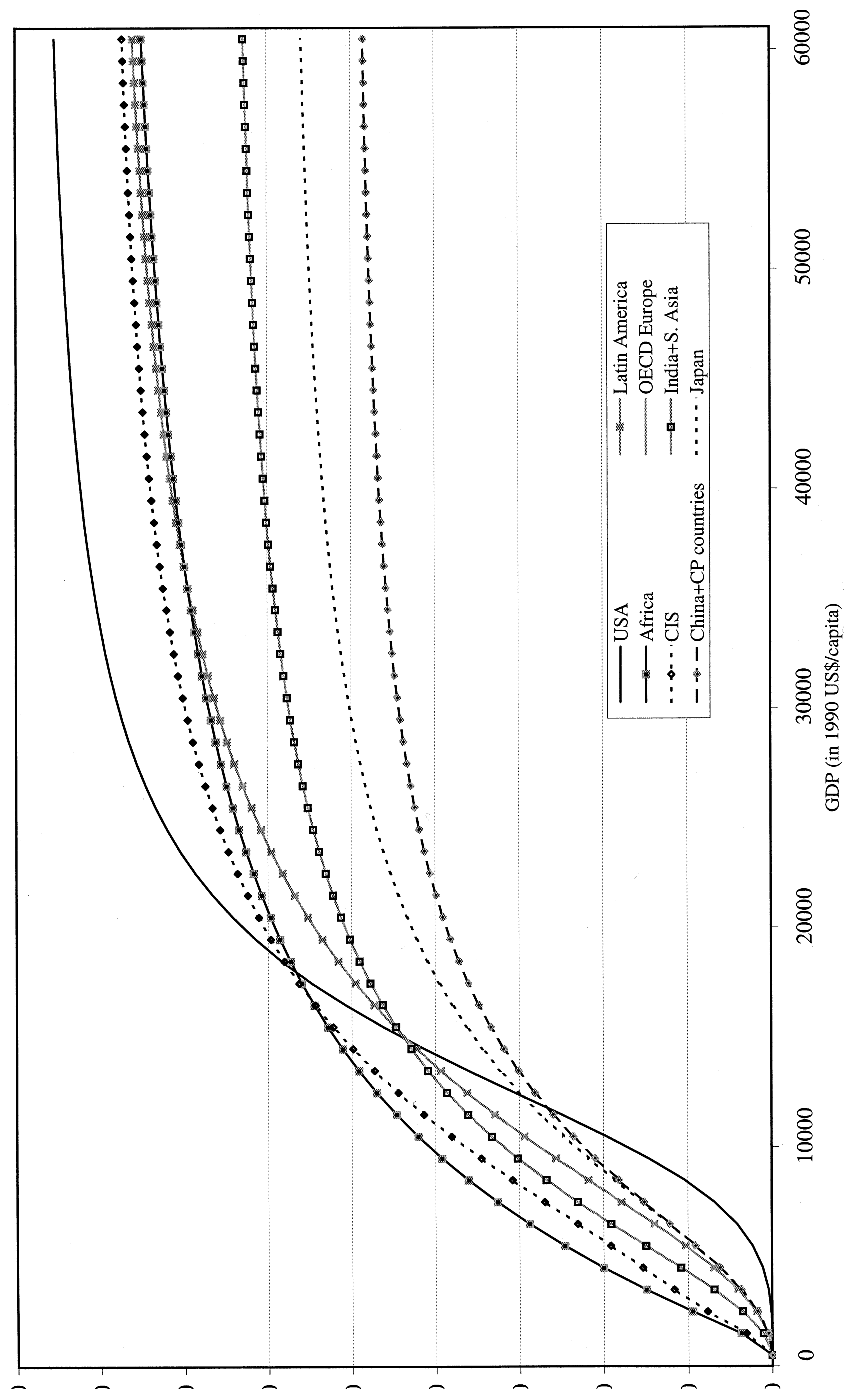

Fig. 6. Constructed relationship between per capita useful energy demand for non-electric and electric transport as a function of income (GDP/capita) in the B scenario.

as possible, based on empirical evidence from the past decades as part of the model calibration. For future years they are chosen in line with the narrative of the B scenario and are indicated in Table 1. Decentralized supply options such as small cogeneration, heat pump, solar heating panel, and photovoltaic systems are assumed to be part of these autonomous and/or price-induced energy efficiency measures. For the supply options, the key assumptions are also indicated in Table 1. Time-dependent constraints on regional fuel imports and exports are introduced if trade flows become implausible from an economic or strategic point of view. Convergences in energy technology in relation to the regional energy supply situation have provided the general guidelines in introducing these assumptions.

Energy-related emission factors are assumed to remain constant or show a modest decline to reflect increasing environmental awareness with growing affluence. Future SO_2 emissions, which contribute to aerosol formation and, thus, are important in assessing climate change, are for the near future based on the assumption that sulfur control policies are implemented that focus on mitigation of acidification and other environmental impacts of high sulfur levels. These reflect the most recent developments in environmental legislation and deviate from the earlier IS92 scenarios. For OECD Europe, Eastern Europe, and CIS, these controls are specified in the second Sulfur Protocol of the Geneva Convention on Transboundary Air Pollution in Europe [45]. For most of the other industrialized regions (Canada, United States, Japan), we take into account national plans for control of sulfur (e.g., Clean Air Act in the United States). After 2010, emissions continue to fall as a result of reductions in energy use, fuel substitution and desulphurization, and technologies such as Flue Gas Desulphurization in the electricity sector. In non-OECD regions, sulfur emissions in this scenario will also become increasingly controlled to avoid large local and regional negative impacts on human health, crop productivity, and ecosystems, particularly in Asia. Using a crude relationship between emission and income levels, emission factors in Asia are assumed to fall linearly by 75% between 2000 and 2050; in the other less-developed regions this reduction scheme starts 25 years later.[17] For methane, the losses due to fossil fuel production, including gas leakages, are assumed to decrease and approach current OECD Europe levels. Emissions of NO_x, CO, N_2O, and VOC due to road transport also decrease as a result of technical improvements in fuel efficiency and the penetration of clean fuels and electric cars. The same holds for NO_x emissions from industrial and utility boilers. For the most important halogenated hydrocarbons and sulphur hexafluoride (SF_6), we have used the emission trajectories as calculated by Fenhann (see in this issue), and our own estimates based on a recently updated version of the model of Kroeze [46]. The emission reductions resulting from the gradual penetration of clean technology in response to people's concerns about local and regional environmental quality, as well as those resulting from subsequent government policy initiatives, have the net result of bringing about the B scenario.

AGRICULTURE AND FORESTRY

The calculation of the GHG emissions from *land use*- and *land cover*-related sources requires making assumptions about dietary preferences, world food trade, animal husbandry and productivity, agricultural technology (cropping intensity and fertilizer use),

[17] The evidence for Europe suggests that impact from acidifying emissions, more than income, have provided the stimulus for emission reduction policies [47]. This may also be the case in parts of Asia. Here, we use the simplifying assumption of per capita income as the explaining variable.

TABLE 1
B scenario Assumptions in the Energy Industry System (EIS) of IMAGE 2

Indicator	General rule
AEEI	All industrialized regions follow a rate of 0.3–0.4%/year for their marginal energy-intensity decline; in other regions, a catching-up period is assumed during which the rate of decline increases for some decades to 1.0–1.5%/year. The actual AEEI-factor depends also on the rate of sectoral activity growth.
PIEEI conservation cost curve	It is assumed that the thermodynamical limit is 80–90% improvement. The marginal investment costs at which energy-efficiency can be improved when fuel prices go up is estimated from literature and statistical time-series. Most cost curves imply that an approximate two-third reduction in energy intensity is possible at less than US$ 10–40/GJ_{saved}, except for the transport sector, where it varies between US$ 40–100/GJ_{saved}. For electricity, this value is US$ 40–70/GJ_{saved}. The higher-end of these ranges is for the industrialized regions.
PIEEI desired payback time	Desired payback times vary from 0.5–2.0 years in past and present, linearly increasing to 2–5 years with time (and income).
PIEEI learning coefficient	The conservation cost curve declines with cumulated investments, using a learning coefficient in the range of 0.2–0.3 For most sectors and regions, this results in a maximum rate of decline of about 0.5%/year.
Useful to secondary conversion efficiency	Conversion efficiencies are assumed to increase an additional 10% between 1970 and 2100 for solid, liquid, and gaseous fuels; for traditional fuels it is assumed to double.
Secondary fuel substitution	The nonsubstitutable fraction of solid fuel (coal) in industry is assumed to decline to 0–15%, for liquid fuel (LLF) in transport linearly to 20% by 2100.
Secondary fuel tax	Oil products (LLF) and gas for transport are taxed at present levels, with an increase in less-industrialized regions up to US$ 3–5/GJ. All other taxes are at present levels and below US$ 2/GJ.
Fossil electric	The thermal efficiency of centrally generated electricity is assumed to converge across regions to 45–48% (coal), 50–53% (oil-HLF), and 53–58% (gas) by 2100, while specific investment costs slightly decline from 1990 levels.
Nonfossil electric	The learning coefficient increases gradually from 0 at present to 0.04–0.07 after 2020–2050, with the higher learning rate in the industrialized regions. After 2040, the resulting specific investment costs are in the range of US$ 1000–2000/kWe. No demonstration programs.
Electric power transmission	Transmission losses are assumed to decline, converging at 8% in 2100.
Coal	Capital-labor ratios in underground mining converge to present-day North American values. In surface mining, the learning coefficient is set at 0.05. Overhead processing costs are assumed to double.
Oil	Supply cost curves are derived from [43] (cf., Figure 5). In oil exploitation, the learning coefficient is set at 0.1.
Natural gas	Supply cost curves are derived from [43] (cf., Figure 5). In gas exploitation, the learning coefficient is assumed to increase from 0 to 0.05. Gas transport investments are assumed to converge across regions to 20% of exploitation investments costs.
Fuel trade	Resource-poor regions are given exogenous, time-dependent constraints on the fraction of regional fuel (coal, oil, gas, biofuel) they are allowed to import.
Biomass-derived fuels	The coefficients of a Cobb-Douglas production function in capital and labor and the land price are set in such a way that, in combination with a learning coefficient of 0.05–0.15, the production costs of biomass-derived fuels drop to US$ 2–3/GJ in land-rich regions (Latin America, Africa). No demonstration programs.

modern biomass or biofuel and timber demand, and emission factors. The latter are presented in Table 2.

Dietary preferences govern the daily caloric intake, which is a function of income, land availability, and a preferred level of food consumption. This daily intake increases between 1990 and 2100 by 4% (REF) to 19% (OECD90) in Annex I regions and by 44 (ALM) to 63% (ASIA) in non-Annex I regions (see Table A2 for acronyms). The contribution of livestock products in the regional diets decreases between now and 2100 to 17% in the OECD90 and to 20 % in REF, while it increases to approximately 10% in ASIA, and 12% in ALM.

World food trade is defined as a function of the self-sufficiency ratio (SSR, cf. Alcamo et al. [47]), which is the ratio between production and consumption. Overall, it is assumed that the amount of trade increases (the regional SSRs double between 1990 and 2050 and remain constant thereafter). For CIS, it is assumed that they turn from an importing region into an exporting region (SSR increases by 0.3 between 1990 and 2100), while China + Centrally Planned countries and the Middle East turn from exporting to importing regions (SSR decreases by 0.2 between 1990 and 2100).

For *animal productivity* (i.e., the amount of meat produced per animal) and the animal slaughter or off-take rates (i.e., the ratio between slaughtered animals and total animals), we assume that industrialized countries are close to the technical maximum level. All other regions are assumed to reach the current OECD Europe level when they reach the current OECD income level. Feed requirements per animal are a function of animal productivity and slaughter rates. We assume that almost all the feed stems from grass and fodder species (cf. Alcamo et al. [47]). The upward trend in cropping intensity will continue up to a region-specific maximum. This trend is defined by crop-specific management factors (cf. Alcamo et al. [47]), which allow crops to grow to a crop-specific maximum. The only exception is the management factors for grass and fodder species that have region-specific values. Regional fertilizer use increases as a function of income level in the course of time to the 1990 OECD level.

The demand for biofuels is met by growing four types of biomass energy sources: woody biomass, nonwoody biomass, sugarcane, and maize [48]. The demand for timber is related—using elasticities—to population, industry value added, and the regional extent of forest [47]. In addition, a reduction of timber use is assumed to be 0% in 2000, 40% in 2050, 60% in 2100, and linear in between. This factor reduces overall demand. The demand for timber and for traditional biofuels is met by wood extraction from forests.

Results

Narrative. In the B scenario, the economic modernization process that transformed the OECD regions over the last 50–100 years spreads throughout the world. Rising incomes lead to better birth control and medical services; the population stabilizes and then declines; and life expectancies rise. Economic growth is characterized by a continuing transition to an information- and service-oriented economy, with economic specialization and increasing trade. Ideas, developed during the 1990s, to tax capital flows and organize a technology transfer fund are becoming reality. High rates of foreign capital investments and incorporated technology transfer make China's and India's metallurgical and chemical industries among the most energy-efficient in the world. The analyses of the 1990s that indicated a 50–60% reduction potential in energy-intensive manufacturing in less industrialized regions turned out to be correct. In the urban residential and service sectors, and in rural areas in Asia, Africa, and Latin America, the use of fuelwood

TABLE 2
B Scenario Assumptions for Emissions Factors[a] in the Terrestrial Environment System (TES) of IMAGE 2

Indicator	General rule
Agricultural N_2O	The revised IPCC methodology for National Greenhouse Gas Inventories [82] is used, except for emissions from soybean fields, which are not distinguished as a separate crop in IMAGE 2, and emissions from animal excreta (see below).
Livestock (CH_4 and N_2O)	Apart from a decreasing emission per unit of product as a result of increasing efficiency, no assumptions are made on extra mitigation. Emissions of N_2O from animal excreta are calculated as a fraction of N excretion.
Rice (CH_4)	Country-specific emission factors are used for China, India, Indonesia, Italy, Japan, Republic of Korea, Philippines, Spain, Thailand, and USA. The global average is used for other countries [83]. Emissions per ha of harvested rice are assumed to grow to the 1990 US level (based on no extra organic amendments) in 2020.
Landfills (CH_4)	The emission factor for developed regions increases linearly to the 1990 OECD Europe level in 2050 and remains constant afterwards. Developing regions grow to the 1990 OECD Europe level as their GDP reaches the 1990 GDP of OECD Europe, according to the log of GDP. If the 1990 level exceeds this maximum level (in case of Canada, USA, OECD Europe, and Oceania), the emission factor remains constant. For this emission factor, all regions are assumed to have an abatement factor of 0% in 2000, 40% in 2050, 60% in 2100, and linear in between. The emission and abatement factors are put on top of the regional change in urban population, which is assumed to grow towards 80% of the total regional population.
Biomass burning (many gas species)	For biomass burning the emission factors of Olivier at al. [84] are used.
Related to deforestation	Clear-cutting forest for agricultural purposes leads to burning of its biomass for warm and tropical forest types. The biomass in temperate and boreal forests is assumed not to be burnt.
Savanna burning	For all regions, an abatement factor is assumed of 0% in 2000, 40% in 2050, 60% in 2100, and linear in between.
Burning of agricultural waste	For developed regions, Latin America and East Asia, the emission factors (expressed as unit gas per unit of food production) drop linearly towards the 1990 emission factor in OECD Europe in 2050 and remain constant afterwards. The other developing regions grow towards the 1990 OECD Europe emission factor when their GDP reaches the 1990 GDP for OECD Europe. This increase is linear with the log of GDP. In addition, an abatement factor is applied. For OECD Europe this factor is 0% in 1990, 50% in 2000, 75% in 2010, 90% from 2020 to 2100, and linear in between. For the other regions, this factor is 0% in year T_0, 25% in year $T_0 + 10$, 50% in year $T_0 + 20$, 75% in year $T_0 + 30$, 90% from year $T_0 + 40$ onward, and linear in between. $T_0 = 1990$ for Canada, USA, Oceania, and Japan $T_0 = 2000$ for Eastern Europe, CIS and China + centrally planned countries, and $T_0 = 2010$ for Latin America, Africa, Middle East, India and East Asia.

[a] Emissions are calculated as $E = A * E_f$, where E is emission levels, A is activity levels (e.g., area, animal population, fertilizer use, burning of biomass), and E_f is the emission factor (e.g., the emission per unit of area, animal, unit of fertilizer applied or biomass burnt). All emission calculations are according to Kreileman and Bouwman [81] except for the sources indicated above.

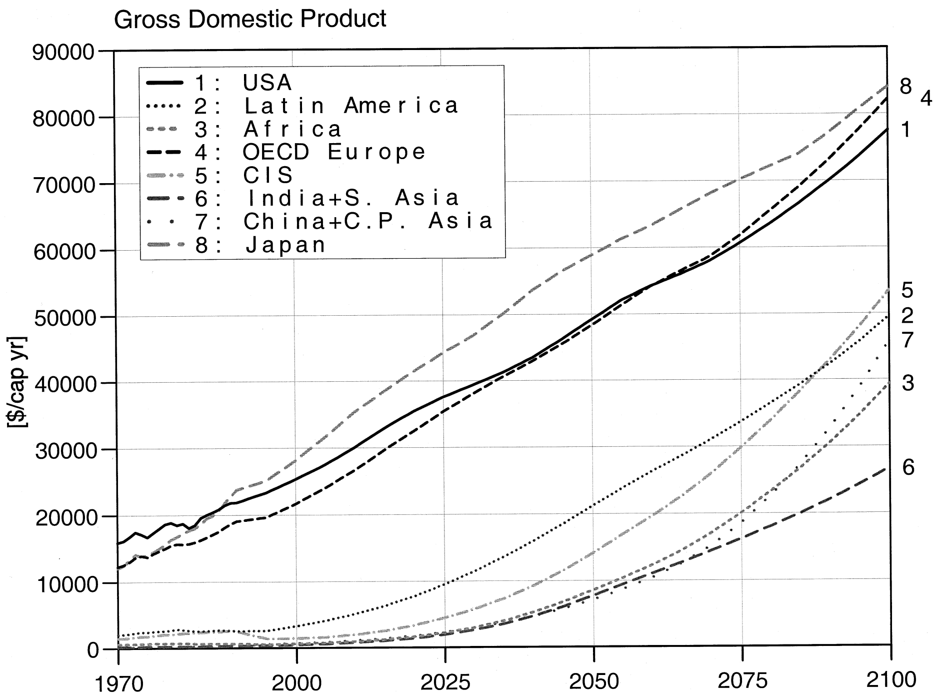

Fig. 7. Pathways of per capita GDP for selected regions in the B scenario.

is diminishing as commercial oil- and gas-based fuels become available. These events not only occur because of cost considerations, but also to relieve the pressure on forests. Governments of urbanized regions generate large investments for public transport systems, partly from fuel taxes, to mitigate congestion and combat local pollution. The "global supercar" and electric vehicles become a reality. There is a continuous flow of energy efficiency innovations at increasingly lower costs. The rapid increase in electricity demand cannot always be met, but large-scale investments from the industrialized regions permit large capacity expansions in the less-industrialized regions.

With regard to supply, the import of relatively cheap and abundant oil and gas in the first decades of the century is in most regions the preferred option. Industrialized regions such as Japan and Western Europe meet their targets for the contribution of nonfossil energy supply by successful RD&D projects and environment-related price policies. This is partly for strategic reasons, as world energy supplies become increasingly strained in spite of energy efficiency gains. The production costs of oil and especially gas, with its expensive transport and distribution infrastructure, start rising after 2030–2040 as depletion is no longer compensated by innovations. Several regions in the world respond with decentralized initiatives: small-scale biofuel production and wind- and solar-powered equipment compete, in combination with continuing energy efficiency improvements, with conventional energy supply systems and fuelwood.

ECONOMY

Figure 7 shows the resulting per capita Gross Regional Product (GRP). Within two or three generations, the presently less-industrialized regions, which by 2050 have a population of 7.3 billion, enjoy incomes similar to those in Western Europe in 1990s.

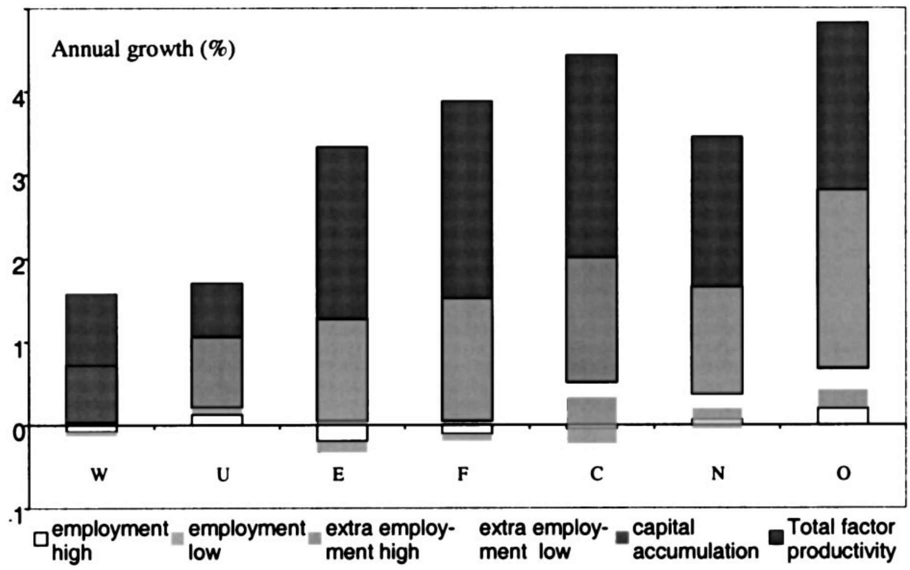

Fig. 8. Importance of factors contributing to economic growth in selected regions in the B scenario (region names corresponding to different bars can be found in Table A1).

All regions experience a gradual decline in the share of the manufacturing sectors, down to 7–10% after 2050. The relatively sheltered service sector grows rapidly in all regions, reflecting the transition to service-oriented economies. Due to comparative cost advantages, regions such as China + Centrally Planned countries experience a continuous growth in per capita Industrial Value Added, exceeding those in the OECD-regions by the middle of next century. The fraction of high-skilled workers in the total labor force almost doubles in regions such as China + Centrally Planned countries and Eastern Asia. At the same time, the ratio of low-skilled to high-skilled workers in the less-developed regions is falling from the present 2:1–5:1 range down to less than 2:1 by 2100, reflecting the result of drawing people from the informal sector into the formal sectors, and raising education levels.

Figure 8 presents the results of a growth accounting exercise, which shows the relative contribution to GRP-growth of employment, capital accumulation, and technology [49]. Changes in employment reflect the increase in the high- and low-skilled labor force as a result of population growth, education efforts, and changing participation ratios and age distribution.[18] The extra employment growth comes from changes in the market wage rate compared to the reference wage rate of job seekers: When the market wage rate increases, this leads to more labor flowing out of social security and the informal labor markets and flowing into the market sector. The contribution from capital accumulation to economic growth is mainly determined by income levels and savings ratios. Total factor productivity related growth reflects technological innovations. It is lowest for the United States because we assume that, at present, it is technologically most advanced. The high growth rate of the Indian economy is without precedent, and is mainly the consequence of converging savings ratios; in China + Centrally Planned

[18] High-skilled labor are those with more than ten years of education. The relative change in high- versus low-skilled labor supply stems only from projected changes in education levels.

countries, the catching-up in technology is a major factor behind economic growth. A final result is the change in the openness of the economy. The key elements in the model implementations are technological growth, changes in consumer preferences, and labor force developments.

Technology is defined as the way in which inputs, labor, capital, and intermediate products are used to generate output. It is an exogenous, but not constant, factor of economic growth and is represented by the total factor productivity (TFP) index, which accounts for the part of growth in a sector that cannot be attributed to increases in inputs. TFP is broadly interpreted as the productivity of all production factors—that is, low- and high-skilled labor, capital, and natural resources—and includes not only sectoral technical change, but also the impacts of infrastructural investments and institutional developments. Empirical estimates have indicated that TFP-growth is a basic factor in explaining growth [38]. We use technology convergence to implement the B storyline, where convergence means that output generated by any given combination of inputs is the same across countries.

Consumer preferences indicate the consumption mix and level that households in a region wish to obtain. Convergence of consumer preferences and changes in preferences toward more environmentally sound consumption patterns are two other elements in implementing the B scenario. The shares of different sectoral products in consumer expenditures are assumed to converge across regions for the same level of total consumption. The expenditure shares in the model consumption function are derived maximizing utility, given the household budget constraint, consumption levels, and prices. Savings ratios are also assumed to converge.

The development of the *labor force* in WorldScan is determined by the growth in the total population, the development of macro participation rates, the skill composition, and the share of the labor force working in the informal sector. Factors such as health are not included, although these could be interpreted as changes in the skills or quality of labor as well. Changes in the participation rates equal the changes in the ratio of people between 15 and 65 years old and total population. Informal sectors in developing regions employ a major part of the labor force. This sector becomes as the sum of regional exports plus imports, divided by two times the GRP. In line with the B narrative of an open world, trade among regions expands. Yet, it turns out that there are divergent trends, because the shift away from nonsheltered resource-intensive manufacturing causes a declining openness in some regions.

ENERGY AND RELATED EMISSIONS

The useful energy intensity, or UEI, declines significantly, resulting from intersectoral shifts and intrasectoral output changes—being one element of the dematerialization in this B scenario (Table 3). UEI drops in the industrialized regions by an average 1.35 %/year over the next 100 years. In the less-industrialized regions, it first rises to a maximum between 1990 and 2040, and then starts falling, resulting at an overall downward trend of 2–3 %/year. In the most advanced region (OECD), autonomous energy efficiency improvement, or AEEI, for non-electricity is a modest 0.2–0.5%/year. Between 2000 and 2030, AEEI reaches a high of 1.0–1.8%/year in the less-industrialized regions, and afterwards declines to 0.2–0.5%/year, representing the technological catching-up of these regions. The rates are much lower for electricity, which is one reason why the fraction of electricity in total useful energy demand rises significantly, to 30–60%. The Price-Induced Energy Intensity Improvement, or PIEEI, which had been significant before 1990 in the industrialized regions, only becomes prominent after 2020–2030 as

TABLE 3

Final Energy Intensity of GRP (MJ/US$) and the Annual Change Rate (%/year) between 1990 and 2100 in the B Scenario. Traditional Biomass Use is Included

Region	Final energy intensity				Annual change rate in final energy intensity (1990–2100)	Primary energy intensity				Annual change rate in primary energy intensity (1990–2100)
	1990	2020	2050	2100		1990	2020	2050	2100	
OECD90	7.3	4.9	2.9	1.4	1.5	9.1	6.1	3.3	1.5	1.6
REF	64.3	23.4	7.5	1.8	3.2	98.7	30.5	10.9	2.1	3.4
ASIA	48.6	16.6	5.4	1.4	3.2	56.1	22.5	7.2	1.5	3.2
ALM	18.5	12.1	5.1	1.3	2.4	20.4	16.3	7.5	1.6	2.3
World	13.8	8.8	4.5	1.4	2.1	17.5	11.5	6.0	1.6	2.2

TABLE 4
Final Use of Commercial Secondary Fuels and Electricity (EJ). Traditional Biomass Use is Excluded

	Commercial secondary fuels				Electricity			
Region	1990	2020	2050	2100	1990	2020	2050	2100
OECD90	90.9	100.0	85.7	65.4	23.9	54.5	56.8	48.7
REF	50.5	28.0	25.1	15.4	8.5	10.6	20.1	15.7
ASIA	34.6	84.0	103.5	63.7	4.3	35.8	92.9	76.9
ALM	21.3	75.0	106.6	79.3	1.8	21.3	90.4	78.6
World	197.2	287.0	320.8	223.8	38.6	122.1	260.1	219.9

fuel prices start to rise in several regions. In fuel-scarce regions such as India + South Asia, up to half of the technical potential is being captured. The PIEEI remains low for electricity because of low price-responsiveness and the penetration of cost-stabilizing nonfossil fuel options.

Final energy demand in the form of commercial secondary fuels increases continuously until 2050, after which it starts falling to about 238 EJ, just below the 1990 level (250 EJ) (Table 4). One reason for this pattern is the phasing-out of traditional fuels. Electricity use continues to rise much faster, from 39 EJe in 1990 to 220 EJe by 2100. This reflects the gradual penetration of electricity as the preferred energy form, first in the industrial, and then in the residential and service sectors. The largest increase in secondary fuel use is in the transport sector, where liquid fuels dominate in the first half of the next century, after which gaseous fuels enter the market and make up to one-third by 2100. Coal remains an important fuel only in industry (up to 40% in some regions); the residential and service sectors switch almost completely to liquid and gaseous fuels.

In combination with efficiency increases in the energy supply system, there is a considerable decline in the ratio of primary energy and GRP (Table 2). For regions such as China + Centrally Planned countries, India + South Asia and Eastern Europe/CIS, the overall energy intensity is falling at an average 3%/year. Most of this decline occurs between 2000 and 2050. This rate is much lower than the realized reduction of 4.6%/year between 1980 and 1997 in China [50]. The constituent factors are an AEEI rate of 1.0–1.5%/year in the next few decades, a dematerialization in the industrial sector thereafter of 1–2%/year, an increasing role for the less energy-intensive service sector, and an improvement of conversion efficiencies on the order of 0.3%/year.[19]

The *electricity generation* system undergoes a huge expansion in the B scenario. Latin American, India + South Asia, China + Centrally Planned countries, and Africa have the largest installed capacity by the end of next century, each having over 5000 GWe. The rate of expansion is very fast; the expansion from 24 GWe to 200 GWe in China + Centrally Planned countries between 1970 and 1994 provides an indication of what is to be expected. In all regions the nonfossil options start to penetrate between 2020 and 2050, reaching globally by 2100 over two-thirds of the total input including hydropower. Fossil fuel use peaks around 2045 at a level of 340 EJ with gas becoming increasingly important; by 2100 it has declined to some 85 EJ, which is roughly the present level. The main driving force for the penetration of nonfossil options is the

[19] It should be noted that this figure needs careful interpretation as we have assumed zero conversion losses for nonfossil options. It would also be more correct to calculate the energy-intensity decline with reference to the ppp-corrected activity levels because we assume that activity levels grow from 1990 levels in international dollars towards the 2100 levels indicated in Figure 7. Such a correction would result in 0.5–1% point lower decline rates.

highly successful development of solar, wind, safe nuclear, and others: their costs fall to levels of 3–5 US cents/kWh by the middle of next century. This makes them increasingly competitive as coal, oil, and gas prices continue to rise.[20]

With regard to the *fossel fuel supply* side, a number of developments occur simultaneously. In some regions there is a marked rise in the production costs of oil and natural gas, up to levels of US$ 6/GJ (US$ 40/bbl). This initially induces expanding oil imports from major suppliers such as the Middle East and CIS, where the costs to produce crude oil and natural gas remain below US$ 3–4/GJ in the next century. A second response is that coal remains relatively competitive and production expands to twice the present level (180 EJ or over 6 billion tons/year around 2040). The cost of coal remains below US$ 1–2/GJ in almost all regions, which is partly due to expansion and innovation in surface coal mining. Especially China + Central Planned countries, India + South Asia, Latin America, and Africa remain or become important coal producers and/or importers. A third response is increasing investments in energy efficiency, coupled with the learning-by-doing process. A fourth response is the gradual penetration of biomass-derived liquid and gaseous fuels to plateau levels of 100 EJ/year around 2050, one third in each of the regions OECD-EE-CIS, Asia and Rest of World. Use of modern biomass becomes especially important in the United States, Latin America, India + South Asia, and Africa. Globally, the pattern of fossil fuel trade changes from one in which the OECD is the major importer and the Middle East the major exporter, to one in which CIS and OECD become major exporters and the presently less-industrialized regions become major importers. It should be noted here that the simulated fuel trade flows are quite sensitive to resource production and transport costs and price elasticities, hence, these results are merely indicative of what could happen.

World primary energy use reaches about 813 EJ/year around 2050, after which it starts declining to about 514 EJ/year by 2100 (Figure 9). In the first decades of the 21st century, there is almost a doubling in fossil fuel use due to the growth of population and economic activities in combination with the first stages of industrialization and increasing conversion losses as electricity becomes the dominant end-use form. In the second half, there is a reversal when population stabilizes and then declines, and economic growth becomes less material-oriented. Renewables increasingly penetrate the market as they become competitors of fossil fuels. Cumulated oil and gas use in 2100 reaches nearly 39,000 EJ, which suggests that the world will have to have learned to exploit unconventional oil and gas resources, such as tar sands and methane clathrates, at acceptable costs. Carbon emissions from the burning of fossil fuels increases to about 12 GtC/year in 2050, then start declining as the transition to nonfossil options continues. Carbon emission per capita still differs among regions, declining in the industrialized and rising in the less-industrialized regions to a range of 0.5–1.5 tC/capita/year in 2100.[21]

[20] The decreasing competitiveness of coal can be related to its perceived inconvenience and dirtiness, in line with strong acid rain abatement strategies. An alternative interpretation could be that clean coal development processes, such as coal desulphurization and liquefaction/gasification, drive up its price as a clean fuel. Such processes are not considered explicitly in this scenario.

[21] Comparisons with the projected primary energy use and related carbon emissions in 2010 after corrections for economic growth and regional differences show at the world level only a minor difference with the Forum scenario of the European Commission in which "the world moves more to consensus and cooperative international structures . . . and the process of global integration produces new imperatives for collective public action. National, European and international institutions are gradually restructured so as to be able to deal more effectively with broader, more complex shared problems and interests" [79]. However, the regional projections differ: in the B scenario the OECD regions, Africa and India + South Asia have lower energy use, whereas Latin America, Eastern Europe, CIS, and China have higher energy use than in the EU forum scenario. Such changes may reflect the rapid changes in perception of how regions are developing.

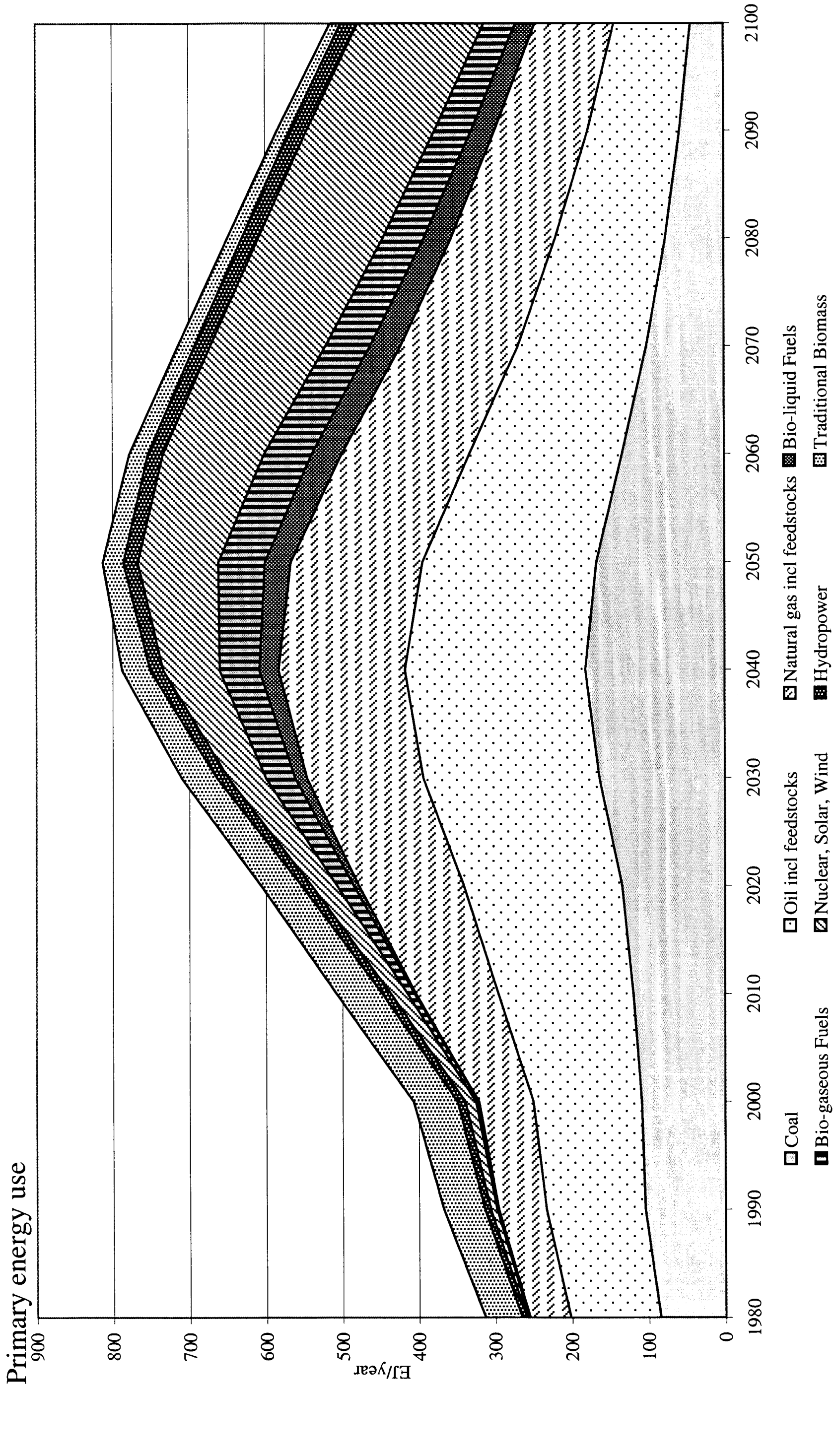

Fig. 9. **World primary energy use in the B scenario.**

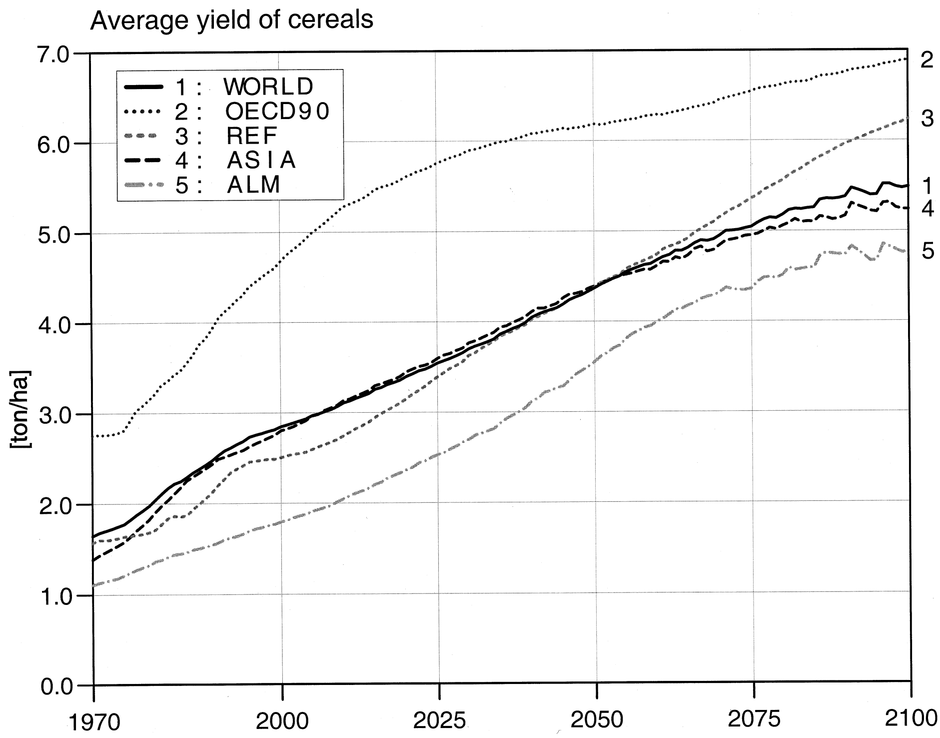

Fig. 10. Simulated average yield of cereals (aggregated from crops: temperate cereals, rice, maize, and tropical cereals as given in Table A2) for four world regions in the B scenario. The actual crop yields are determined from rain-fed potential yields, soil conditions, and management levels. The crop yield represents yield per harvested crop, and does not include cropping intensity.

Emission of non-CO_2-GHGs (CH_4, SO_2, NO_x, CO, VOC) from fossil fuel combustion show a similar pattern as the CO_2 emissions: after an increase of 50–100%, they gradually decline to below present levels. This implies for China + Centrally Planned countries, for instance, an increase in the emissions to 20 MtS/year by 2010—60% above 1990 levels—and then a decrease to about 9 MtS/year in 2050 and 4 MtS/year by 2100. The resulting global sulfur emissions increase until 2020–2030, then decrease to levels below the representative sulfur control scenarios described in Posch et al. [51], IIASA-WEC [52] and Grübler [53]. The dominating contributors of CFCs are C_2F_6 (as a substitute for CFC applications), SF_6 (from the electricity sector) and HFC-134a, 143a and 236fa (as CFC applications substitutes.

AGRICULTURE AND FORESTRY AND RELATED EMISSIONS

Results for the B1 scenario illustrate the consequences of the assumptions regarding agricultural production and land use (Figures 10–13). Average cereal yields for REF, ASIA, ALM, and the world increase approximately by a factor of four (Figure 10), while cereal yields for OECD start from a higher initial value and increase by only a factor of two.

Examples of development of livestock are given in Figures 11 and 12. The total cattle population includes dairy and nondairy cattle. The productivity of nondairy-cattle populations changes as a result of slaughter weight and off-take rate. The total number of cattle (i.e., milk plus beef cattle) shows a decreasing trend in the next century. The

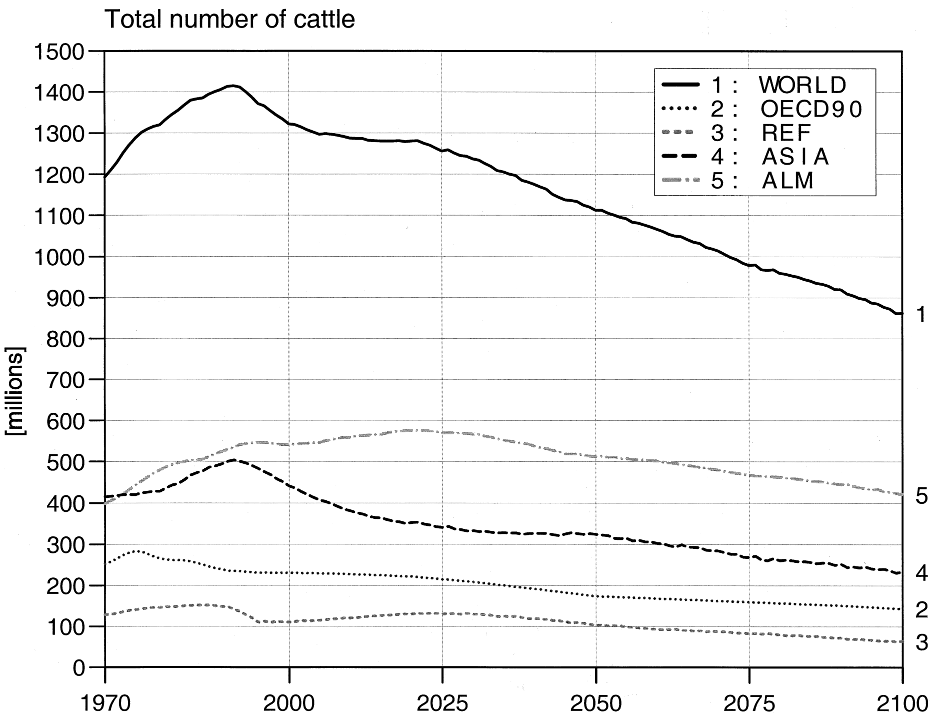

Fig. 11. Simulated total number of cattle (dairy plus nondairy) for four world regions in the B scenario.

population of dairy cattle decreases because the increase in productivity is faster than the growth of milk consumption. The number of slaughtered animal (beef) increases in the period 1995–2060, which is the net result of increasing animal productivity and increasing consumption of meat.

Based on the demand for food, feed, timber, and biofuels, the IMAGE 2 model computes future changes in land use and land cover (Table 5). For Africa and the Asian regions, the increasing demands lead to an increase of agricultural land in the first half of the next century and a decline thereafter. In the other regions, total agricultural land decreases continuously over the next century. These dynamics lead to a worldwide expansion of forest area (30%) in the latter half of next century. Plantations for modern biomass or biofuels show a strong increase in almost all regions. Cultivation occurs on surplus agricultural land and does not lead to additional deforestation like in many earlier scenarios [4, 48]. Globally, the major increase in demand for food and feed in the initial period 1990–2030 is almost completely compensated by an increase in productivity. This results in a minor decline of global forest area up to 2030, while beyond 2030, forest areas start expanding again after agricultural land is abandoned. There are, however, regional differences in this pattern (Table 5). In East Asia and Africa the expansion only starts late in the second half of next century.

As a result of the simulated deforestation patterns up to 2030, CO_2 emissions of biomass burning due to deforestation remain an important source of the CO_2 emissions. As a result of increased timber use, global CO_2 emissions stemming from the slower decay of timber products (with an assumed life time of 10 to 100 years) become more

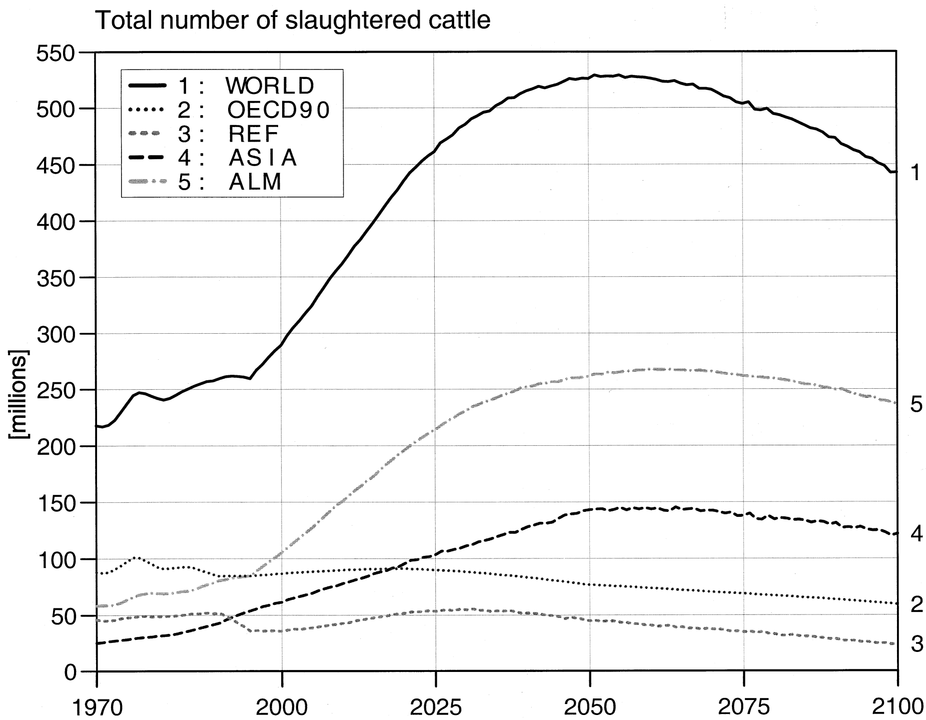

Fig. 12. Simulated number of slaughtered cattle for four world regions in the B scenario.

important after deforestation halts. These two sources result in a CO_2 emission of about 1 GtC/year up to 2030, and about 0.5 GtC/year thereafter (Figure 13). While the CO_2 emission contribution of land use-related sources is small compared to the energy-related sources, emissions of CH_4 and N_2O from land use-related sources dominate over those from energy. The increase in population and livestock results in increasing emissions of most of the land use-related sources of CH_4 in the first half of the next century and a decline thereafter (Figure 13). This results in an emission level in 2100 that is close to current levels. The trend of land use-related N_2O emissions is strongly determined by the number of animals and the use of synthetic fertilizer. These emissions show a pattern similar to that of the land use-related sources of CH_4. For the emissions of other gases (Figure 13), most of the trends are related to the trend of deforestation and the resulting CO_2 emissions.

OVERALL EMISSIONS AND THEIR CONSEQUENCES

Table 6 presents the contribution of different categories to global CO_2 emissions. The global CO_2 emissions peak at 12.8 GtC/year around 2040, after which there is a decline to below 1990 levels. The global CO_2-equivalent emissions show a similar trend: an increase from about 14 GtC/year in 1990 to a peak of about 19 GtC/year in 2040, and then a decline to about 11 GtC/year in 2100. As a consequence, the CO_2 concentration increases to 543 ppmv in 2100, and the CO_2-equivalent concentration to 606 ppmv in 2100, with both showing a stabilizing trend at the end of the next century. The increase in the global average surface temperature between 1990 and 2100 resulting from the buildup of CO_2 and other GHGs is about 1.4°C, while the computed sea level rise is about 30 cm between 1990 and 2100. In contrast with a stabilizing trend for the

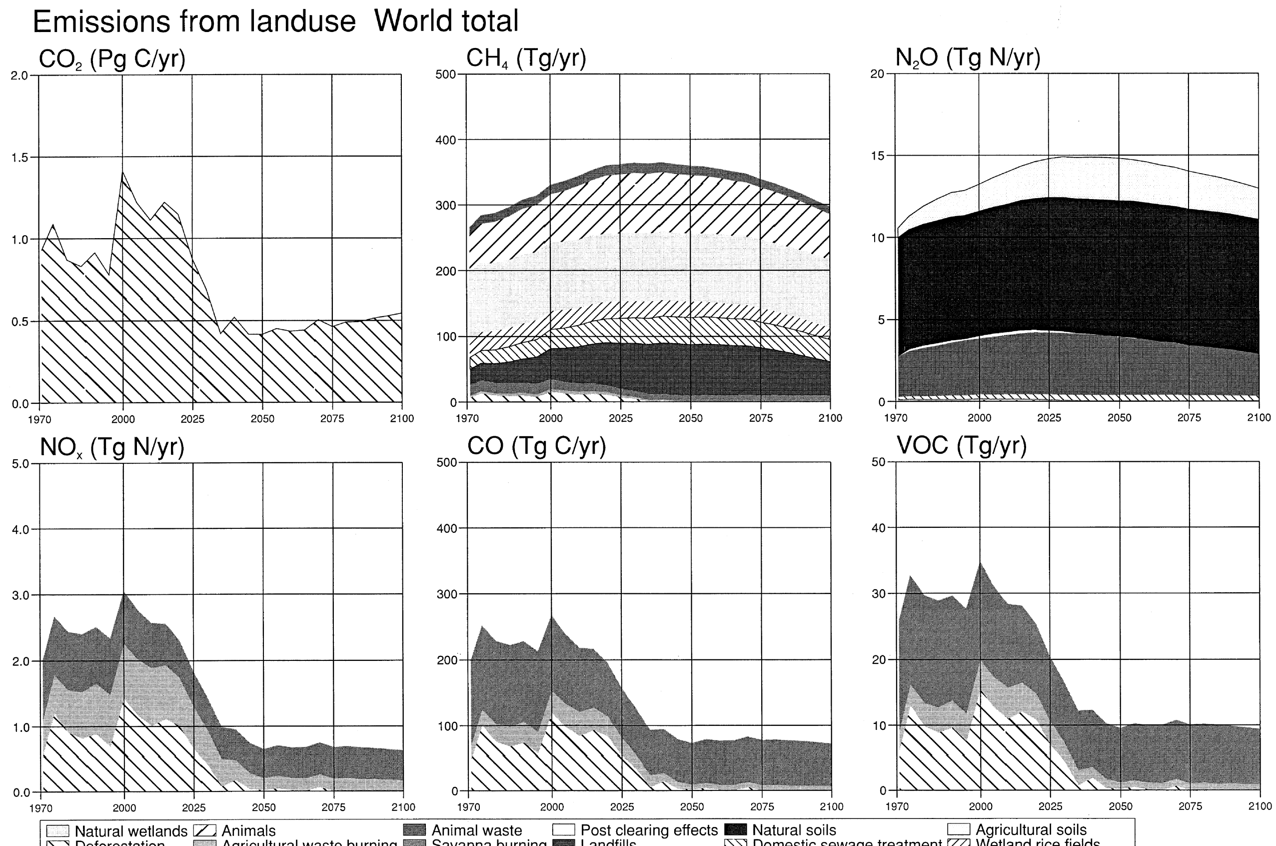

Fig. 13. Global emissions of land use-related sources of the major GHGs and ozone precursors in the B scenario.

TABLE 5
Regional Areas of Cropland, Biomass Energy, Pasture and Fodder Species, Forest and Total (million ha)

	Cropland				Biomass energy				Pasture and fodder species				Forests				
Region	1990	2020	2050	2100	1990	2020	2050	2100	1990	2020	2050	2100	1990	2020	2050	2100	Total
Canada	46	25	20	19	0	2	6	4	28	18	12	10	573	596	633	679	951
United States	190	149	174	198	2	2	13	9	243	183	149	134	304	354	368	379	915
Latin America	149	168	154	99	1	16	43	46	590	417	262	182	912	1,001	1,094	1,241	1,997
Africa	180	254	273	196	1	28	49	24	904	1,087	895	515	584	383	452	697	2,928
OECD Europe	91	83	88	76	1	2	13	9	64	52	43	34	157	174	167	199	569
Eastern Europe	48	29	24	16	1	1	10	7	20	14	8	5	38	53	60	70	114
CIS	230	180	130	82	0	3	31	39	371	305	204	143	1,108	1,229	1,291	1,410	2,163
Middle East	67	98	103	89	0	1	4	4	203	279	268	279	32	2	2	2	654
India + S. Asia	213	255	225	109	0	7	47	24	22	28	40	25	128	90	73	150	503
China + CP countries	109	104	113	70	0	3	28	12	525	699	661	342	154	46	49	331	1,168
East Asia	60	60	56	37	0	2	19	14	14	21	22	19	206	193	180	190	305
Oceania	48	85	61	41	0	1	1	1	450	301	223	210	62	120	173	181	773
Japan	4	7	8	5	0	1	4	2	0	0	1	0	19	15	10	13	31
World	1,436	1,498	1,429	1,038	8	68	268	194	3,435	3,404	2,785	1,899	4,277	4,258	4,551	5,543	13,071

TABLE 6
Total Emissions and Climate Impacts

	CO_2 Emissions (GtC/year)				Concentrations (ppmv)		Temperature increase	Sea level rise
	Energy	Industry	Land use	Total	CO_2	CO_2-equivalent	(°C since 1970)	(cm since 1990)
1970	4.2	0.1	0.9	5.2	325	332	0.00	0
1990	6.3	0.2	0.9	7.4	357	381	0.28	2
2020	9.8	0.2	1.1	11.1	419	463	0.72	8
2050	11.5	0.2	0.4	12.1	492	547	1.18	15
2100	5.0	0.2	0.5	5.7	543	606	1.65	32

concentrations, the sea level rise in the second half of the next century is faster than in the first half. This is caused by the slow response of the oceans to changes in the climate system. A temperature rise of 1.4°C and a sea level rise of 30 cm may seem rather small, but present understanding suggests that this may cause serious disruptions to natural vegetation and human settlements in various regions of the world. In the context of the present scenario, one may argue that there are enough resources and ingenuity to adapt to such changes, but one might as well speculate that such adaptation will have adverse consequences on economic growth or at least on disposable income. It should also be noted that the choice of the year 2100 as the final year tends to obscure the fact that fossil fuels will still play a role in the 22nd century, and that global CO_2-equivalent emissions will continue to rise for a period of at least several decades and the impacts will last for even longer periods.

Forces against a B future. Clearly, the future sketched above may not unfold for a variety of reasons. A first question is whether the "modernization process" can continue unhampered worldwide throughout the next century. There are signs that the forces towards cultural identity and diversity are strong and against globalization and liberalization (see e.g., [54]). The reality of a global village may remain the privilege of a thinly spread elite, which becomes increasingly indifferent to local concerns [55]. What is increasingly seen as market fundamentalism may give way to other forms of fundamentalism. Rapid economic growth will require huge organizational skills, and even more so in a world with rising population and diminishing resources. Second, the pledge to sustainable development by many government and other organizations demands regulation—of trade and finance, of workers' rights, environmental matters, etc. Present trends show that, even if governments and multinational corporations cooperate in a vein of "enlightened self-interest," there are many opportunities for less bonafide people and organizations to circumvent such regulations and exploit free-rider behavior. Third, people in the industrialized regions and the more affluent ones in the less-industrialized regions may not be willing to sacrifice present consumption-oriented lifestyles, or may resist the changes needed to fit the new, efficient technology. This will pose severe constraints on the ability of national governments to initiate and persist in policies towards sustainability, such as intensified R&D, as governance and institutional regimes erode and social coherence deteriorates.

Such threats, a staggering modernization process, the failure to shape international governance structures, the inability to deal with large-scale unemployment, and other problems may well lead, in combination with pockets of extreme wealth, to great social tensions [9, 56].[22] After periods of turbulence, some regions may manage to restore community-based, local forms of governance and resource management. For this purpose, they may wish to protect themselves from free trade and financial market practices that undermine such initiatives. In other regions, the emphasis may be on their own cultural and religious roots as an alternative to Western-style consumerism, and focusing more on sharing than on increasing what is produced [57]. This could lead to significantly higher population growth and lower economic productivity growth.

Conclusion

The scenario presented in this article suggests that a continuing decline in population growth and an equity-, environment-, and service-oriented economic growth could, in

[22] Several authors have pointed out that high market-oriented economic growth may hit some hard physical and social limits long before the affluence levels of US$ 80–120,000/capita/year per are reached [19, 11]. Evidence of this is also given in the 15 key trends presented in the State of the Future 1997 report [80].

combination with energy efficiency improvements, lead to less than a tripling of primary energy use in the world. Timely research and demonstration efforts would prepare the world for a transition away from fossil fuels, which could limit the growth in energy-related carbon emissions to less than twice the 1990 level. Emissions from other GHGs and from changes in land use may also decline in the second half of the next century if appropriate abatement measures are taken and food consumption and agricultural practices evolve in sustainable directions. In principle, such a future could materialize with sufficient, worldwide commitment to sustainable development in which technology transfer and environmental and equity concerns rank high. If such a future were to unfold—prosperous, fair and green—humankind would still face the risk of serious adverse climate change impacts. This points to the need for climate-change mitigation policies even in this, in several respects optimistic, scenario, although it could be argued that a B world has both the commitment and the resources to cope with such impacts in a humane and effective way.

It should be emphasized that the scenario presented here does not pretend to be value-free.[23] It is optimistic about the effectiveness and fairness of global cooperation; about the willingness of consumers to opt for energy efficiency and pollution abatement investments and for less material-oriented lifestyles; and about the potential for low-cost nonfossil energy supply options. Because the new IS99 scenarios for the IPCC are supposedly non-climate-intervention scenarios, it may be argued that the scenario presented here does not qualify. It should be borne in mind, however, that many actions may be taken outside the domain of government policy that can contribute substantially—if only in the form of side-effects—to GHG emission reductions.

Some may interpret this scenario as a proof that climate policy is not urgent; others may reject it because they fear precisely such an abuse. Still others will argue that the projected high monetary incomes are incompatible with environmental and social concerns—certainly without a stringent climate policy. Finally, green-technology optimists may love it. This scenario is one out of many scenarios covering a range of possible futures. The scenario presented in this paper certainly does *not* represent an easy-going path. To the contrary, the future we have pictured qualitatively and quantitatively is in many ways nothing less than a Great Transformation: it requires a degree of commitment and concern and an amount of social, technical, and institutional skills that are without precedent in many regions. Indeed, its feasibility can rightly be doubted in view of the major trends in the last part of the previous century. In this sense, we present this scenario more as a challenging invitation to imagine and realize such a future than as a utopian whim.

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[23] Normative scenarios depict situations and conditions as one would hope they would emerge; exploratory scenarios attempt to describe plausible futures by taking into account constraining and counteracting conditions, possibly starting from a normative scenario [80]. In this sense our scenario is largely normative.

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TABLE A1
WorldScan Classifications

Regions		Sectors		Production factors	
W	European Union	L	Agriculture and food	L	Low-skilled labor
J	Japan	A	Coal	H	High-skilled labor
U	United States	N	Natural gas and oil	K	Capital
R	Remaining OECD	R	Other raw materials	F	Fixed factor
L	Latin America	C	Consumption goods		
C	China economic area	K	Capital goods		
N	Dynamic Asian economies	I	Intermediate goods		Intermediate inputs
O	Other Asia and rest of world	W	Utilities		
S	Sub-saharan Africa	S	Nontradables	R	Other raw materials
M	Middle East/North Africa	D	International transport	A	Coal
F	Former Soviet Union			N	Natural gas and oil
E	Eastern Europe			I	Intermediate goods

TABLE A2
IMAGE 2.1 Classifications

Regions	Sectors	Food and energy crops
1. Canada	1. Industry	Food crops
2. United States	2. Transport	Temperate cereals
3. Latin America	3. Residential	Rice
4. Africa	4. Services	Maize
5. OECD Europe	5. Other	Tropical cereals
6. Eastern Europe		Pulses
7. CIS (former USSR)		Roots and tubers
8. Middle East		Oil crops
9. India + South Asia		Biofuel crops
10. China + Centrally Planned countries		Sugar cane
		Maize
11. East Asia		Woody biomass
12. Oceania		Nonwoody biomass
13. Japan		Feed crops
		Grass and fodder species

Note: Aggregation of regions: OECD90: regions 1, 2, 5, 12, 13; REF: regions 6, 7; ASIA: regions 9, 10, 11; ALM: regions 3, 4, 8.