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Energy Perspectives for Eurasia and the Kyoto Protocol

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About the Paper

This paper was presented at the Workshop on Architectural Issues in the Decision of Climate Change Policy Instruments, 13-14 August, 1998, Snowmass. An earlier version of the paper was presented at the International Conference on "Russia's and Other CIS-Countries' Energy Potential – Crucial Link Between Europe and Asia-Pacific", 31 March to 2 April, 1998, Moscow.

Abstract

In collaboration with the World Energy Council (WEC), IIASA conducted a five-year study of long-term global and regional energy perspectives. Using IIASA's integrated modeling framework, the study explores a broad range of global energy developments and their consequences, such as the likely financing needs and environmental impacts. This paper summarizes the main features and findings of the this study focusing on implications of global perspectives for Eurasian regions.

One of the important results of the study is the need for further energy integration in Eurasia to achieve both goals of supplying the energy services needed for economic development and reducing the adverse impacts on the environment at all scales. Clean fossil fuels would continue to be an important sources of these energy services and would lead to further decarbonization of energy. This, however, requires the emergence of large scale interconnected energy grids in Eurasia and implies a drastic energy-geopolitical shift. Such developments could dramatically improve the match between demand and supply for hydrocarbons (oil and gas) and in the long-term promote even further integration of Europe and Asia, e.g., through gas and electricity networks.

Such ambitious Eurasian energy grids would bring large economic benefits to gas (and energy) exporting regions and would enable healthier economic development throughout the region by the provision of cleaner and more flexible energy forms to most of the citizens. Financing would be a challenging problem but probably only during the initial phases of the long-term construction of Eurasian energy grids. After a few successes private financing is likely to be attracted because of the high potential economic benefits. A possible, but very speculative initial financing scheme is proposed in the paper involving global carbon dioxide trading permits. Should the Kyoto emissions reduction agreement be implemented, Russian Federation is likely to acquire a large "emissions bubble" by 2010. Tentative estimates made at IIASA indicate that the "bubble" might be as large as 300 MtC annually for the territory of the former Soviet Union (mostly Russia and Ukraine) during the first two decades of the next century. (For a more detailed discussion of specific emissions numbers for Russia and Ukraine, see paper by Victor, Nakićenović and Victor, also presented at the Snowmass Workshop.) The paper calls for further analysis of new Eurasian energy grids and possible financing mechanisms that would lead to lower carbon intensities in Asia as well as lower adverse environmental impacts at all scales.

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1 Introduction

The challenge of providing adequate energy services to enable the economic development of a growing world population while minimizing environmental impacts at the local, regional and global levels is the focus of the research activities in the energy area at the International Institute for Applied Systems Analysis (IIASA). The ultimate objective is to gain a better understanding of the linkages between energy use, development, and global change.

This work started with a detailed assessment of the specific technologies that might play a role in reconciling the seemingly conflicting objectives of development and environmental protection. The work led to the development of analytical frameworks and a series of long-term energy and emissions scenarios to assess how these new technologies might actually come into widespread use and create substantial benefits. One focus of this work on global and regional scenarios is on policy issues associated with the development of future energy systems.

At the same time, it is important to look at the long-term global features of such scenarios, and their near-term local and regional consequences. These consequences will most likely drive policy decisions more forcefully than long-term global perspectives. In examining near-term local and regional consequences, it is particularly valuable to link together research that is often done separately in distinct research disciplines – for example, economic development, energy systems, technological change, global warming, acid rain, and land use. Such linked analysis – cutting across different research fields – is called *integrated assessment*. The merit of integrated assessment at IIASA is that it combines the experience and richness of different state-of-the-art disciplinary models into an integrated scenario formulation framework (Nakićenović *et al.,* 1995).

In collaboration with the World Energy Council (WEC), the IIASA integrated scenario formulation framework was used to explore the prospects for improving the global availability and quality of energy services, and the wider implications these improvements may have. The study explores a broad range of global energy developments and their consequences, such as likely financing needs and environmental impacts. These findings were presented in the joint IIASA-WEC report on *Global Energy Perspectives to 2050 and Beyond* (IIASA-WEC, 1995) and a number of related publications (Nakićenović, *et al.,* 1995; Grübler *et al.*, 1996; Nakićenović and Rogner, 1996; and Grübler and McDonald, 1996). During the last three years, these study findings were reviewed and evaluated by ten WEC regional expert groups. The revised final report on the global and regional study results will be published in a commercial book by Cambridge University Press in September 1998. This paper summarizes the main features and findings of the study focusing on the implications of global perspectives for Eurasian regions.

2 From Resource Limitations to Cleaner Energy

The world is not running out of energy, even with the global population expected to double by 2050 and to reach 12 billion by 2100 (see insert in Figure 3). Indeed, there are enough potential resources, from coal to renewables, so that the world will have choices. It will not be necessary to push every resource to the limit just to keep up with population and economic growth. This is also the case in Eurasia, but like at the global level, vast energy resources are concentrated in only a few areas. They include in particular the enormous oil and gas deposits in the Siberian and Caspian regions. For example, the Russian Federation accounts for almost 40 percent of proven global natural gas reserves and for 27 percent of the current global gas production. It has large resources and production of coal and oil as well. This concentration of global and regional energy reserves and resources indicates the need for expanded energy trade and increasing energy interdependence in Eurasia and in the world.

Which energy sources and forms will predominate in the future will depend less on resource limits than on which fuels can be most successfully tailored to match consumers' needs. What consumers are looking for are higher levels and improved quality of energy services. In the future, this will result in a continuing, pervasive, and persistent tendency toward more convenient, more flexible, and ever cleaner structures and forms of energy end use. As incomes increase around the world, people will demand more efficient, cleaner, and less obtrusive energy services.

Understanding long-term energy perspectives is essential for building a future that is more prosperous and more equitable. In the IIASA-WEC study, scenarios of the future were constructed to analyze which policies or investments make the most sense today. Because the future is uncertain, it is important to build a range of scenarios covering many of the possible futures that we can envision. In the context of the study, scenarios are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future could unfold. Such a range makes it possible to distinguish features of the future that are likely to be robust in the face of change and those that are likely to be the most sensitive.

3 Six Scenarios of Energy Systems Alternatives

The IIASA-WEC study explores the prospects for improving the global availability and quality of energy services, and the wider implications these improvements may have. The study centers on three cases of future social, economic and technological development for 11 world regions. They are designated as Cases A, B, and C (Table 1). Case A includes three scenario variants and reflects a *high-growth* future in terms of vigorous economic development and rapid technology improvements; Case B represents a *middle course*, with intermediate economic growth and more modest technology improvements; and Case C is *ecologically driven*, incorporating challenging policies to simultaneously protect the environment and enhance economic equity in two scenario variants, which both lead to lower energy use but high overall growth, especially in the South.[1]

[1]The three cases are differentiated into six scenarios of energy systems alternatives, three Case A scenarios (A1, ample oil and gas; A2, return to coal; and A3, non-fossil future), a single Case B scenario (middle course), and two Case C scenarios, (C1, new renewables; and C2, renewables and new nuclear).

	Case A	Case B	Case C
Economic growth	High	Medium	Low (North) High (South)
Energy intensity improvements	Medium	Low	High
Technology/resource availability	High	Medium	Low (fossil) High (non-fossil)
Number of scenarios	3	1	2

Table 1: Overview of main scenario characteristics.

4 Significant Improvement of Energy Intensities

In all scenarios, economic development outpaces the increase in energy, leading to substantial reductions of energy intensities. As individual technologies progress, and as inefficient technologies are retired in favor of more efficient ones, the amount of primary energy needed per unit of gross domestic product (GDP) – the energy intensity – decreases. In some developing regions, the intensity of commercial energy can increase initially as the traditional and less efficient energy forms are replaced by commercial energy, but the intensity of total energy decreases in these cases as well. With all other factors being equal, the faster economic growth, the higher the turnover of capital, and the greater the energy intensity improvements.

In the six scenarios, improvements in individual technologies were varied across a range derived from historical trends and current literature about future technology characteristics. Combined with the economic growth patterns of the different scenarios, the overall global average energy intensity reductions vary from about 0.8 percent per year, in line with the historical experience, to a high figure of 1.4 percent per year. These figures bracket the historical rate experienced by more industrialized countries during the last hundred years, which was approximately one percent per year as the long-term average, and cumulatively lead to substantial energy intensity decreases across all scenarios. Efficiency improvements are significantly higher in some regions, especially over shorter periods of time.

These differences in the global developments across the six scenarios are reflected in even larger regional variations. The East Asian “miracle” with double digit average growth during the early 1990s has been interrupted recently but prospects of continued sound growth are good for coming decades. The economies of Central Asia, the Russian Federation and East Europe have undergone a period of profound change and reforms as reflected in a deep recession and economic decline during the 1990s. The prosperous economies of West Europe have focused on reducing high unemployment that accompanied humble growth levels.

The IIASA-WEC scenarios start in the base year 1990 and were originally developed five years ago so that the actual trends of the last years can be compared with initial developments in the long-term scenarios. Figure 1 shows the energy intensity improvement rates for a few regions for the three cases of economic development compared to the historical trends. They range from vigorous reduction of about four percent per year for China and other centrally planned economies (CPA) in Asia to a (temporary) increase of energy intensities in reforming economies of East Europe and Central Asia. It is worth noting that the scenario trajectories have provided an excellent anticipation of the sort-term developments during the 1990s especially for the reforming economies in Eurasia.

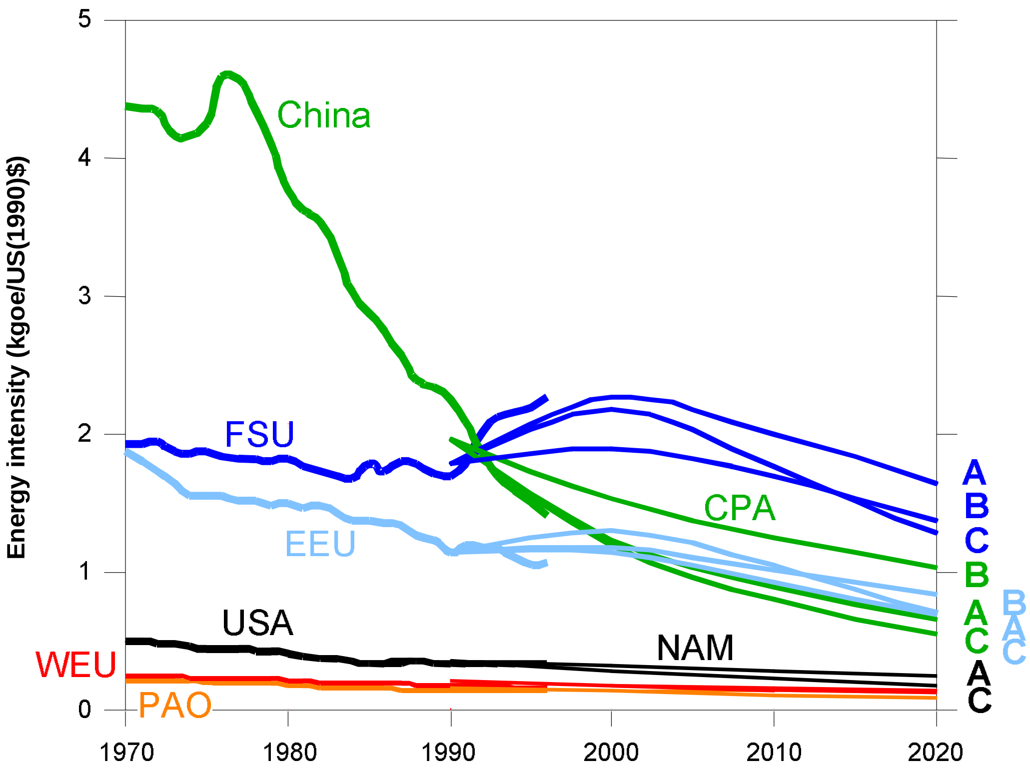

Figure 1: Primary energy intensities for six representative of the 11 world regions, historical trends from 1970 to 1996, and developments in three cases from 1990 to 2020, primary energy in kgoe divided by GDP in US$ expressed at 1990 exchange rates.

All scenarios assume that the next decades are characterized by successful reform and restructuring in the whole Eurasia leading to sustained investments in energy sector and economic development that are reflected in long-term improvement of energy intensities.

In addition to the energy intensity improvements, the rates of technological change and availability of energy resources also vary in a consistent manner across the scenarios. For example, the high rates of economic growth are associated with rapid technological advance, ample resource availability, and high rates of energy intensity improvement. Conversely, low rates of economic growth result in a more limited expansion of energy resources, lower rates of technological innovation in general, and lower rates of reduction in energy intensities.

5 Increasing Global and Regional Energy Needs

World population is likely to double by the middle of the 21st century as economic development continues, reaching 12 billion by the year 2100 (see insert in Figure 3). The likely result, according to the scenarios, is a 3- to 5-fold increase in world economic output by 2050 and a 10- to 15-fold increase by 2100. By 2100, per capita incomes in most of the currently developing countries will have reached levels characteristic of the developed countries today, making current distinctions between the two groups of countries obsolete.

The economic growth trajectories are illustrated in a novel way in Figure 2. In this figure, the sizes of different world regions analyzed in the study are proportional to their current GDP (expressed at market exchange rates). In 1990 the economic map of the world, which also approximates the energy-use patterns (see Figure 6), looks odd, reflecting current disparities among regions. Most developing regions are barely discernible

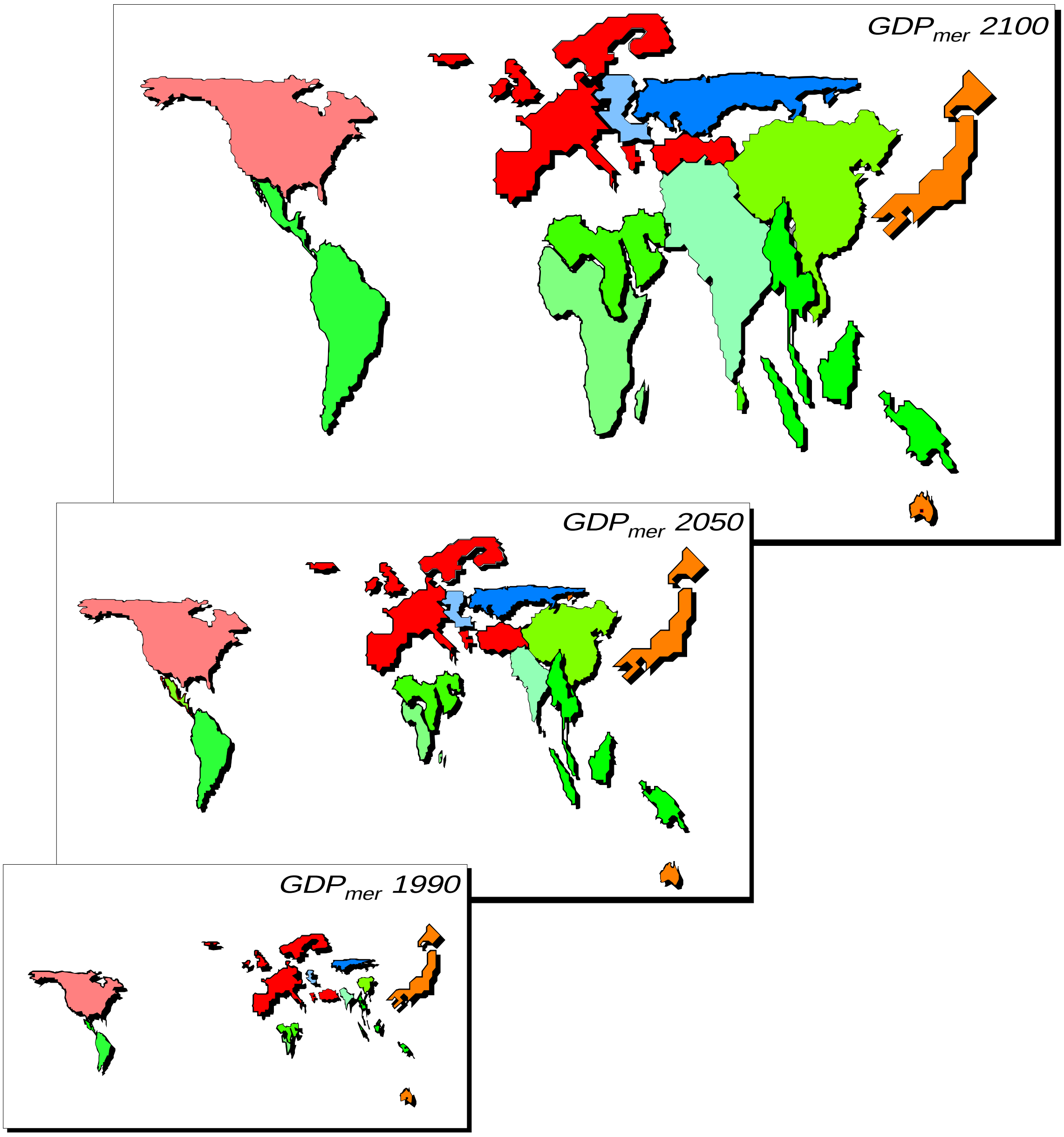

Figure 2: The changing geography of economic wealth for "Middle Course" Case B scenario, 1990, 2050, and 2100. The areas of world regions are proportional to their respective 1990 levels of GDP, expressed at 1990 market exchange rates.

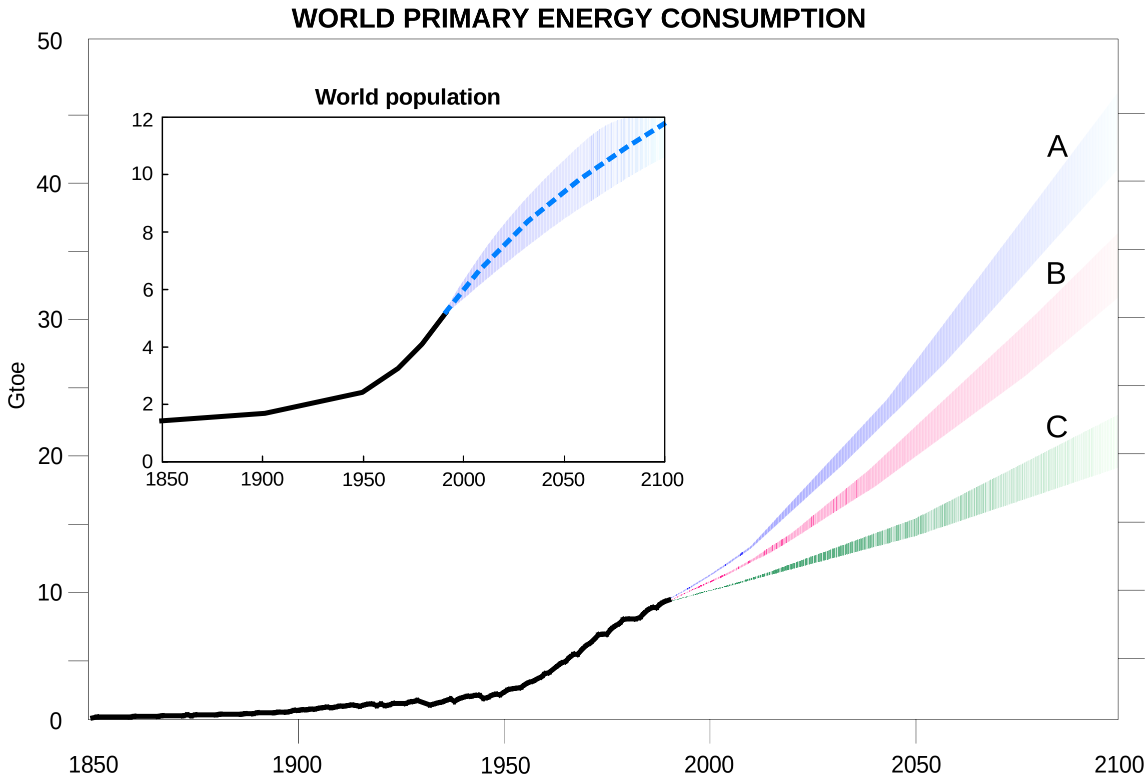

Figure 3: Global primary energy use, 1850 to present, and in the three cases to 2100, in Gtoe. The insert shows global population growth, 1850 to present, and the projection to 2100 (Bos *et al.*, 1992), in billion (10^9) people.

compared with Japan, Western Europe, and North America. Compare, for example, the size of Japan in 1990 with that of China and the Indian subcontinent.

For 2050 and 2100, the figures correspond to the median Case B scenario (Case B is shown because it has the lowest rates of growth). The top map shows world continents according to economic activities as they appear in the year 2100. In terms of economic development as well as access to energy, the world map for 2100 looks less odd; not only are the regions larger, reflecting their economic and energy use growth, but disparities among the regions are smaller, bringing the maps much closer to the geographic maps with which we are familiar.

The maps give a positive view of the future by illustrating a case of successful global development. The world is affluent and the difference between the poor and the rich as we know it today disappears. In most regions of the world the standards of living approach those currently found in Western Europe. This change is possible with slower growth in energy requirements due to impressive improvements in energy efficiency and conservation that lead to a reduction in energy intensities.

Nonetheless, in many parts of the world local difficulties will persist, and despite rapid economic development adequate energy services may not be available to every citizen, even in 100 years.

Global demand for energy services will grow by as much as an order of magnitude by 2050. Primary energy requirements will grow less, because of improvements in energy intensities (see Figure 1); the study envisages a 1.5- to 3-fold increase in primary energy use by 2050, and a 2- to 5-fold increase by 2100. The six scenarios are grouped into three different levels of primary energy consumption covering this wide range of alternative developments (Figure 3).

In particular, there is an enormous potential for growth of energy needs, trade and interconnected energy infrastructures in Eurasia. It is the industrialized countries of Europe that led the region's growth in energy demand during the 20th century. But by 2000, or shortly thereafter, energy demand of the developing countries of Asia will pass that of Western Europe, Eastern Europe, and the Newly Independent States of the former Soviet Union (FSU) combined. Through at least 2050 Asia's demand growth will be the fastest in the world. Today Asia's primary energy demand is 2.4 Gtoe. In 2050 it is estimated to be between 7.6 and 9.5 Gtoe across the six scenarios, absent stringent environmental constraints. Regional coal resources will be used extensively, but demand growth in Asia will also require large imports. Demand growth will also reflect persistent worldwide trends toward ever more flexible, more convenient, and cleaner forms of energy, and in Asia local and regional air pollution problems will accelerate the shift. The challenge is to match the rich energy resources of Eurasia to growing demands. Resources and demands must be matched geographically through trade, transportation networks, and energy grids. They must be matched financially through investment flows and reforms designed to attract those investment flows. And they must be matched in terms of flexibility, convenience, and cleanliness.

6 Higher Quality and Convenience of Energy Forms and Services

The scenarios cover a wide range of energy supply possibilities, from a tremendous expansion of coal production to strict limits on it, from a phaseout of nuclear energy to a substantial increase in its use, from carbon emissions in 2100 that are only one-third of today's levels to emission increases of more than a factor of three. Yet, for all the variations explored in the alternative scenarios, all manage to match the likely continuing push by consumers for more flexible, more convenient, and cleaner forms of energy (Figure 4). This means that all energy is increasingly transformed and converted into quality carriers such as electricity, liquids, and energy gases. For example, the direct use of solids by final consumers disappears by 2050.

Alternative structures of future energy systems are capable of meeting these stringent demands for higher-quality energy end use and services. Despite all the variations, the scenarios look quite similar through 2020, and all still rely on fossil fuels. However, after 2020 the scenarios start to diverge.

The roles of different primary energy sources vary across the six scenarios, contributing to divergence. Some continue to be fossil-fuel intensive, others envisage stronger shifts toward alternative sources of energy such as renewables or nuclear power. The geophysical availability of energy resources is not a major constraint *per se*. Instead, the availability of energy resources and the rates at which they are converted into reserves are a function of the nature of the envisaged development strategies themselves. Part of the divergence in the structures of energy systems depends on policy choices and development strategies. For example, two Case C scenarios that assume aggressive international cooperation focused on environmental protection and international economic equity use much less fossil fuel than the other scenarios. Figure 5 illustrates this long-term divergence in the structures of energy systems across the scenarios.

Each corner of the illustration's triangle represents a hypothetical situation in which all primary energy is supplied by a single energy source: oil and gas on the top, coal on the lower left, and renewables and nuclear energy on the lower right. Nuclear energy and new renewables are grouped together because they are the principle non-fossil energy

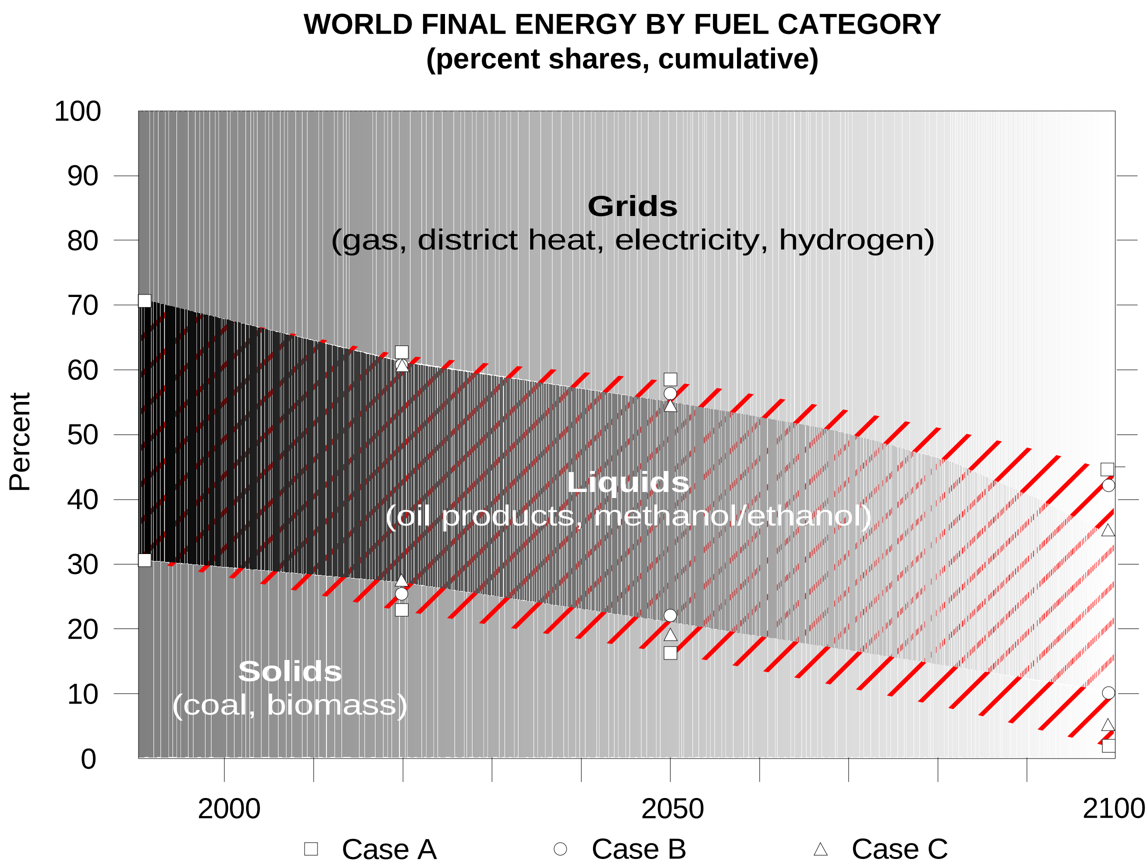

Figure 4: World supply of final energy by form: solids (coal and biomass), liquids (oil products and methanol/ethanol), and grids (gas, district heat, electricity, and hydrogen). Overlapping shaded areas indicate variations across the three cases.

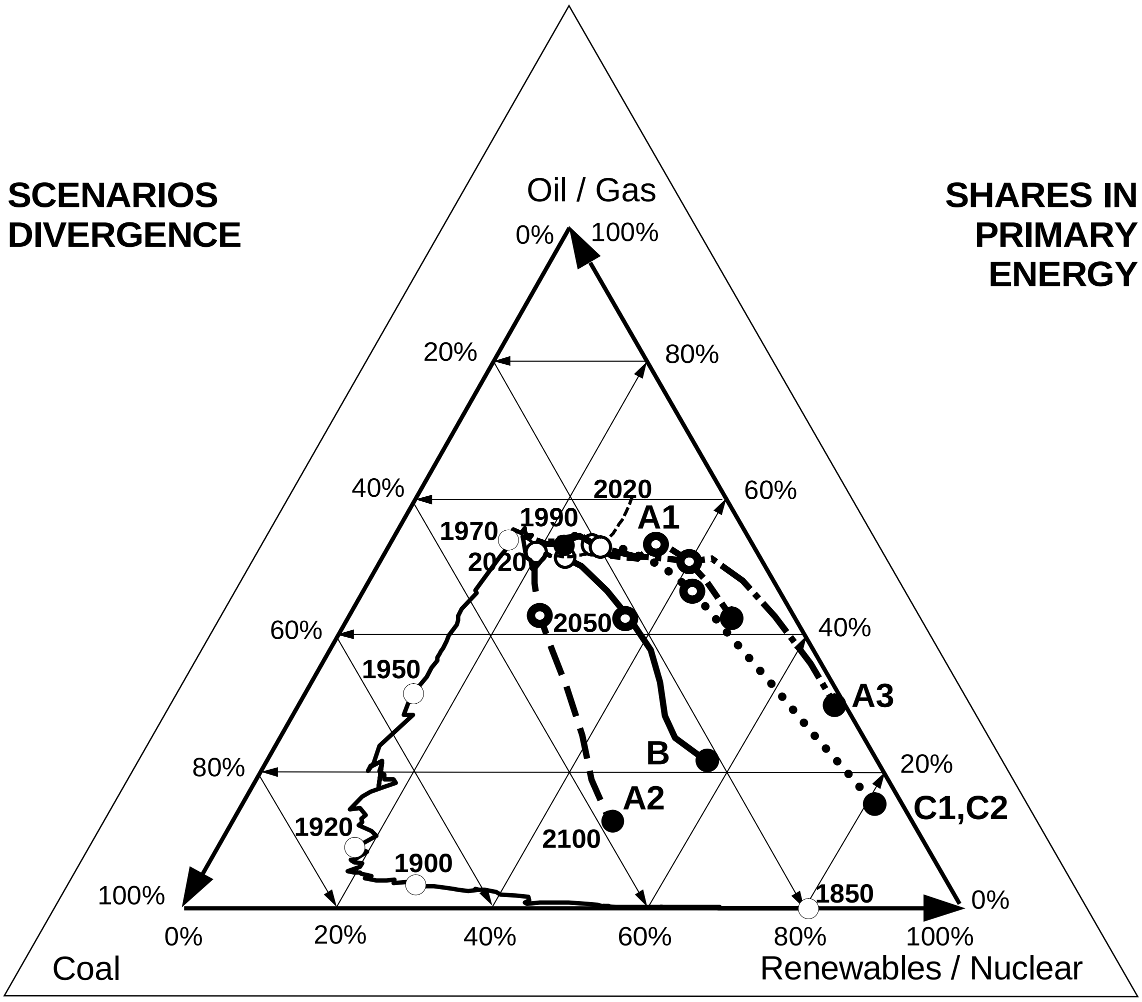

Figure 5: Divergence in the structures of energy systems. Contribution from oil and gas, coal, and nuclear and renewable energies (in percent).

alternatives available in the longer term. The illustration shows the historical development of the global energy system starting in the 1850s, when most primary energy needs were met by traditional (usually unsustainable) sources of energy such as wood and animal power, as well as the development trajectory to 1990.

Scenarios branch out during the post-2020 period. Some become coal intensive, like the high-growth Scenario A2, others are more renewable and nuclear intensive, like Scenario A3 and the two ecologically driven Scenarios (C1 and C2). All of them eventually lead to a partial shift from fossil fuels to other sources of energy; however they follow alternative development paths. As the paths spread out, they form diverging future developments. To some extent they are mutually exclusive.

Most of the post-2020 divergence will depend on technological developments and industrial strategies implemented between now and then. Which energy sources in 2020 will most closely match the more flexible, more convenient, and cleaner forms of energy desired by consumers? Which will have made the investments in research and development that will give them a technological edge? And which will have successfully refocused their businesses away from merely providing tons of coal, or kilowatt-hours of electricity, toward providing increasingly flexible, convenient, and clean energy services to consumers?

The answers to these questions will be determined between now and 2020. Near-term investment decisions and efforts in technology research and development will determine which of the alternative development paths will become dominant in the post-2020 period. Because of the long lifetimes of power plants, refineries, and other energy investments, there is not a sufficient turnover of such facilities to reveal large differences in the scenarios prior to 2020, but the seeds of the post-2020 world will have been widely sown by then.

7 Implications of Global Energy Developments for Eurasia

The IIASA-WEC study identified Eurasia as a region with enormous potential for growth in energy demand, trade, and interconnected energy infrastructures and grids. In all scenarios, the region becomes the largest energy consumer in the world. Provided appropriate infrastructure investments are made, it also develops the largest internal and external energy market. Scenarios indicate that by 2020 energy demand in the region could surpass current *global* energy consumption levels of 9 Gtoe and, by 2050, 15 Gtoe.

Growing regional energy use is illustrated by the energy map in Figure 6. There the eleven regions of the IIASA-WEC study are drawn in proportion to their present levels of energy use (see also Figure 2 for comparison with regional levels of economic development). In 1990 energy use in the rapidly developing countries of Asia was comparatively small relative to the industrialized countries in Western and Eastern Europe, the former Soviet Union, and Japan. This imbalance changes dramatically in the long-run. By the mid-21st century Eurasia would account for close to two thirds of global energy use.

Eurasia has substantial energy resources and substantial technological and financial expertise that will be needed to match rapidly expanding energy needs with required energy supply. For instance, with rising incomes, high quality fuels such as gas and electricity will need to expand faster than the energy sector as a whole. Yet, with the exception of Western Europe (and LNG imports in Japan), grid connections and therefore trade possibilities for gas and electricity are largely undeveloped. The key question is therefore how best to apply available expertise and resources (technological, financial) to mobilize Eurasia's energy resources for economic and social development.

The IIASA-WEC study indicates that coal will remain largely a domestic or regional resource with its markets increasingly confined to the upstream conversion sector (electricity

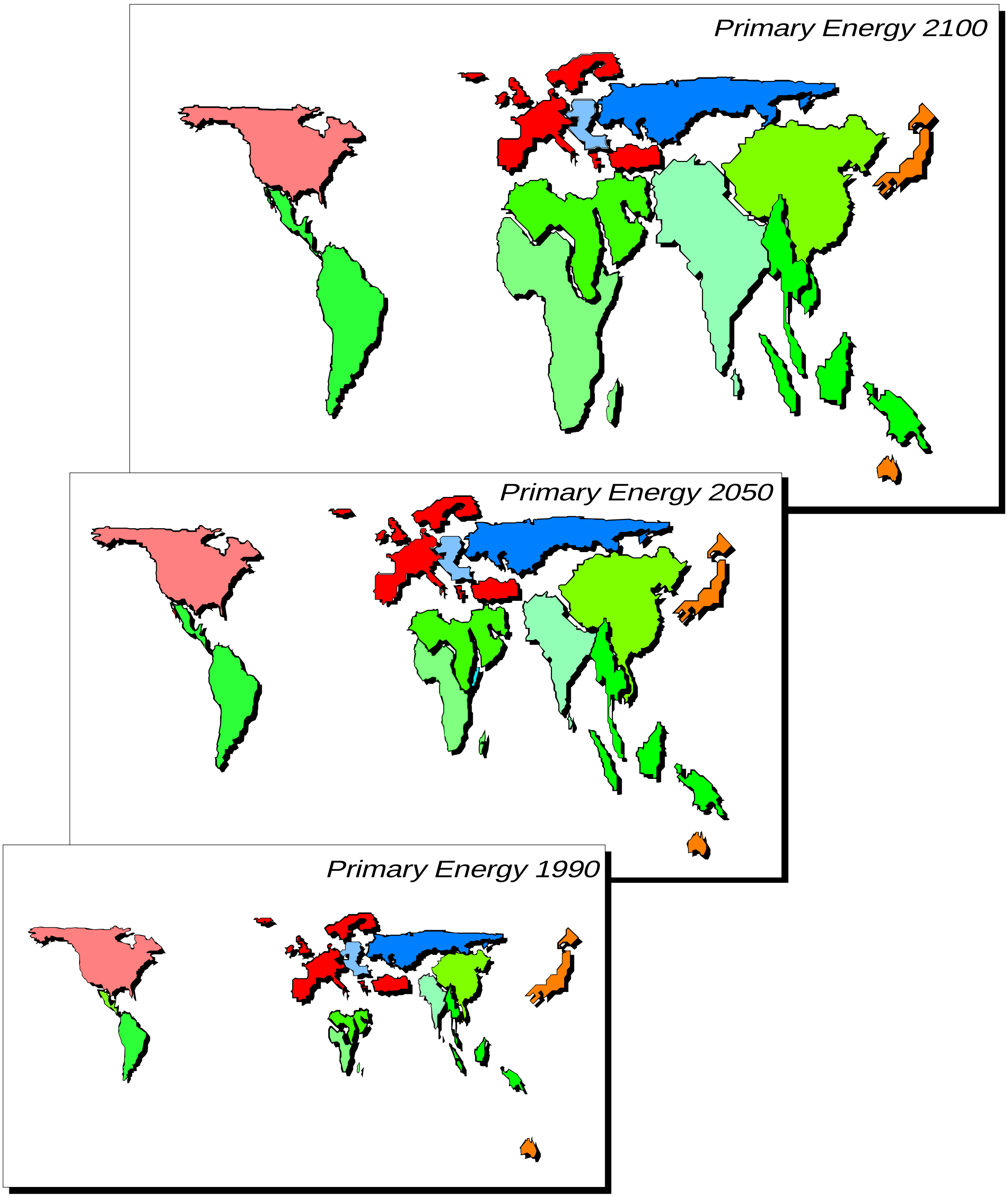

Figure 6: The changing geography of primary energy, "Middle Course" Case B scenario, 1990, 2050, 2100. Area of world regions are proportional to their respective 1990 levels of primary energy use (see also Figure 2).

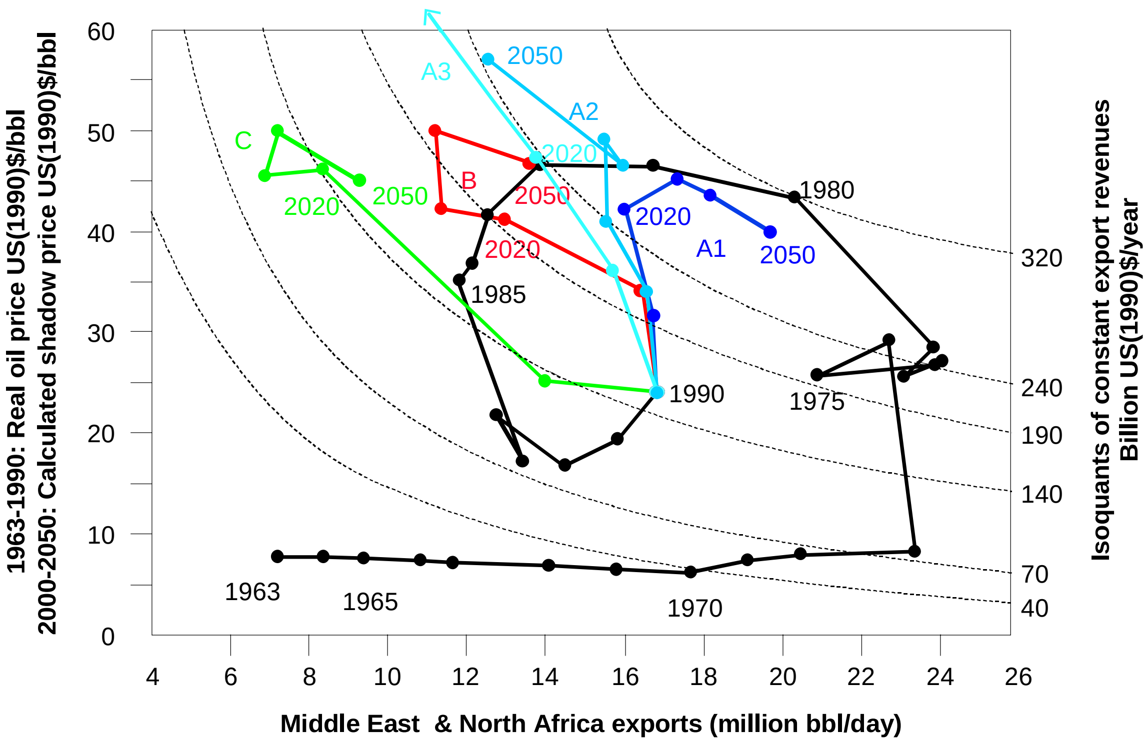

Figure 7: Crude oil export quantities and revenues of Middle East & North Africa, 1960 to 1996 and in six scenarios to 2050.

and, in the long-term, synfuels). Conversely, oil and natural gas with their associated versatility and, in the case of gas, cleanliness are both premium end-use fuels (for transport, services, and households) as well as premium industry feedstocks (for petrochemicals). With rapid developments in the economics and efficiency of gas turbines, natural gas is also becoming increasingly attractive in the power plant sector. Thus, balancing supply and demand for oil and natural gas will constitute the main political, infrastructural, technological, and financial challenge in the decades to come. This problem is of particular importance for developing the vast hydrocarbon resources of the Caspian region and Siberia.

8 Increasing Energy Trade and New Infrastructures

Crude oil and oil products dominate currently international energy trade. Through 2050 they also remain the most traded energy commodities in the IIASA-WEC scenarios, although the spread across scenarios is quite large. Trade in piped natural gas and LNG increases substantially, and by 2050 gas becomes the key traded energy commodity. In general, global energy trade patterns shift from primary energy to secondary energy, which improves trade flexibility and thereby lowers geopolitical concerns.

The most striking result from the IIASA-WEC study is the persistent growth in Eurasian import needs outside the Russian Federation and the Caspian region. This is due to comparatively low oil and gas resource endowments in Western Europe and Japan plus growing demand in the developing economies of Asia. Overall, annual imports of oil and gas into the region could increase to between 1.7 and 3 Gtoe, with gas trade accounting for more than one Gtoe. These projected trade flows into Eurasia approximate or exceed 1996 global trade in oil (1.9 Gtoe) and gas (0.4 Gtoe by pipeline and LNG). The largest

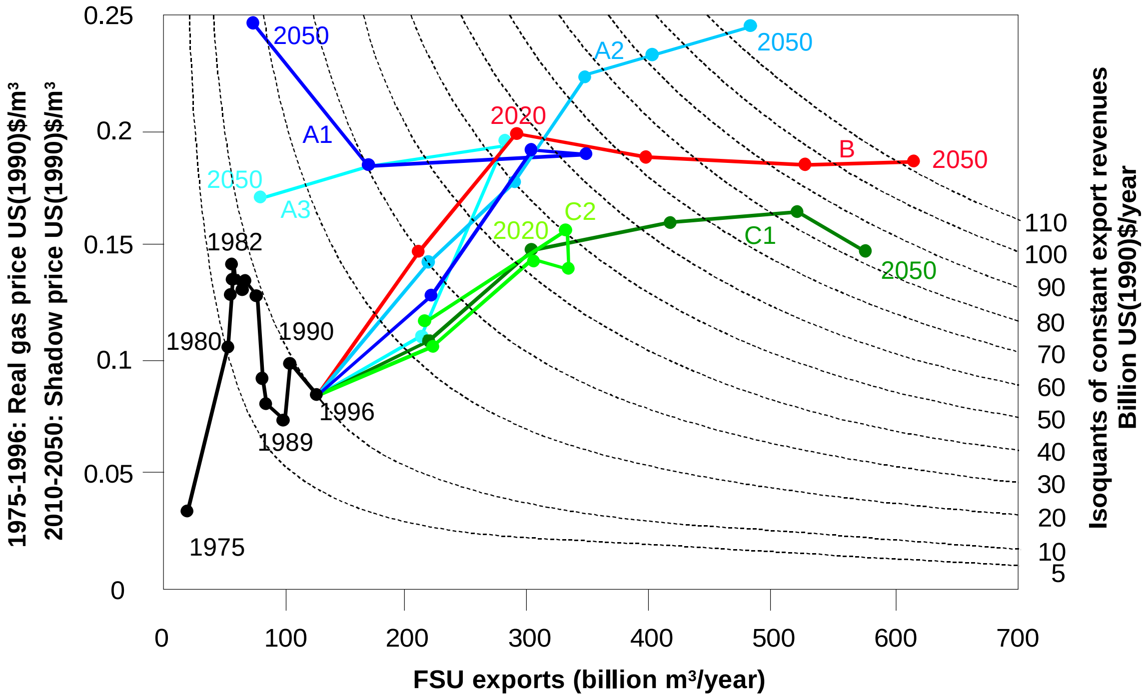

Figure 8: Natural gas export quantities and revenues of former Soviet Union, 1975 to 1996 and for export from the Siberian and Caspian regions in six scenarios to 2050.

players in terms of export capabilities remain the Middle East for oil, and the Siberian and Caspian regions for gas. Projected export quantities and revenues across the six scenarios are summarized in Figures 7 and 8.

Figure 7 shows oil export versus prices and resulting total export revenues for the Middle East and North Africa. The dashed lines in the figure are isolines reflecting constant export revenues. The historical trajectory of oil prices and exports for the region has moved counter-clockwise through very volatile changes in prices and total revenues.[2] In general prospects for oil exporters are bright. Through 2050 it is unlikely that revenues will fall below the 1990 level of about US$140 billion. But there are important differences due to different possible technological and environmental developments. In scenarios reflecting greater technological progress this creates greater access to resources and thus higher exports at slightly elevated prices. Long-term export revenues rise as high as US$300 billion annually in the A1 Scenario. If technological change is slower (Case B), or environmental policies limiting fossil fuel use stricter (Case C), the replenishment of reserves and demand are lower, and the price component becomes more important in revenue generation. Export volumes slip as reserves are replenished more slowly, prices rise, and revenues vary as a function of the scenario-specific oil substitution possibilities.

Figure 8 displays a similar export-price-revenue diagram for gas exports for the former Soviet Union. A consistent finding is that through 2020 gas exports always increase to at least 300 billion cubic meters per year with export revenues increasing to at least US$50 billion, i.e., five times 1996 values. After 2020 gas export prospects from the region could bifurcate. The most likely scenarios suggest growth will continue because alternatives are not developed quickly enough (Scenarios A2 and B) or because gas is favored by environmental policies (Scenario C1). In cases where more rapid technological progress

[2] Prior to 1990, revenues in the figure are equal to quantity times average price. Beyond 1990, revenues are scenario calculations of crude oil shadow prices representing the marginal value for any particular year. Revenues and prices are therefore higher than if calculated with average prices.

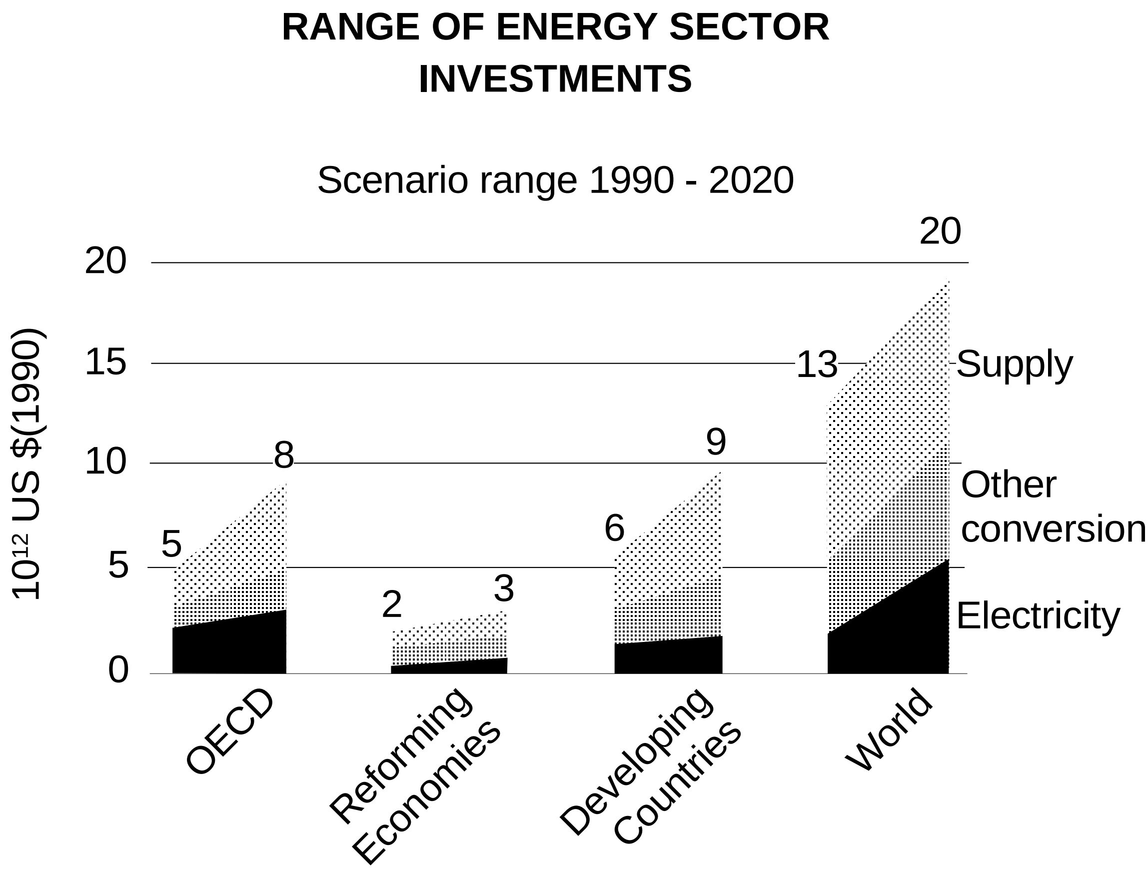

Figure 9: Range of cumulative energy sector investments for OECD, Reforming Economies, Developing Countries, and World, 1990 to 2020, in US$ trillion (10^{12}) at 1990 prices.

makes it possible to tap unconventional gas resources outside the region or for non-fossil energy technologies to massively penetrate energy markets, long-term export potentials are somewhat reduced (Scenarios A1, A3 and C2). However, revenues from gas export are unlikely to fall below US$30 billion per year.

9 The Challenge of Capital and Financing Requirements

A conclusion that is consistent across all six scenarios is that the capital requirements of the energy sector will be extremely large, but not infeasible. Over the next three decades, capital requirements across the scenarios are estimated to range between US$13 to 20 trillion ($10^{12}$) at 1990 prices (Figure 9). The latter amount equals the total 1990 global economic output. The developing region's share rises sharply from today's 25 to 30 percent to between 42 and 48 percent, and they become the largest energy capital investment market in all cases. As a share of GDP, global energy investments range from 1.5 to 1.9 percent. They are highest in the reforming economies of Central and Eastern Europe and Central Asia where they could amount up to 7.0 to 9.0 percent of GDP. These high investment needs are a legacy of the high energy intensity of the former centrally planned economies and recent declines in investments that went along with economic recession. The result is a substantial need for reconstruction and upgrading of energy infrastructures.

The good news is that the investments would decrease as the share of GDP throughout the world, but there are also two pieces of bad news. First, the challenge will be that an

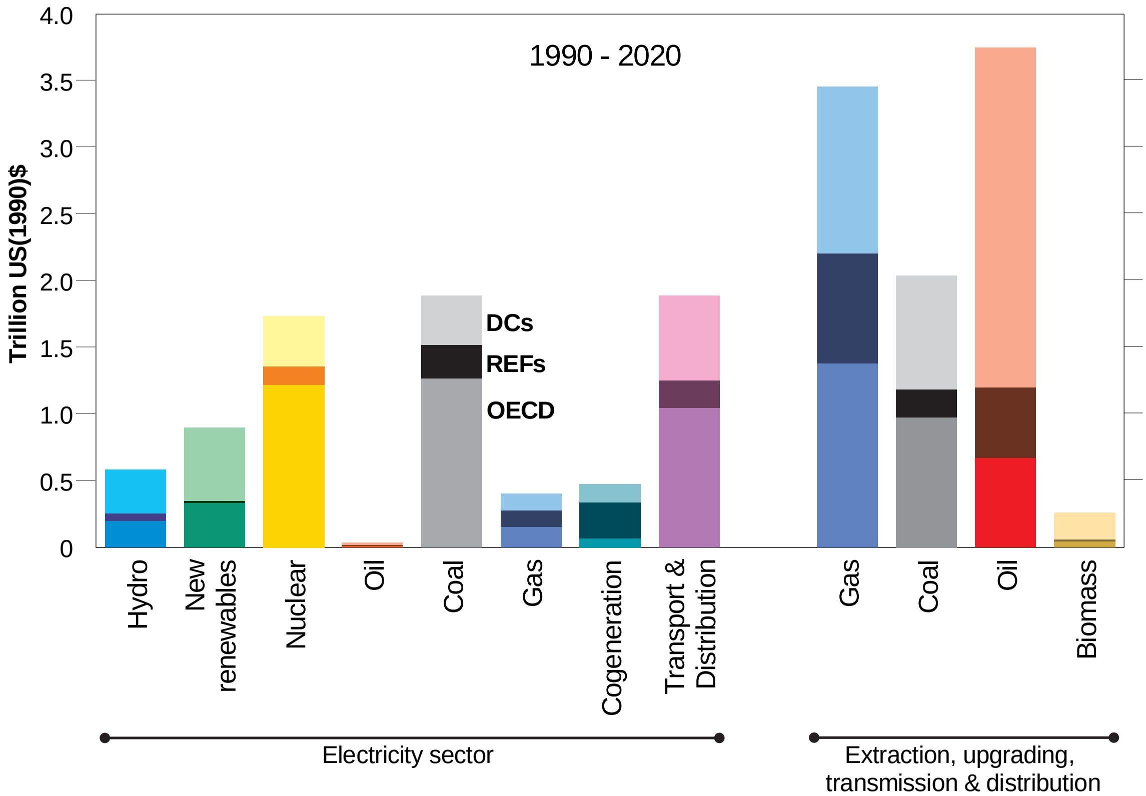

Figure 10: Breakdown of global cumulative energy sector investments for Case B scenario, from 1990 to 2020, in US$ trillion (10^{12}) at 1990 prices.

increasing fraction of the capital requirements will need to be raised from the private sector, where energy needs will face stiffer competition and return on investment criteria. Second, most of the investments that must be made are in the developing countries, where currently both international development capital and private investment capital are often scarce. The situations in the reforming economies of Europe and Central Asia are equally difficult. Reforms will be needed in many countries if potential energy investments are to fare successfully when evaluated against stiffer competition and return on investment criteria than they have faced in the past.

Investment needs by sector are illustrated in Figure 10 for the central scenario (Case B). Overall, investment needs are dominated by the infrastructure-intensive oil and gas sectors (with investment needs of US$ three trillion (at 1990 prices) each from 1990 to 2020, followed by investment needs for nuclear and coal based electricity generation. Other scenarios in the IIASA-WEC study conclude that such investments could be lowered through increased use of natural gas. This would require stepped-up investments in gas production facilities and especially transcontinental gas infrastructures (pipelines and LNG facilities).

Overall, the study concluded that the most important bottlenecks in energy sector investments in Eurasia are perceived risks to investors both in the Caspian region and in the Russian Federation, as well as the long pay-back times required in building up a capital intensive transcontinental gas transport infrastructure. The scenarios also indicate however substantial economic and environmental returns from an extended Eurasian gas pipeline system that in the long-term may become interconnected and pave the way for similar developments for electricity.

10 Local and Regional Environmental Impacts

Local environmental impacts are likely to continue to take precedence over global change. According to the IIASA-WEC study, the natural capacity of the environment to absorb higher levels of pollution will also likely become a limiting factor on the unconstrained use of fossil fuels. In rural developing areas worldwide, the demand for cleaner energy end uses includes a shift away from cooking with wood and coal in inefficient traditional open fireplaces. This change will reduce indoor pollution levels, currently estimated to be 20 times higher than in industrialized countries.

An urgent environmental problem in densely populated metropolitan areas is the high concentration of particulate matter and sulfur dioxide. Here, both cleaner fuels such as natural gas and active abatement measures will be required. Regional air pollution could also prove problematic, especially in the rapidly growing, densely populated coal-intensive economies of Asia. In the booming cities of China and Southeast Asia, high levels of air pollution must be addressed with both cleaner fuels and active abatement measures. A high dependence on coal with no abatement measures, would result in significant regional acidification and cause key agricultural crops in the region to suffer acid deposition that is 10 times the sustainable level before 2020. People worldwide already suffer from local and regional air pollution, and both governments and individuals are taking steps to improve the situation. These actions are part of the drive toward higher efficiencies and cleaner fuels. They also have the positive spin-off effect of reducing carbon emissions and possible global warming, although that is not their principal motivation.

Figure 11 shows projections for sulfur deposition in Asia using IIASA's RAINS-ASIA model. Without abatement measures, sulfur emissions could cause key agricultural crops to suffer acid deposition ten times sustainable levels. These results emphasize the positive environmental implications of increased availability of gas and other clean fuels in Asia. However, such positive developments can materialize only after required up-front investments in energy infrastructures are made that match the potential increases in gas demands with the large gas resources available both in Siberia and the Caspian region.

In addition to consistency with local environmental and energy objectives, expanded gas use also lessens the possible global warming implications of increased fossil energy use. Of all fossil fuels, gas has the lowest CO_2 emissions per unit energy and thus the lowest global warming impact (provided methane leakages are controlled). In general, the shift to higher quality fuels results is the continued decarbonization of the energy system, and decarbonization means lower adverse environmental impacts (including reduced CO_2 emissions) per unit of energy consumed, independent of any active policies specifically designed to protect the environment.

Energy investments and energy strategies must be chosen in anticipation of uncertain environmental constraints. What we can conclude from the IIASA-WEC study and subsequent work at IIASA is that some constraints (e.g., on carbon emissions) are more uncertain than others (e.g., on sulfur emissions), and that in the face of uncertainty in general some strategies (e.g., accelerating technological progress, more emphasis on clean energy supplies such as natural gas, and enhanced cooperation in international energy technology R&D, nuclear safety, and energy infrastructures) are more robust than others. They constitute appropriate contingency strategies for the energy sector in the face of future uncertainties that are capable of generating progress across the diverse domains of energy demand, technology, and environmental policy.

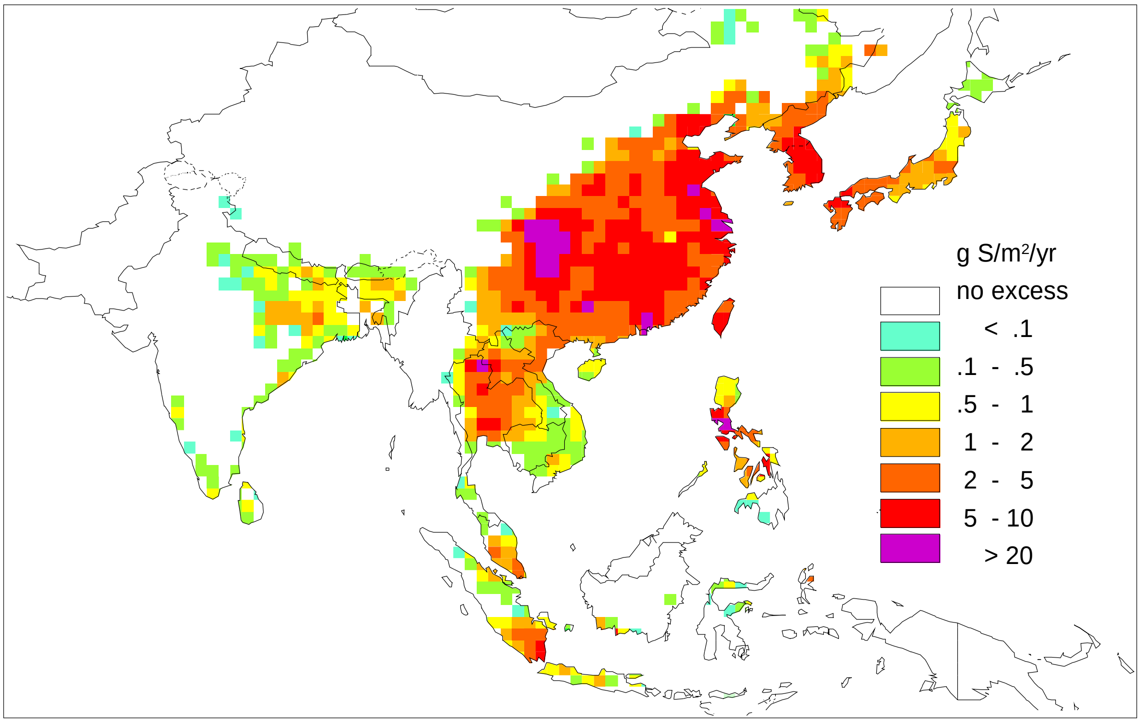

Figure 11: Excess sulfur deposition above critical loads of ecosystems and agricultural crops for a high growth, coal intensive scenario with unabated sulfur emissions as calculated with the IIASA RAINS-ASIA model.

11 Energy Decarbonization Reduces Environmental Impacts

The continuing shift toward higher-quality fuels means continued decarbonization of the energy system. Decarbonization means lower adverse environmental impacts per unit of energy consumed, independent of any active policies specifically designed to protect the environment. At the global level, decarbonization translates into lower carbon dioxide (CO_2) emissions and a lower risk of global warming.

However decarbonization may not be enough to offset future increases in greenhouse gas emissions and concentrations, especially in cases where fossil fuel use continues to be the primary source of world energy. Like the future structures of the energy systems, the CO_2 emissions paths for the six scenarios diverge as well (Figure 12). They range from very high emission levels for the coal-intensive high growth Scenario A2 to emission reductions in the ecologically driven Case C Scenarios sufficient to lead to atmospheric concentrations of about 430 ppmv after 2100 (Figure 13). This result is consistent with the lowest concentration levels analyzed during the Intergovernmental Panel on Climate Change *Carbon Dioxide Concentrations Exercise* (IPCC, 1996). An important feature of this result is that very low CO_2 emissions trajectories are not achieved by constraints, but rather by high levels of economic, technological, and social development. The environmental awareness increases and results in environmental protection on all scales – local, regional, and global.

Thus, the decarbonization of energy is not sufficient to reduce future emissions of greenhouse gases, given the expanding energy needs of a growing world economy. Additional active policies are required. In some cases, they are mutually reinforcing; policies to reduce global CO_2 emissions, for example, also reduce acidification risks. In other cases, they work at cross purposes; restrictions on nuclear power, for example, may mean

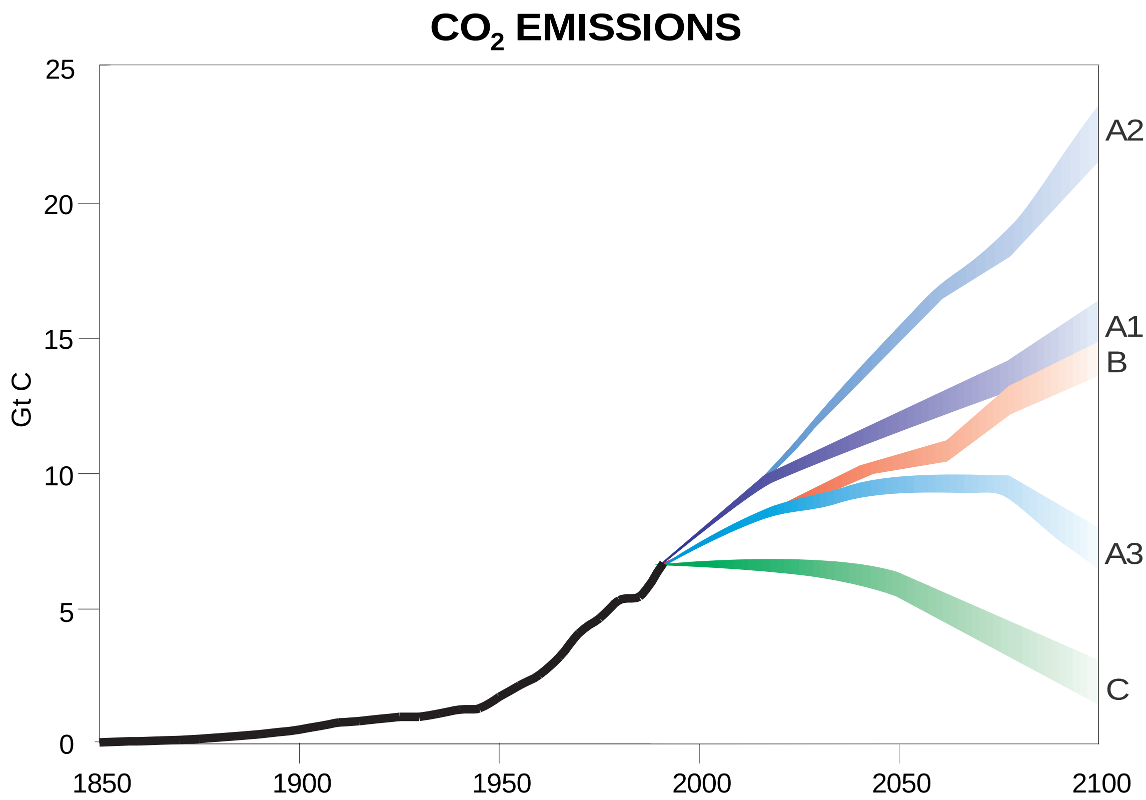

Figure 12: Global energy-related carbon emissions, 1850 to 1990, and for three scenario families to 2100, in GtC.

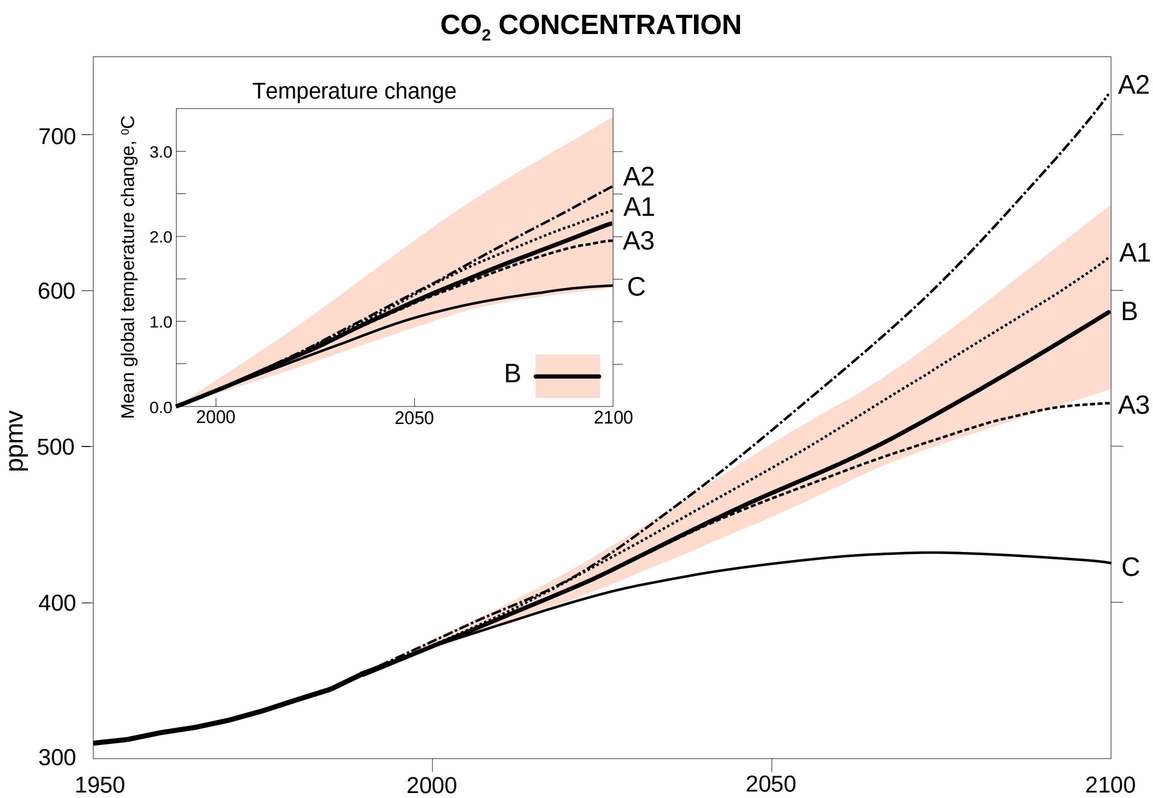

Figure 13: CO_2 concentration (ppmv), 1950–2100, and global mean temperature change (°C), 1990–2100. The (substantial) model uncertainties are indicated for Case B.

a greater dependence on fossil fuels.

In all cases, however, faster technological improvement means quicker progress toward the clean fuels desired by consumers, and cleaner fuels mean a cleaner environment. Thus, near-term investment decisions and efforts in technology research, development, and demonstration will determine which of the alternative development paths analyzed in the IIASA-WEC study might become dominant in the post-2020 period. The choices may be wide open now. They will be a lot narrower by then.

12 Emerging Energy Networks and Grids in Eurasia

One of the important results of the study is the need for further energy integration in Eurasia to achieve the two goals of supplying the energy services needed for economic development and reducing the adverse impacts on the environment at all scales. Clean fossil fuels would continue to be an important source of these energy services and would lead to further decarbonization of energy. This, however, requires the emergence of large scale interconnected energy grids in Eurasia and implies a drastic energy-geopolitical shift. Such developments could dramatically improve the match between demand and supply for hydrocarbons (oil and gas) and, in the long term, promote the further integration of Europe and Asia, e.g., through gas and electricity networks.

Historically, energy infrastructures have evolved radially through interconnections between a few large centers of energy demand and yet fewer centers of energy supply, as exemplified by the gas transport infrastructure between Urengoy and Western Europe, or the LNG route from Indonesia to Japan. At least from the demand side, a newly emerging "polycentric" structure could offer numerous advantages: enlarged resource availability, diversified supply, improved economics, and a cleaner environment. Studies at IIASA have indicated vast potential economic and environmental benefits for gradually spreading out energy infrastructures from the Caspian region and Siberia to Asia with the long-term strategic objective of connecting energy infrastructures on a truly Eurasian scale. The example given in Figure 14 shows natural gas flows for a global scenario with rapid economic development. Even larger networks would be required for lowering the contribution of domestic coal in rapidly developing parts of China and Southeast Asia. A more ambitious gas trade within Eurasia could involve gas flows to Asia that would match or exceed those to Europe. Similar electric grids would be also required. Such ambitious Eurasian energy grids would bring large economic benefits to gas (and energy) exporting regions and would enable healthier economic development throughout Eurasia by the provision of cleaner and more flexible energy services.

Financing would be a challenging problem but probably only during the initial phases of the long-term construction of Eurasian energy grids. After a few successes, private financing is likely to be attracted because of the high potential economic benefits. A possible, but very speculative initial financing arrangement might involve global carbon dioxide trading schemes. Should the Kyoto emissions reduction agreement be implemented for the so-called Annex I countries that include OECD countries and the reforming economies in Europe, the Russian Federation is likely to acquire a large "emissions bubble" by 2010. Tentative estimates made at IIASA indicate that the "bubble" might be as large as 300 MtC in 2010. These excess emissions rights could be sold to Europe and North America, as these regions will be severely limited by the agreed emissions reductions (of about five percent by 2010 for whole Annex I region compared to reference year 1990). Thus, the Russian "bubble" would be invested to further development throughout Eurasia while reducing the long-term emissions in Asia. Shortly after 2010 this "bubble" is likely to

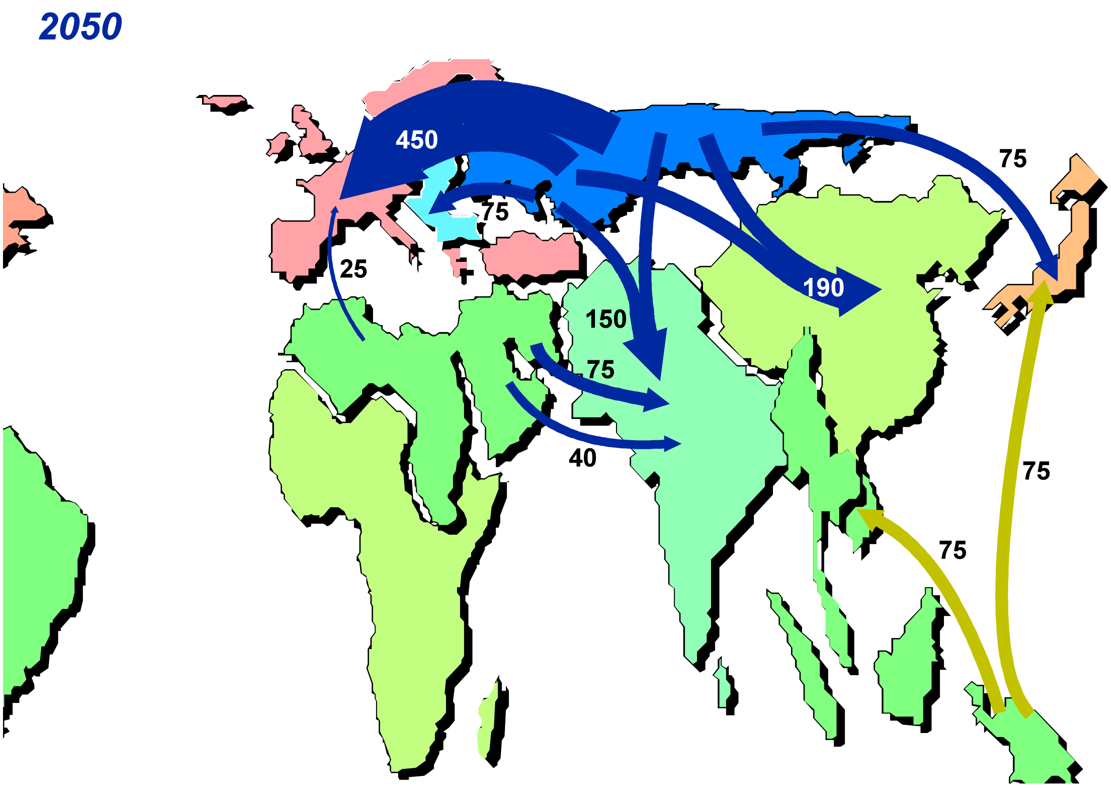

Figure 14: Natural gas trade within Eurasia in 2050 for a global scenario with rapid economic development, flows denote pipelines and LNG routes, width of trade "arrows" is proportional to gas flows, numbers are in Mtoe, area of Eurasian regions is proportional to primary energy consumption in 2050.

disappear as energy consumption increases in the Russian Federation. In the meantime it could provide a steady financing source for longer-term potential economic and environmental benefits from the Eurasian energy grids. For example, at about US$50 per tC (ton of carbon), the "bubble" would generate annual financial flows of up to US$15 billion.

The challenging long-term perspective of emerging Eurasian energy grids merits further detailed analytical scrutiny and in-depth discussion among all involved regional actors. Methodological tools, in the form of large-scale integrated energy demand and supply models with endogenized trade flows, are available at IIASA as a result of over 10 years of model development. Such an in-depth analysis of long-term energy markets is only limited by a lack of imagination – not the absence of appropriate methodology.

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