The Soviet Union: A Strategy of Energy Development with Minimum Emission of Greenhouse Gases

April 1990

Global Studies Program
Pacific Northwest Laboratory
Advanced International Studies Unit

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

PNL-SA-18094

THE SOVIET UNION: A STRATEGY OF ENERGY DEVELOPMENT WITH MINIMUM EMISSION OF GREENHOUSE GASES

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April 1990

Prepared for
the U.S. Environmental Protection Agency
under a Related Services Agreement
with the U.S. Department of Energy
Contract DE-AC06-76RLO 1830

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FOREWORD

The publication of this study completes the first stage of a productive and exciting collaboration between Pacific Northwest Laboratory (PNL), operated by Battelle Memorial Institute, and the Energy Research Institute of the Academy of Sciences of the Soviet Union. Alexei Makarov, director of the Energy Research Institute, first suggested in November 1988 that we cooperate on a research project of mutual interest. In January 1989, I traveled to Moscow to discuss the details of our cooperation and signed an agreement with Dr. Makarov to produce this research paper.

This paper represents an important contribution to the energy and climate policy debate. It is the first of its kind, so far as we know, prepared in the Soviet Union. It demonstrates considerable potential for reducing growth in greenhouse gas emissions, and it underscores the importance of taking actions that make sense for economic reasons. The text also emphasizes the importance of United States-Soviet cooperation not only in scientific research, but in sharing technology and building commercial ties.

This report is one of a dozen case studies of selected nations organized by the Advanced International Studies Unit (AISU) of Pacific Northwest Laboratory. A set of eight is being published separately as a book by the Conservation Foundation.

This research was sponsored by the Global Climate Division of the Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency (EPA). Dennis Tirpak, the division director, saw the need for this research long before the climate issue became popular and provided the support and encouragement to make it happen. Paul Schwengels, Barry Solomon, and Daniel Lashof of the EPA staff served not only to keep the intergovernmental wheels turning, but provided thoughtful, substantive reviews of this work.

AISU organized a workshop to review this and other case studies in Budapest, Hungary, in December 1989. In Budapest, Jim Skea and Ian Brown provided detailed reviews of the Soviet case. Richard Benedick, Peter Faross, Marie Kostalova, Andrezj Kassenberg, Erik Haites, Tamas Jaszay, Yuri Sinyak, Stanislaw Sitnicki, Jayant Sathaye, Kjell Roland, Kenji Yamaji, and Jean-Charles Hourcade provided useful comments. Vadim Eskin from the Soviet Union attended and played a key role. Jae Edmonds also provided important comments.

Overcoming the obstacles to a collaboration such as this one requires extraordinary support. The PNL staff--especially Carl Imhoff, Stan Kolar, Dee Sutton, and Claudia Wattenburger--delivered. I am very grateful.

And I am especially grateful to our Soviet colleagues. Their work represents a critical step in a vital process.

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Alexei A. Makarov received his Ph.D. in Energy Economics from the Leningrad Polytechnic Institute. He is a Corresponding Member of the Academy of Sciences of the USSR and is director of the Energy Research Institute of the Academy of Sciences and State Council on Science and Technology.

Makarov is one of the foremost specialists in energy technology and policy in the Soviet Union. He is chairman of the interagency committee on the Soviet energy future. He is chairman of the Scientific Council for Complex problem of energetics of the National Academy of Sciences.

Before he helped to found the Energy Research Institute in Moscow, Makarov was deputy director of the Siberian Energy Institute near Lake Baikal. He is the author of several books, including Methods of Research and Measurement of Energy Systems. His recent articles reflect his leading role in the formation of future Soviet energy policy. These articles include "New Stage of Energy Development in the USSR," "New Concepts of Energy Development in the USSR," and "Energy Balance of the USSR."

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Igor Bashmakov is a leading Soviet scientist in the field of energy and greenhouse gas emissions policy. Bashmakov received his Ph.D from Moscow State University in Mathematical Economics. Before joining the Energy Research Institute, he held positions with the Central Mathematical Economic Institute. He has also specialized in Soviet and world oil supply issues.

Bashmakov is currently Head of the World Energy Laboratory in the Energy Research Institute, Soviet Academy of Sciences. He is the coauthor of two books, Actual Problems of Energy Conservation and Orbits of Global Economy; and one article, "A Comparison of Overall Energy Structure of USSR, Western Europe, and the United States."

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THE SOVIET ENERGY BALANCE IN 1990

The Soviet Union, with 289 million people and one-eighth of the world's economic output, is a major world energy producer and consumer, yielding only to the United States in its scale of energy consumption (see Table 1). The role of the USSR is especially significant in the development of the oil and gas supply, accounting for more than 20 percent and almost 40 percent of world production of oil and natural gas, respectively. From 1977 to 1987, the Soviet Union accounted for almost 80 percent of the growth in world production of natural gas. A significant share of Soviet oil and gas is exported.

TABLE 1. Comparison of the Energy and Carbon Intensities of the Soviet Union, the United States, Western Europe, and the World, 1990 (estimated)

	USSR	USA	Western Europe	World
National income ($ billion)[a]	1,430	2,550	2,460	11,400
Consumption of primary energy (EJ)	61.06	81.76	58.01	376.51
Energy intensity (GJ/$1000)	42.11	32.06	23.58	33.03
Carbon dioxide emissions (MT of carbon)[b]	1,018	1,460	920	6,862
Ratio[c] (kg of carbon/GJ)	16.67	17.85	15.86	18.23[c]
Carbon intensity of national income[d] (kg of carbon/$)	0.70	0.57	0.37	0.60

(a) In 1983 U.S. dollars; purchasing power parity as calculated according to Soviet methodology.
(b) Includes noncommercial types of fuel.
(c) Not corrected for consumption of energy resources for nonenergy needs.
(d) Carbon emissions from burning fossil fuel per unit of national income.

Source: Authors

Principal characteristics that distinguish the Soviet energy balance from the energy balances of other countries or groups of countries include

- a high share of natural gas in energy production (38 percent) and consumption (38 percent)
- a large share of energy exports (16 percent of production)
- a high level of cogeneration development
- a high share (54 percent) of industry, construction, and agriculture in total end-use energy consumption
- a relatively low share of electricity in energy end-use, but a comparatively high degree of centralized heat supply.

CURRENT GREENHOUSE GAS EMISSIONS

The energy balance is an essential basis for determining greenhouse gas emissions. Carbon dioxide is the most important greenhouse gas, and energy facilities are especially important in releases of this gas. The total emissions of carbon dioxide from fossil-fuel combustion are expected to be just over 1 billion tons[a] in 1990 (see Table 2). Power plants are the principal source of energy-related carbon dioxide emissions in the Soviet Union, accounting for 36 percent. Of the total consumption and losses, 7 percent come from the energy sector; 32 percent come from industry, construction, and agriculture; 10 percent come from transport; and 15 percent come from the residential and commercial sectors. Emissions from the various types of fossil fuel are distributed rather evenly: coal and other solid fuels produce 38 percent; oil produces 33 percent; and natural gas accounts for 29 percent. In terms of end use, more than two-thirds of Soviet carbon emissions are produced by the industrial and energy supply sectors.

We have compared the energy and carbon intensities of the economy of the Soviet Union with the

(a) In this report, ton denotes a metric ton.

TABLE 2. Soviet Fossil-Energy Carbon Dioxide Emissions (million tons of carbon), 1990 (estimated)

Sectors	Coal	Oil	Gas	Total End-use	Total Primary[a]
Industry, Construction, and Agriculture	123	120	84	327	520
Transportation	--	102	4	106	127
Residential and Commercial	84	24	41	149	205
Electricity Generation	(166)[b]	(72)[a]	(126)[a]	364	--
Energy Sector	12	21	41	74	168
Total	385	339	296	1,020	1,020

(a) Includes carbon emissions due to electric generation losses.
(b) Emissions due to electric generation losses should not be added to totals; these are distributed among end-use Sectors.

Source: Authors

United States, Western Europe, and the world as a whole. We calculated carbon emissions by including commercial and noncommercial fuel types, and we have evaluated national income in terms of purchasing power parity and in 1983 U.S. dollars.[1] In accordance with these calculations, economic output in 1985 totaled $1.19 trillion for the Soviet Union, $2.15 trillion for the United States, and $2.23 trillion for Western Europe. The Soviet Union accounts for about 12 percent of world economic output and 15 percent of carbon dioxide emissions. The Soviet Union's higher share in aggregate emissions can be explained by its higher energy intensity. Our estimates suggest that in 1990, Soviet energy intensity will exceed levels in the United States by 30 percent, Western Europe by 78 percent, and the world by 27 percent. This higher level of carbon intensity is predetermined by energy intensity and exceeds the U.S. level by 23 percent, the Western European level by 90 percent, and the world average by 17 percent.

The carbon dioxide intensity of the Soviet energy balance turns out to be relatively low. The emissions of carbon dioxide per unit of primary energy consumed is lower in the Soviet Union than in the United States by 7 percent.[2] Only Western Europe has a more favorable energy mix, owing mainly to a higher proportion of nuclear power.

A higher ratio of hydrogen to carbon in the Soviet fuel balance is an effect of higher quality energy resources, illustrated by the ratio of carbon dioxide emissions to the amount of primary energy resources consumed (including noncommercial types of fuel). The worldwide trend in this ratio is downward; it has fallen from 0.79 to 0.53 between 1860 and 1970. But from 1970 to 1984, this ratio fell in the Soviet Union by 21 percent, while it fell by a mere 1 percent in the United States and by 22 percent in Western Europe.

Assessing emissions of methane, particularly natural gas leakage, is difficult. We estimate that the aggregate leakage of gas in the Soviet Union at all stages from production to consumption equals 2 percent of the domestic gas production. Transmission leaks account for 1.1 to 1.2 percent, distribution leaks account for 0.6 to 0.7 percent, and production leaks account for 0.1 to 0.3 percent of total production. We estimate that methane emissions will amount to 12 million tons in 1990. Assuming that one molecule of methane is equivalent in greenhouse effect to ten molecules of carbon dioxide and taking into account the proportional mass ratio, we deduce that 1 ton of methane is equivalent in greenhouse effect to 7.5 tons of carbon.[3] Given the level of methane emissions and their greater greenhouse effect on a molecule per molecule basis, methane leaks add about 2.5 kg of carbon equivalent per gigajoule (GJ) of gas used. This addition means that natural gas has a total carbon equivalent emissions rate of just under 16 kg per GJ, which is still lower than the rates for oil (19.7 kg per GJ) and coal (23.9 kg per GJ).

Nitrous oxide is a potent, long-lived greenhouse gas sometimes associated with energy use. Reliable data on specific emissions of this greenhouse gas, however, are not yet available. Consequently, we will not estimate Soviet N_2O emissions.

Aggregate emissions of greenhouse gases from burning fossil fuels in the Soviet Union in 1990, converted on the basis of carbon equivalents, amount to about 1.1 billion tons of carbon, excluding N_2O and chlorofluorocarbons. This total includes the equivalent of 90 million tons of carbon from methane.

THE DYNAMICS OF SOVIET GREENHOUSE GAS EMISSIONS

Our analysis of future Soviet greenhouse gas emissions begins with a Base Case Scenario of economic growth in the Soviet Union and two sensitivity tests using optimistic and pessimistic growth variations (referred to as the Optimistic and Pessimistic Variations). In the Base Case Scenario, national income is assumed to grow by an average of 3 to 3.5 percent per year through 2005 and 2.5 to 3 percent per year from 2005 to 2020. The Optimistic Variation assumes that national income grows by an average of 4.5 to 5 percent per year through 2010, slowing to 3.5 to 4 percent per year thereafter. The Pessimistic Variation assumes that national income grows by an average of 2.2 to 2.5 percent per year through 2005, and 2 percent per year in the period to follow. In each of these three cases, the current declining trend in energy intensity (elasticity index) was extrapolated.[4]

Electricity demand growth outstrips nonelectric energy demand in each case, and the share of total fuel required for electricity generation increases from 24 percent at present to 34, 38, and 29 percent in the year 2020 in the Base Case Scenario and the Optimistic and Pessimistic Variations, respectively. The probable dynamics of energy production are projected on the basis of optimizing the level and mix of energy production, primarily with the criterion of minimum levelized supply costs. This projection was carried out on the Energy Research Institute's System OCTOPUS, a computer model which embodies the optimization methodology. This system permits a wide spectrum of research connected with national primary energy production and transformation.

System OCTOPUS operates in one of the two following regimes:

1. minimization of capital and operating levelized costs, with final products being assumed

2. maximization of levelized profit (using shadow prices) with given rates of final product prices.

For this study, the first regime was used for the following final products: motor fuel; electricity; centralized heat supply; fuel for boilers and furnaces; oil, gas, and coal exports; and nonenergy uses of energy resources. The discount rate we applied varied between 8 and 12 percent by technology.

System OCTOPUS incorporates both renewable and fossil energy sources, as well as detailed end-use technologies. Renewable energy systems include nuclear and nonconventional sources of electricity and heat supply. Fossil energy systems involve several cost stages, including preparation of energy supplies, production, transport, and transformation of oil, gas, and coal.

The mathematical approaches used in System OCTOPUS to model renewable and fossil energy supplies resemble systems of ordinary nonlinear differential equations with stochastic parameters. Submodels take into account peculiarities of energy production and transformation processes, especially the nonlinear character of "input-output" dependence in preparation of the resource base; energy production, transport, and transformation of recoverable fossil energy; the impact of progress in science and technology; and the uncertainty of the technical and economic parameters of "cost-production" characteristics.

Model results for oil production dynamics are practically the same in all scenarios and correspond to maximum economically motivated levels. The dynamics of natural gas consumption in the first two scenarios (the Base Case Scenario and the Optimistic Variation) are also practically the same and correspond to maximum economically motivated levels of production. However, in the pessimistic economic growth variation (the Pessimistic Variation), gas production is about 10 percent lower because of lower demand for power generation. Thus, these three economic growth cases differ mainly to the extent that coal production and nuclear energy are required to supply varying levels of electric power. However, coal dominates increases in the Asian part of the Soviet Union, and nuclear power dominates increases in the European region.

Emissions of greenhouse gases in these cases have been calculated for domestic consumption of energy resources, excluding energy exports.

Similarly, nonfuel energy uses have been excluded. Again, these cases represent a Base Case Scenario and the two variations and do not include potential technical measures for reduction of greenhouse gas emissions. Emissions of greenhouse gases have been estimated separately for carbon dioxide and methane, and the estimates allow for the differences in radiative forcing (see Table 3).

TABLE 3. Soviet Base Case Greenhouse Gas Emissions (million tons of carbon)

	1990	2005	2020
Base Case Scenario			
Carbon dioxide	1,020	1,315	1,650
Methane	12	16	18
Optimistic Variation[a]			
Carbon dioxide	1,020	1,460	2,060
Methane	12	17	20
Pessimistic Variation[b]			
Carbon dioxide	1,020	1,235	1,480
Methane	12	16	18

(a) This high economic growth case serves as a sensitivity test.
(b) This low economic growth is a sensitivity test

Source: Authors

Current trends in energy development in the Soviet Union would mean a continual rise in greenhouse gas emissions. Carbon dioxide emissions would, depending on the rate of economic growth, increase 21 to 43 percent by 2005 and 65 to 100 percent by 2020. Each variation of the Base Case Scenario shows a steady trend in increasing levels of emissions.

STRUCTURAL CHANGE SCENARIO

The Soviet economy can no longer sustain continued growth in energy consumption and the corresponding demand for increasing energy production. If current trends continue, capital and other resources will be required in amounts so large as to preclude the possibility of realizing any but the Pessimistic Variation of the Base Case Scenario.

J. D. Kononov, a specialist in energy and economy at the Siberian Energy Institute, has shown that the sum of investments for exploration, exploitation, transformation, transportation, and distribution of energy resources should not exceed 5 to 5.5 percent of national income. Exceeding this limitation reduces annual rates of economic growth in accordance with the following expression:

$$Tn = Ti - 0.2\,(Ke/Y - 0.05)$$

where Tn and Ti = new and initial rates of national income growth
Ke/Y = ratio of gross fixed capital investment in the energy sector to national income.

This relationship necessitates implementation of official Soviet policy to develop less energy-intensive industries and services and to slow development of energy-intensive industries. Models of economic development and energy consumption show that such structural change allows substantial reductions in energy intensity. If broader use is made of energy-efficient technologies and equipment, energy intensity may decline much faster than would be possible with current trends.[5] Such structural change, however, is conditional on a considerable reduction of military expenditures.

Assuming successful structural change, energy demand differs only slightly among cases using the economic growth rates assumed for the Base Case Scenario and the Optimistic Variation. The chief reason for this surprising result is the effect of structural change on electricity demand, which appears similar for energy-intensive basic industries in both the Pessimistic and Optimistic Variations. Likewise, differences in the dynamics of national income can be explained mainly by different development rates of less energy-intensive process industries.

Because the economic growth scenarios do not differ greatly in the dynamics of energy demand, the production dynamics of major energy resources also appear similar. Differences in the scenarios may be attributed mainly to the criterion of minimizing the cost of energy development. That is, the model curtails use of the most expensive energy sources, reducing levels of oil production and nuclear supply and decreasing coal production from the most costly mines.

Emissions of greenhouse gases vary only slightly with economic growth in the Structural Change Scenario. Emissions are substantially lower than in the scenarios where existing trends continue (the Base Case Scenario and the Optimistic Variation) and even somewhat lower than in the Pessimistic Variation. Nevertheless, these working scenarios all show substantial growth of greenhouse gas emissions in the years 2005 and 2020 as compared with the present level. Structural change, however, would reduce emissions dramatically (see Figure 1). Thus, by realizing the long-term strategy of restructuring the economy of the USSR, which has enhanced overall efficiency in recent years, it would be possible without any special effort to greatly curb the growth of greenhouse gas emissions.

The possibility of channelling a substantial part of Soviet military spending into rapid development of industries that cater to public needs is one of the important conditions of realizing an economic restructuring strategy; this strategy directly depends on international relations. Of course, restructuring particularly depends on cooperation with the United States in the field of disarmament.

Structural change in the Soviet Union would have several important effects on the Soviet energy mix (see Figure 2 for current estimated energy use). These effects include

- reduction of the share of energy provided by liquid fuels, relative stabilization of the shares of solid fuel and natural gas, and growth in the shares of renewable sources of energy and nuclear energy

- increase in the shares of electricity, transportation, residential and commercial sector energy requirements, along with the reduction in the shares of heavy industry, construction, and agriculture.

Continued electrification of the economy would bring about an increase in emissions from power generation. Growth of electric power demand would cause well over half the growth of overall emissions of greenhouse gases from 1990 to 2020. This change implicitly means a reduction in the share of emissions produced in industry, construction, and agriculture, as well as in the residential and commercial sectors.

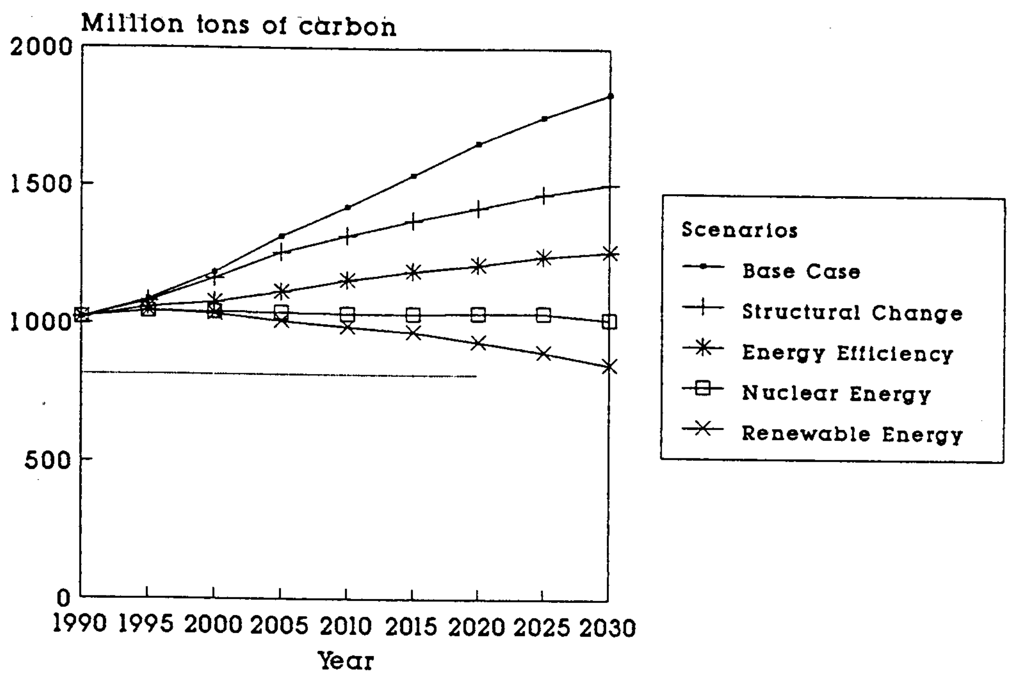
ENERGY EFFICIENCY SCENARIO

In the Structural Change Scenario, Soviet energy intensity would decrease at an average annual rate of 1.6 percent between 1990 to 2005 and 1.7 percent between 2006 to 2020. These figures are near the upper range of energy conservation rates achieved recently by industrially developed capitalist countries. The industrial sector should reduce energy intensity at a rate of 1.8 percent per year through 2005 and 2.4 percent per year in the period to follow. Between 2005 and 2020, energy consumption in industry is projected to grow by 9 percent compared with national income growth of 56 percent.

The scale of energy-efficient technology and equipment use envisaged in the Base Case Scenario was defined on the basis of actual capability for production by Soviet machinery. But the Energy Efficiency Scenario projects the use of energy conservation beyond the Structural Change Scenario in order to realize the cost-effective technological potential for efficiency in the Soviet Union. We estimate this potential for the year 2005 to total about 14.7 exajoules (EJ). Direct capital investments needed to realize this potential would amount to about 50 billion roubles, but this investment would save energy at a cost less than the marginal cost of energy supply. Even after this investment has been made, there would remain large, unused amounts of energy conservation, though realizing that conservation would call for still greater capital investments. Another 2.9 EJ could be saved in 2005, provided fixed capital investments are increased to about 6 to 7 roubles per GJ saved. Another 1.8 EJ may be saved if investments are raised to 9 roubles per GJ.

Analysis of energy conservation costs has shown that as a rule these costs are less than the levelized costs of increased energy production (see Table 4 and Figure 3). Hence, energy conservation is one of the most reasonable ways of cutting carbon emissions.

Significantly, only 25 to 30 percent of the cost of energy efficiency improvements are derived from implementing measures at the point of use. The remaining 70 to 75 percent results from the expense and difficulty of expanding domestic production of



Source: Authors

FIGURE 1. Carbon Emissions in the Soviet Union, 1990-2020

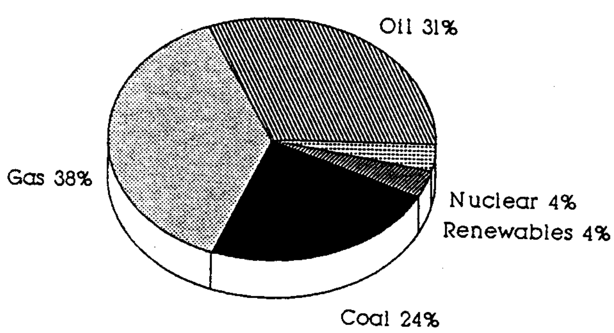


FIGURE 2. Soviet Energy Use, Estimated 1990
(Total = 61 EJ)

energy-efficient equipment and materials. Certain peculiarities of the national price system make domestically manufactured energy-using equipment only half as expensive as similar foreign systems. Therefore, importing technologies and equipment to further enhance energy conservation would be costly. Given current price ratios, importing these technologies would be practicable only if exporting countries were to grant credits for selling such technologies to the Soviet Union. This situation may change radically, however, if the rouble becomes convertible and Soviet prices adjust to world levels.

By using these or other economic means, an even larger potential for energy efficiency may be achieved. Our estimates show that if the energy sector in the Soviet Union, including end-use consumers, is reoriented after 1990 on the basis of the most advanced technologies and equipment, energy consumption may be reduced by 7.6 to 9.4 EJ in 2005, and by 14.7 to 17.6 EJ in 2020, compared with the Structural Change Scenario (see Table 5). The Energy Efficiency Scenario meets the criterion of minimum costs for energy development and does not envisage special measures to reduce greenhouse gas emissions.

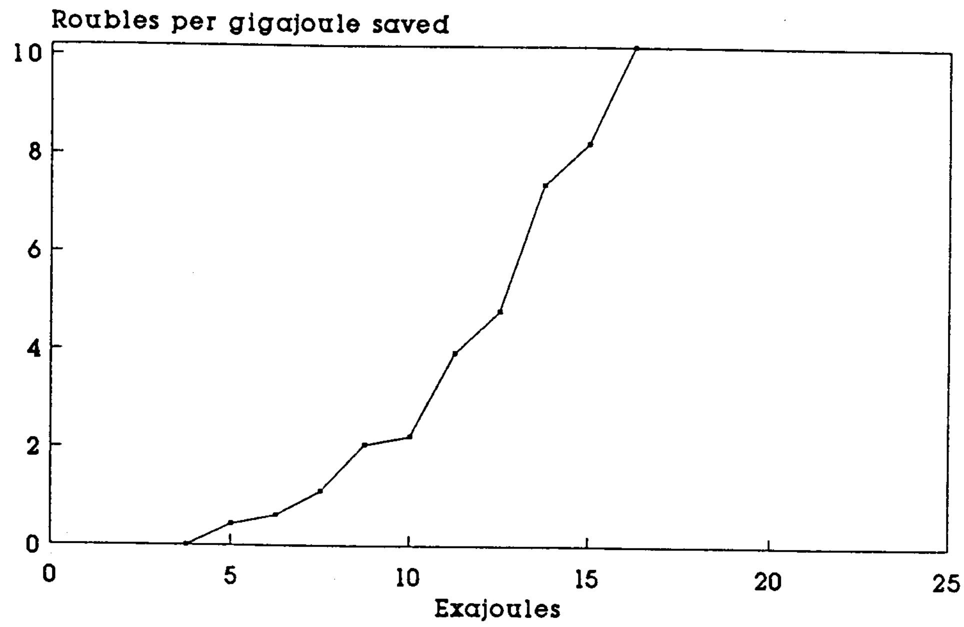
In the Energy Efficiency Scenario, Soviet energy intensity declines at an average annual rate of 2.1 percent per year between 1990 and 2020. Thus,

TABLE 4. Selected Soviet Energy Efficiency Measures, 1990-2005

Measures	Annual Energy Savings in 2005[(a)]	Total Capital Cost 1990-2005[(b)]	Levelized Cost[(c)] A B
	(EJ)	(Roubles)	(Roubles/GJ)
Regulated electric drive	1.4	3.7	0.71/0.82
Efficient lighting	1.1	8.5	2.41/2.99
Gas turbine and combined cycle plants	0.7	5.0	1.64/2.18
Low capacity multi-fuel boilers	0.7	3.3	1.09/1.27
Centralized ovens w/ efficiency x 2-3	0.6	1.2	0.47/0.55
Insulation of steam supply networks	0.5	0.4	0.24/0.28
Control and measurement in energy use	0.5	1.7	1.11/1.41
Switching small boilers to high-grade fuels	0.4	0.3	0.20/0.23
Switching low-efficiency ovens to large boilers	0.3	0.7	0.53/0.54
Improve gas compressors in pipelines	0.3	4.7	3.38/3.95
Shift from harvesters to site threshing	0.3	0.2	0.19/0.22
Advanced technologies for industrial heating	0.2	0.18	0.22/0.27
Scrap recycling in steel industry	0.4	-	-
Insulation of cattle breeding buildings	0.2	0.4	0.42/0.42
Reduction of electric transmission losses	0.2	1.3	1.85/2.29
Automation of heating stations	0.2	0.4	0.52/0.57
Replacing wet cement clinker w/dry method	0.2	1.4	1.93/1.86
Improved brick production	0.1	0.9	1.80/1.80

(a) Annual energy savings in 2005 with volume of penetration for 1991-2005.
(b) Sum of capital cost during 1991-2005.
(c) Two approaches were applied to levelized cost calculations:
 (A) = Soviet approach calculated in accordance with the formula:
 LC = (En + 1/T + OC) * CAP, where LC = levelized cost:
 En = normative ratio for payback of capital investment (En = 0.12);
 T = lifetime of investment;
 OC = ratio of operating cost to capital cost (OC = 0.05);
 CAP = investment cost of capital.
 (B) = used in western countries is based on:
 LC = [(ACCR * CAP) + OPER] fuel savings
 ACCR = i/ (1 - (1 + i) ** -1) - annual capital change rate;
 i = discount rate (i = 0.1);
 l = lifetime of investment;
 OPER = annual operating costs
(d) Levelized cost of energy production.

Source: Authors



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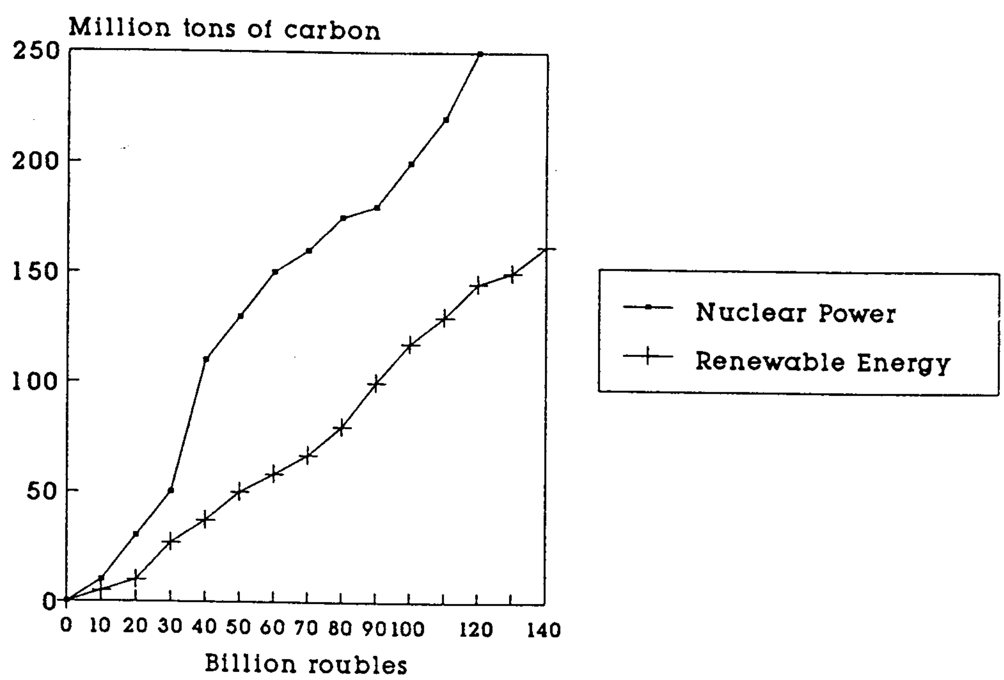

Source: Authors

FIGURE 3. Soviet Energy Efficiency Costs and Carbon Emissions Reduction Costs for Nuclear Power and Renewable Energy

TABLE 5. Energy Demand in the Soviet Union, 1985-2030 (EJ)

Scenario	1985	2005	2030
Base Case	54.4	83.2	123.4
Structural Change	54.4	79.0	106.6
Energy Efficiency	54.4	70.3	85.6
Interfuel Substitution	54.4	70.3	85.6

energy intensity drops by about 47 percent by 2020 and by 57 percent by the year 2030. To maintain such a high rate of energy conservation for four decades would be an extremely complex task. It took the United States about 70 years to reduce its energy intensity by half, which it did first between 1851 and 1929 and again between 1921 and 1990. Great Britain achieved its first 50 percent reduction over the 100 years from 1850 to 1950, and its second 50 percent reduction may be achieved in 50 years (1951 to 2000). Note that these comparisons are of economic systems which include the use of firewood and draught animals.

The Energy Efficiency Scenario reduces emissions 12 percent by the year 2005 and 16 percent by 2020, compared with the Structural Change Scenario. This outcome, however, allows growth in emissions equal to 12 percent by 2005 and 22 percent by the year 2020 relative to the 1990 level (see Table 6).

TABLE 6. Carbon Emissions in the Soviet Union, 1985-2030 (million tons of carbon)

Scenario	1985	2005	2030
Base Case	900	1,315	1,836
Structural Change	900	1,256	1,506
Energy Efficiency	900	1,114	1,260
Interfuel Substitution	900	1,008	853

The largest reductions are attained in the energy sector and in industry. Nevertheless, special measures for energy conservation can significantly reduce greenhouse gas emissions in the Soviet Union.

INTERFUEL SUBSTITUTION SCENARIO

We have created an Interfuel Substitution Scenario by modifying the Energy Efficiency Scenario to make maximum use of energy resources which do not produce greenhouse gases. This scenario was created in two steps: the first step was a nuclear power variant and the second step was a renewable energy variant. In the first step, nuclear power's share in electricity and heat production was gradually increased. The limits of nuclear power production were determined on the basis of growth in demand for electricity and heat. That is, the penetration of nuclear power was constrained by the retirement rates of fossil generating facilities, the technological limitations of electricity and heat supply systems, and the limitation of nuclear power predominately to providing base load power generation and to supplying heat to large consumers.

The additional use of nuclear energy for electricity and heat supply requires significantly larger expenditures in the energy sector. By using all technically realizable nuclear capacity in combination with the maximum cost-effective energy efficiency, it is possible from a technical point of view to stabilize greenhouse gas emissions after the year 2005 at a level exceeding that of 1990 by only 4 percent. Similarly, it is technically possible to reduce the amount of emissions in absolute terms after the year 2020. However, this result will require 140 billion roubles in additional costs (see Figure 3). Though the increment of investment required for the maximum development of nuclear energy was offset somewhat by savings resulting from a slowdown in the growth of coal and gas production, estimates nevertheless show that additional investment of about 400 roubles per ton of carbon reduced is required if an additional reduction in greenhouse gas emissions is to be attained. Thus, the economic cost of using nuclear power to cut emissions is higher than the cost for using intensive energy conservation in the Soviet Union, as also appears to be the case in the United States.[6]

Another method of reducing emissions consists of wider penetration of renewable energy sources, such as energy extracted by heat pumps or hydroelectric (including microplants), wind, solar, and geothermal power. The scale of these technologies is determined by their economic competitiveness and the country's mechanical engineering capabilities. In this case, we assume growth in electricity output at hydropower plants of 360 billion kWh by the year 2005 and 515 billion kWh by the year 2030, as compared with the previous scenarios. In energy, the additional contribution made by renewable sources of energy would total 0.6 EJ in 2005, 1.6 EJ in 2020, and 3.1 EJ in 2030. Expanded penetration of renewable energy would entail considerable growth in expenditures for energy development because of higher capital costs (see Table 7 and Figure 3). Additional investments appear to be higher than in the nuclear scenario, but their effects are much lower. A reduction in emissions by one ton of carbon per year will require an additional investment of about 800 roubles through 2005. However, by the year 2020, this cost should drop to about 700 roubles.

TABLE 7. Capital Costs of Soviet Renewable Energy Systems (roubles per kW)

Technology	1990	1995
Solar Central Power Generation	5,200	1,200
Photovoltaic (remote application)	20,000	12,000
Wind Farms	2,500	1,200
Geothermal Power Stations	2,600	NA
Mini hydropower Stations	2,200	1,200

Source: Authors

TECHNOLOGICAL MEANS OF SUPPRESSING GREENHOUSE GAS EMISSIONS

Special technical means for reducing greenhouse gas emissions are now available, and others are being developed. We specifically consider reducing methane by cutting natural gas losses by half, that is, from 2 percent to 1 percent of the gross production of natural gas in 2005. This means of curbing greenhouse gas emissions is highly effective in economic terms. The cost of natural gas leakage reduction does not exceed 4.1 roubles per GJ. If combustion of 1 GJ of methane produces 13.8 kg of carbon, leakage of the same volume of methane is equivalent in climatic effect to an emission of about 139 kg of carbon. If one takes into account the savings in investment costs for methane production, preparation, and transportation (worth 7.5 roubles per GJ), the cost of emissions reduction is a negative value of about 24.5 roubles per ton of carbon equivalent.

Technical measures are being developed to suppress emissions of carbon dioxide. It is hard to assess the success of this work or to set terms for its practical realization. In an optimistic scenario, it is assumed that these measures will reduce carbon dioxide emissions by 5 percent and 10 percent by the years 2005 and 2020, respectively.

According to some estimates, installation of facilities for scrubbing carbon dioxide at large thermal power plants may raise investment costs per unit of capacity by 1.7 to 3 times the current costs and electricity production costs by 60 to 100 percent.[7] Naturally, these estimates are only approximate. But if they are taken into account and if the factor of growth is assumed to be equal to 2.5, capital costs per ton of carbon will total 325 roubles. In that case, 16.3 billion roubles will be required to reduce emissions of carbon dioxide by 50 million tons annually by 2005, and 29.3 billion roubles would be needed to reduce emissions by 90 million tons by 2020.

SUMMARY OF CONTROL COSTS

Our analysis assumes that special measures for emissions reduction must not increase energy development investment costs by more than 15 percent. With this constraint, emissions growth can be halted in the period between 1995 and 2000. Emissions growth can be reduced by 14 percent by the year 2005, with a steady decline of 25 percent by 2020 and 35 percent by 2030 (see Figure 3).

Additional goal-oriented steps in energy efficiency and accelerated nuclear energy development can make a major contribution. Technical measures for emission suppression are also possible; their total contribution to the solution of this problem may be quite significant. Renewable sources of energy seem to be least the promising option for reducing the greenhouse gas emissions in the Soviet Union.

POLICIES FOR GREENHOUSE GAS EMISSIONS CONTROL

Carbon emissions in the Soviet Union are expected to total just over 1 billion tons in 1990. Methane emissions would add the equivalent of at least 100 million tons of carbon. If present economic and energy development trends continue, the combined emissions total will grow steadily and, depending on the rate of economic growth, will increase by 150 to 200 percent by the year 2020.

These trends are expected to change in the Soviet Union, however, for reasons not directly related to greenhouse warming. Structural change and the need for economic efficiency can significantly cut emissions. Our Structural Change Scenario reflects these opportunities, but its realization requires

- demilitarization of world politics and transition to genuine disarmament
- reduction of military spending[8]
- reorientation of military production toward the production of consumer and capital goods
- radical economic reform with new economic mechanisms which harmonize the society's economic interests, stimulate initiative, and create conditions for a transition to efficient resource use in a new model of economic development
- economic restructuring that would reduce the share of resource- and energy-intensive industries in the production of consumer and capital goods
- further integration of the Soviet Union into the world economy with the intent of increasing the efficiency of the Soviet economy.

This set of measures would effectively reduce the energy intensity of national income and, as a consequence, the growth of emissions to 30 to 40 percent. This reduction of carbon emissions would total 75 to 100 million tons by the year 2005 and 300 to 640 million tons by the year 2020. Thus, as a result of measures not connected directly with the control of greenhouse gas emissions, the Soviet Union's share of global carbon emissions would remain unchanged.[9] Stabilization of emissions at the 1990 level, however, will require greater effort and additional expenditure, which includes the following major contributions to this task:

- Implement additional energy efficiency measures which reduce by 2.1 percent per year the energy intensity of the national economy, cutting primary energy consumption additionally by 14.7 EJ in 2020. This feat would cut carbon emissions by 140 million tons by the year 2005, and by 210 million tons by the year 2020.
- Maximize use of nuclear energy, increasing its share in the energy balance in 2020 to 15.5 EJ against 7.6 EJ in the Base Case Scenario. This measure would cut carbon emissions by 75 million tons by 2005 and by 175 million tons by 2020.[10] However, such a rate of nuclear energy development will require large investments.
- Maximize use of renewable sources of energy, with the enormous associated investment requirements. This policy would reduce carbon emissions by 30 million tons by 2005 and 100 million tons by 2020.

Emissions can be reduced with technological means, including

- reducing methane leaks from 2 percent to 1 percent of gross withdrawals of natural gas, which would cut emissions by about 50 million tons of carbon equivalent by the year 2020
- scrubbing or otherwise physically removing carbon from fuels, which could cut emissions by 50 million tons by the year 2005 and by 90 million tons by 2020 in the most optimistic case.

Therefore, applying additional costly measures theoretically allows not only stabilizing carbon emissions by the year 2020 but reducing them by 25 percent compared with the 1990 level. However, even stabilizing emissions at the 1990 level seems utopian since it would require large material resources and investments from the economy, which might stunt economic growth and reduce the already low standard of living. At the same time, it should be noted that any realistic policy in some measure bears an imprint of Utopia; otherwise, the policy may become a pragmatic attachment to the current situation, useless for solving complex problems.[11]

Effective international cooperation can create favorable conditions to begin to solve the problem of stabilizing emissions. We can single out several directions for such cooperation:

- Grant soft credits to the Soviet Union by international monetary institutions for importing energy conservation equipment.
- Create joint ventures with western companies to produce energy saving hardware.
- Exchange and conduct international analyses of energy efficiency in order to identify the scale and structure of potential energy conservation, including the possible terms and conditions of its realization.
- Embed in public consciousness the idea that energy savings is the principal, and most economically effective, means of solving many global problems of world energy development.
- Expand cooperation in the field of nuclear safety, in conjunction with cost reductions of a new generation of nuclear power plants.
- Expand cooperation to achieve cost reductions for renewable sources of energy.
- Implement joint programs for minimizing methane leakage at all stages from production to consumption.
- Improve technologies for removing and sequestering carbon dioxide.

It will be possible to finance goal-oriented programs for emissions reduction only when the joint efforts of climate experts in various countries dispel the mist of uncertainty regarding the global and regional consequences of climate warming and when it is shown that these consequences are really fraught with catastrophe. Some Soviet experts believe that climate changes in our country may be favorable, at least for agriculture.[12]

NOTES AND REFERENCES

1. The calculations were made by B. Bolotin, scientist from Institute of World Economy and International Relations.

2. This comparison includes fuels used for nonenergy purposes.

3. Bach, W. November 1988. "Modelling the Climate Effects of Trace Gases: Reduction Strategy and Options for Risk Policy," Proceedings of the World Congress on Climate and Development, Hamburg.

4. EDITOR'S NOTE: In considering the authors' assumption of economic growth, the reader must bear in mind that official Soviet statistics are not easily converted for estimating real GNP growth. Most recent data available in the West indicate that during 1984 to 1988 real income in the Soviet Union grew by an average 1.8 percent per year. Some analysts will therefore consider the authors' Pessimistic Variation as rather optimistic, given the current difficulties in the Soviet economy. The authors themselves would not necessarily disagree with such an argument.

5. Makarov, A. A. 1989. "A New Stage in the Development of Power Industry of the USSR, Energeticka i transport 4:57.

6. Keepin, B., and G. Kats. 1988. "Greenhouse Warming, Comparative Analysis of Nuclear and Efficiency Abatement Strategies," Energy Policy 18(6):538-561.

7. Cheng, H. C., and T. Steinberg. November 1986. "A Study on the Systematic Control of CO_2 Emissions from Fossil-Fueled Power Plants in the U.S." Environmental Progress 7(4)245-259.

8. In 1989-1990, the Soviet Union plans to reduce its armed forces by 12 percent, its military budget by 14 percent, and its production of weapons by 20 percent.

9. Bestchinsky, A.A., and I.A. Bashmakov. 1987. "Energy: Hopes and Expectations." Energia: Ekonomika, Tekhnika, Ikologia 6:11-17.

10. This policy would increase the nuclear power capacity installed in the Soviet Union from 126,000 megawatts to 250,000 megawatts in the year 2020.

11. Gobb, T.B., D.G. Steets, T.D. Vaselka, and A.M. Wolsky. 1986. "The Effect of Acid Rain Legislation on The Economics of CO_2 Recovery from Power Plants." Environmental Progress 7(4):247-256.

12. Golitsyn, G. 1988. "Climate and Economic Priorities," Kommunist 6:97-105.

APPENDIX

SUPPLEMENTARY DATA ON SOVIET ENERGY AND EMISSIONS

TABLE A.1. Soviet Energy Supply and Demand (Percent of World Total), 1987

	Production	Consumption
Coal	15.6	15.9
Oil	21.3	15.2
Natural Gas	39.3	33.4
Nuclear Energy	10.0	10.0
Hydro-electric power	10.6	10.6
Total	22.0	18.5

Source: Derived from BP Statistical Review of World Energy, June, 1988.

TABLE A.2. Soviet Energy Consumption, Structural Change Scenario, 2005

	Type of Fuel (EJ)[a]							
Sector/Item	Solid Fuel	Liquid Fuel	Natural Gas	Renewable[b] Energy	Nuclear Power	Elec-tricity	Heat	Total
Total Primary Energy	18.17	21.62	32.67	3.46	3.81	-0.62	--	79.11
Electricity Generation[c]	-9.52	-2.14	-13.04	-3.46	-3.81	10.14	7.62	-14.21
Energy Sector	-0.44	-1.17	-4.10	--	--	-2.34	-1.17	-9.23
Final Energy Consumption	8.20	18.31	15.53	--	--	7.18	6.45	55.67
Industry, Construction, & Agriculture	5.42	6.00	8.20	--	--	4.98	4.69	29.30
Transportation	--	6.30	0.44	--	--	0.59	--	7.33
Residential & Commercial	2.49	1.76	4.10	--	--	1.61	1.76	11.72
Nonenergy Uses	0.29	4.25	2.78	--	--	--	--	7.33

(a) Calculated according to the Organisation for Economic Cooperation and Development (OECD) methodology.
(b) Includes hydroelectric power.
(c) Including cogeneration.

Source: Authors

TABLE A.3. Soviet Energy Consumption, Structural Change Scenario, 2020

	Type of Fuel (EJ)[a]							
Sector/Item	Solid Fuel	Liquid Fuel	Natural Gas	Renewable[b] Energy	Nuclear Power	Elec-tricity	Heat	Total
Total Primary Energy	22.27	22.56	37.94	6.00	7.62	-0.88	--	95.52
Electricity Generation[c]	-14.21	-1.76	-14.06	-6.00	-7.62	14.50	9.67	-19.48
Energy Sector	-0.44	-1.32	-4.98	--	--	-2.93	-1.32	-10.99
Final Energy Consumption	7.62	19.48	18.90	--	--	10.69	8.35	65.05
Industry, Construction & Agriculture	4.67	4.54	9.67	--	--	7.03	6.00	31.94
Transportation	-	7.76	0.88	--	--	1.03	--	9.67
Residential & Commercial	2.34	2.05	5.27	--	--	2.64	2.34	14.65
Nonenergy Uses	0.59	5.13	3.08	--	--	--	--	8.79

(a) Calculated according to the OECD methodology.
(b) Including cogeneration.
(c) Includes hydroelectric power.

Source: Authors

TABLE A.4. Soviet Carbon Dioxide Emissions (millions of tons of carbon), Structural Change Scenario

Sector/Industry	1990	2005	2020
Total	1,020	1,260	1,420
Electricity Generation[a]	364	490	620
Energy Sector	74 (168)[b]	90 (211)	100 (233)
Industry, Construction, & Agriculture	327 (520)	385 (641)	350 (670)
Transportation	106 (127)	135 (165)	170 (217)
Residential and Commercial Sectors	149 (205)	160 (243)	180 (300)

(a) Includes cogeneration.
(b) The sums in the brackets represent electricity generation emissions distributed by sector of electricity consumption.

Source: Authors

TABLE A.5. Soviet Greenhouse Gas Emissions, Structural Change Scenario

Sector/Industry	1990	2005 (percent)[a]	2020
Total	100.0	100.0	100.0
Electricity Generation[b]	35.73	38.9	43.7
Energy Sector	7.3 (16.5)	7.1 (16.7)	7.0 (16.4)
Industry, Construction, & Agriculture	32.0 (51.0)	30.6 (50.9)	24.6 (47.2)
Transportation	10.4 (12.5)	10.7 (13.1)	12.0 (15.3)
Residential and Commercial Sectors	14.6 (20.1)	12.7 (19.3)	12.7 (21.1)

(a) The sums in the brackets represent electricity generation emissions distributed by sector of electricity consumption.
(b) Including cogeneration.

Source: Authors