

Session 1: State of the Art in computer models related to climate change

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Overview of Socio-economic Models

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OVERVIEW OF SOCIO-ECONOMIC MODELING

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Socio-economic models play an important role in integrated assessment models (IAMs) for climate change. They determine the rate of emissions of greenhouse related gases and quantify and value impacts of climate change. A variety of different models are incorporated within the IAM paradigm. This discussion is limited in scope to an important subset - that of socio-economic models. Specifically, we will focus on models which are responsible for forecasting emissions of energy-related greenhouse gases.

As a consequence we will not address the modeling which is undertaken to assess impacts of climate change, or even agriculture-land-use modeling which is responsible for tracing an important share of overall carbon emissions. Rather we will focus on the most important determinant of anthropogenic climate change, energy-related carbon emissions.

Energy-related fossil fuel carbon emissions are responsible for more than 80% of anthropogenic carbon emissions with this share expected to grow to almost 100% by the end of the next century (IPCC, 1996a). Similarly, the net contribution to global warming of all other greenhouse related gases, including sulfur is essentially zero, the cooling effect of sulfur roughly balancing the warming effect of the other gases.

Energy related emissions models have been employed to address two principal questions: How much are future emissions likely to be? and, What is the cost of climate change mitigation by controlling emissions? Research into these questions has proceeded for at least two decades. Research exploring both of these questions can be traced at least as far back as Nordhaus (1977).

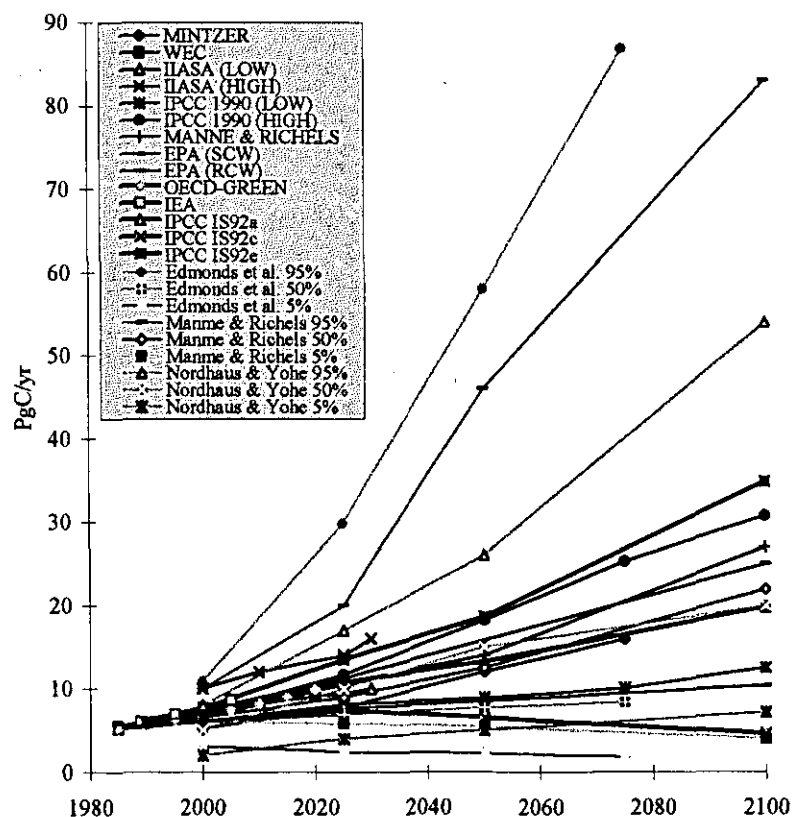


Figure 1: Global Fossil Fuel Carbon Emissions
Baselines from Various Studies

Much of the existing research has focused on the annual rate of emissions, and this focus is reflected in current calls to reduce the annual emissions rate to that of 1990. The

annual emissions rate is important not in itself, but because annual increments add to the *total* amount of greenhouse-related gases in the atmosphere. The total amount determines the overall concentration of these gases, and the concentration determines the amount of climate change. We will return to this distinction between annual emissions and cumulative emissions in the section on costs.

FUTURE EMISSIONS

Several important results emerge from the this literature. First, emissions are expected to rise with time. Second, non-annex I nations' emissions are expected to exceed Annex I emissions before the middle of the 22nd century. And, third, emissions from coal use are anticipated to become the dominant source of carbon emissions before the middle of the 22nd century.

Global Fossil Fuel Carbon Emissions

The growth in annual future fossil fuel carbon emissions with time is a general finding of the energy forecasting community (Alcamo et al., 1995). While there is great uncertainty regarding the degree of growth, only a few forecasts, embodying combinations of unlikely assumptions, anticipate fossil fuel carbon emissions to be lower in 2100 than in 1990 without policy intervention. Figure 1 displays a sampling of emissions trajectories.

However, the concentration of carbon dioxide in the atmosphere is more closely associated with *cumulative* emissions than with an emissions *rate*. While the range of emissions in the year 2100 spans almost two orders of magnitude, cumulative emissions spans less than an order of magnitude. Thus, in the absence of policy intervention to control emissions the concentration of carbon dioxide is anticipated to be higher in the year 2100 than in 1990. Exactly how much higher the concentration will be depends on whether the future follows a high or low emissions track.

Non-Annex I Emissions

Non-Annex I economies and their populations are anticipated to grow faster than Annex I economies. Furthermore, it is generally assumed that the development process will lead to relatively rapid rates of labor productivity growth in non-Annex I nations. The relatively rapid increases in economic activity in turn implies relatively rapid increases in the demand for energy and thus relatively rapid increases in fossil fuel carbon emissions, as shown in Figure 2.

Global emissions models vary in the degree to which they include regional energy and economy detail. With two notable exceptions, modelers have developed their regional estimates based on

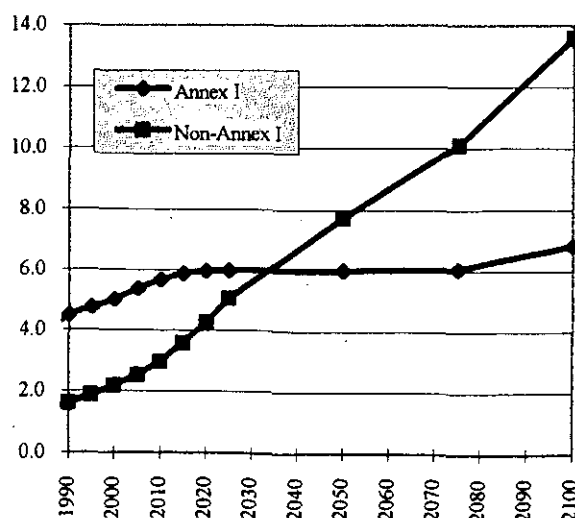


Figure 2: Annex I and Non-Annex I Fossil Fuel Carbon Emissions in IS92a

analysis developed within the modeling group. A new approach has been developed by the Second Generation Model (SGM) (Edmonds et al., 1995) and Asian-Pacific Integrated Model (AIM) (Morita et al., 1993). These two modeling groups have adopted a strategy of forming collaborations with modelers in each of their regions. The regional model and data are developed jointly with the regional groups, and the resulting forecasts reflect regional expert knowledge.

The Energy Transition

Another feature of emissions forecast models is a transition from oil and gas to coal. This transition is the direct consequence of the finite resource base assumed for conventional oil and gas. The carbon contents of the resource base of conventional fossil fuels are given in Table 2. For comparison, Table 1 shows the cumulative emissions over the period 1990 to 2100 from the CO₂ concentration stabilization scenarios developed by Wigley et al. (1996). The resource base of conventional oil and gas is smaller than the allowable cumulative emissions over the period 1990 to 2100 of the 450 ppmv ceiling. Without a significant consumption of coal and other unconventional fossil fuels, the concentration of carbon in the atmosphere cannot exceed 500 ppmv.

In future scenarios, coal is used to provide liquids and gases. The use of coal as a feedstock for liquids and gases is the direct consequence of the finite resource of conventional oil and gas, whose production cannot expand at the same rate as global economic activity. In addition, coal is used to generate electric power. The time path of conventional oil and gas production, and solids transformation for the IS92a scenario, are shown in Figure 3.

Table 1: Cumulative Carbon Emissions

Concentration Ceiling (ppmv)	Cumulative Emissions 1990 - 2100 (PgC)
350	363
450	714
550	1,043
650	1,239
750	1,348

Source: Wigley et al. (1996).

Table 2: Carbon Content of Fossil Fuel Energy Resources Potentially Available After 1990

Energy Form	Resource Base (PgC)	Range of Resource Base Estimates (PgC)	Additional Occurrences (PgC)	Resources plus Additional Occurrences (PgC)
Conventional Oil ^{a,b}	170	156-230	200	156-430
Conventional Gas	140	115-240	150	115-390
Unconventional Gas	410	--	340	750
Gas Hydrates	--	--	12,240	12,240
Coal ^{b,c,d}	3,240	--	3,350	3,240-6,590
Oil Shale ^{d,e}	40,000	--	--	40,000

Source: IPCC (1996a) p.87. ^a Includes conventional and tar sands. ^b Source: IPCC (1996b). ^c Assumes 50% unrecoverable coal in the resource base. ^d Range estimates are not available due to the abundance of the resource. ^e Source: Edmonds and Reilly (1985).

The rapid escalation in the use of coal is projected to occur sometime in the first quarter of the 22nd century. The timing of the transition depends on the rate of increase in global energy demand and the total conventional oil and gas resource base. If the resource base is larger, the date of transition is shifted toward the end of the first half of the 22nd century, while it occurs toward the beginning for smaller resources.

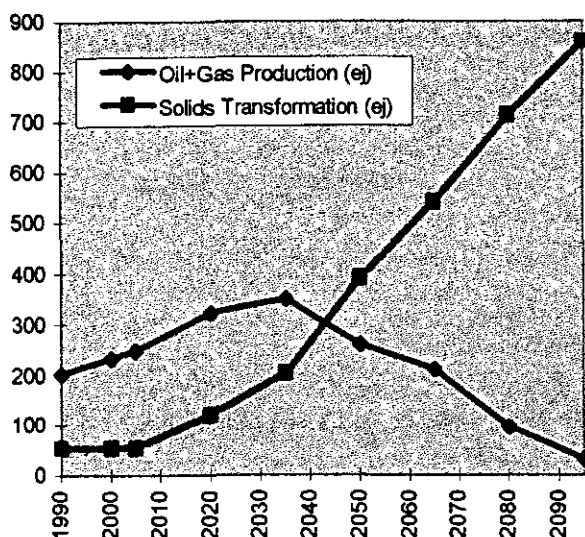


Figure 3: Conventional Oil and Gas Production and Coal Use in Energy Transformation (EJ/yr)

The transition is accompanied by an escalation in the price of conventional oil and gas; the price rises to the point at which coal liquids and gases become economic. This transition occurs not at the peak of production of conventional oil and gas, but at the point where the rate of expansion of conventional oil and gas falls behind that of the global energy system. This transition also provides the economic incentive for the expansion of non-carbon energy technologies.

Sources of Emissions Growth

Various studies have explored the principal sources of emissions growth (see, e.g., Nordhaus and Yohe 1983, Reilly et al. 1987, and Manne and

Richels 1994). The principal sources of emissions growth are generally technological and economic. This is also true for other uncertainty based models such as ICAM (Dowlatabadi, 1997). In economic models emissions depend on the rate of productivity growth for energy and non-energy inputs to the production of GDP. Increases in the rate of productivity growth for energy inputs tend to reduce the rate of emissions, while increases in other factor productivities increase the demand for energy by increasing the overall scale of economic activity. Similarly important is the composition of economic activity and energy demand. Developing nations are generally anticipated to experience an increasing share of economic activity in their modern sectors and a decreasing share of economic activity in their traditional sectors. As the modern sector is more carbon intensive than the traditional sector, carbon emissions tend to grow more rapidly than overall economic activity in the early stages of development.

Population growth is a highly controversial factor. The number of people is the base determinant of the scale of human activity, which in turn is a primary determinant of the scale of emissions. But other factors are also powerful. Productivity and the composition and nature of human activities are potentially more powerful. These factors are responsible for the paradoxical situation in which many populous, but poor, nations have lower emissions than rich, but low population, nations. Because the range of population growth over the next century is relatively limited compared with the range of potential economic growth and energy intensity improvement, population growth tends to be a relatively less important source of overall uncertainty in future emissions.

THE COST ISSUE

The relationship between emissions mitigation, relative to a reference case, and the cost in terms of foregone GDP is shown in Figure 4 for a variety of studies. The scatter of estimates reflects the variety of circumstances under which cost calculations were developed, as well as the fundamental uncertainty associated with the estimate of cost.

While there is considerable disagreement regarding precise figures, a clear pattern of increasing cost in association with greater mitigation efforts exists in Figure 4. In general, the higher the reference emissions level, the greater the relative emissions reduction required to return emissions to a prescribed level. For example, if emissions double between 1990 and 2050, then a 50% reduction in emissions is required to return to 1990 levels, while if emissions quadruple, then a 75% reduction in emissions is required to return to 1990 levels. In turn, the greater the relative emissions reduction, the greater the cost.

Figure 4 also shows some extreme cases in which cost estimates are either very high or very low. The estimate of Goldemberg et al. (1987) reflects the effect rapid development and deployment of advanced energy technologies might have on costs. In contrast Walley and Wigle (1991) reflects the cost of meeting carbon constraints without the benefit of technology development.

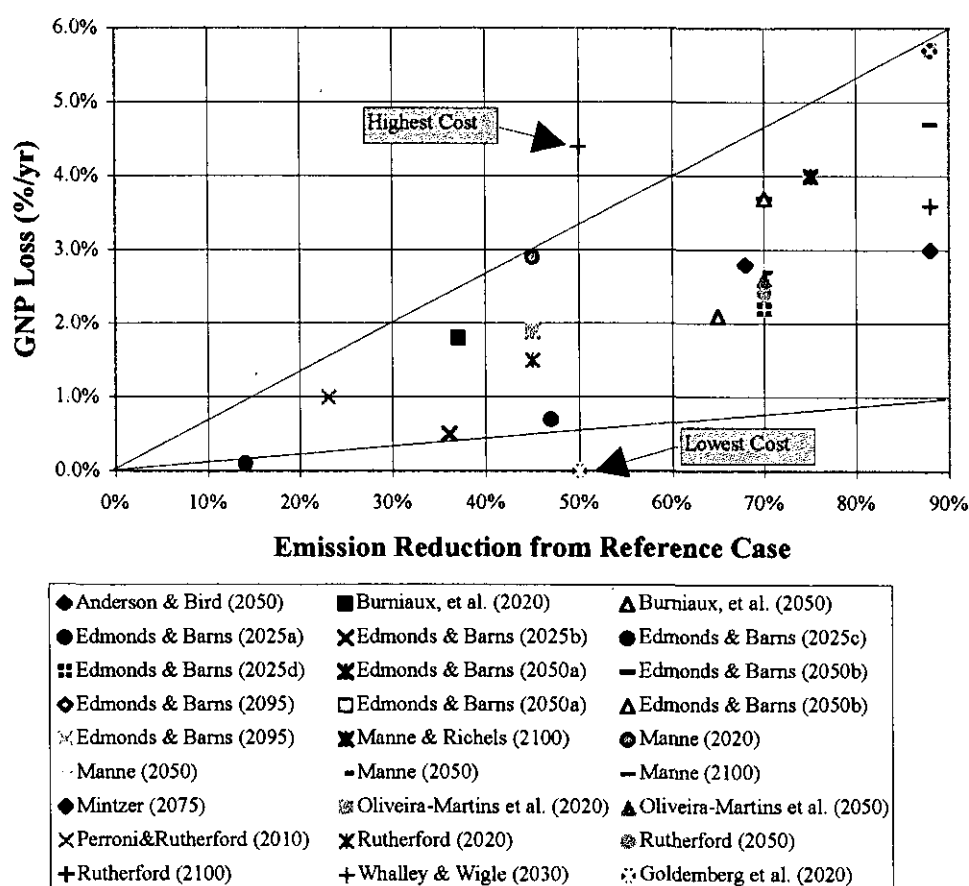


Figure 4: Range of Cost Estimates for Mitigation, Global Models

Other factors are also important in determining the costs of emissions mitigation. These include:

1. The suite of technologies available for mitigation and the marginal cost of employing these technologies in preference to fossil fuel technologies,

2. The degree of geo-political participation and flexibility in where mitigation efforts are undertaken, and
3. The degree of flexibility in when emissions mitigations are undertaken.

With a great deal of fundamental work on annual emissions rates accomplished, socio-economic research has begun to focus on the ultimate goal of reducing projected cumulative emissions, that is, to focus on concentrations of greenhouse-related gases in the atmosphere. Focus on a concentrations ceiling, rather than on a ceiling for annual emissions, yields findings that open new possibilities for international agreements.

“When” Flexibility

Much recent work has focused on the problem of implementing the goal of the Framework Convention on Climate Change (FCCC), which is “...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (United Nations, 1992, p.5).

Several important and interesting results have begun to emerge from that research. First, it may be cheaper to stabilize the concentration of greenhouse related gases than it would be to stabilize emissions. Since the stabilization of CO₂ concentrations eventually requires a long-term commitment to ever decreasing emissions, the result was surprising.

The logic is simple. Consider the case of stable fossil fuel emissions at 1990 levels. This trajectory leads to a concentration of atmospheric CO₂ of approximately 500 ppmv in the year 2100. However, the concentration continues to rise in the post 2100 period. To stabilize the concentration at 500 ppmv requires that fossil fuel carbon emissions be lower than 1990 levels in the year 2100.

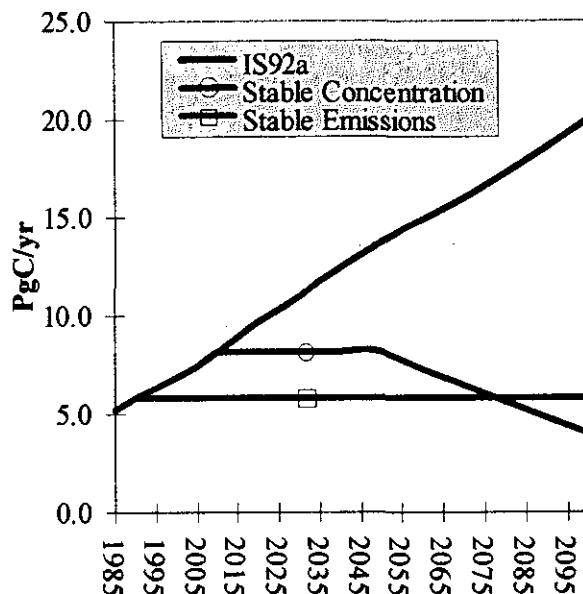


Figure 5: Comparison of Fossil Fuel Emissions Paths for Stabilizing Emissions and the Atmosphere

But to a first approximation the concentration depends on cumulative emissions, and if atmospheric CO₂ stabilization requires that emissions be lower than 1990 levels in the year 2100, then at some point prior to the year 2100, emissions can, and will, be greater than 1990 levels. This feature implies a window of opportunity for emissions to rise. Since the cost of emissions reductions is greatest in the near term, then total cost can be reduced by allowing emissions to grow initially.

The savings in mitigation costs, over the emissions stabilization case, will be greater for several reasons.

- First, emissions mitigation technologies by the year 2100 will doubtless be cheaper than at present.
- Second, displacing the costs in time implies that the discount rate can be brought to bear on the problem. That is, the total value of resources that would have to be set aside

today to undertake a given financial obligation are smaller the further in time the obligation is to be undertaken, because the power of compound interest can be employed.

- In addition, allowing emissions to continue to grow temporarily implies that existing capital stocks are not required to operate in a manner different than originally anticipated.

- Finally, the carbon cycle works in favor of higher near-term growth. Over the course of 110 years cumulative emissions are somewhat more than 30 PgC higher in 500 ppmv “Stable Concentration” than in the “Stable Emission” case. This “carbon cycle dividend” is equivalent to about five years of fossil fuel emissions at 1990 rates. Richels and Edmonds (1995) estimated that the economic cost of stabilizing emissions was about 50% greater than the cost of stabilizing the atmosphere at 500 ppmv.

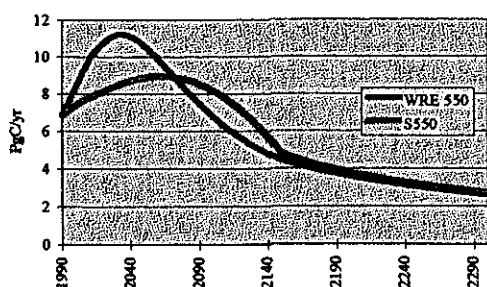


Figure 6a: WRE and S Series
Emissions Trajectories for a 550 ppmv
CO₂ Concentration Stabilization

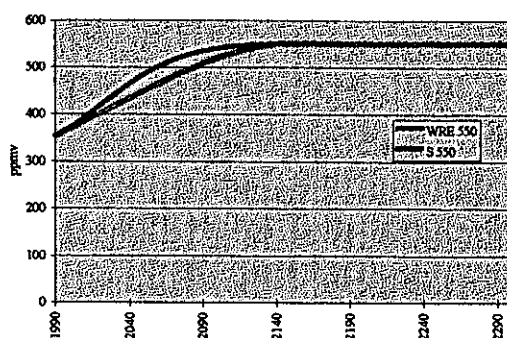


Figure 6b: WRE and S Series
Concentration Trajectories for a 550 ppmv
CO₂ Concentration Stabilization

These observations lead to a reconsideration of pathways for stabilization of the concentration of atmospheric CO₂. Not all CO₂ concentration pathways are alike. Whereas the IPCC (1995) had constructed a set of emissions pathways which stabilized atmospheric CO₂ concentrations at 350, 450, 550, 650, and 750 ppmv, these pathways are not unique. Wigley et al. developed an alternative set of pathways that were characterized by higher near-term emissions and lower mid-term emissions. Figure 6a shows the IPCC (1995) emissions and Figure 6b the concentration trajectories (S 550) compared with those developed by Wigley et al. (WRE 550).

The WRE 550 emissions path is generally associated with lower economic costs than the S 550 path. See for example, Edmonds et al. (1996). On the other hand, the pathway is also associated with higher transient CO₂ concentrations. These concentrations imply higher transient radiative forcing and potentially greater transient climate change. This in turn could imply regionally greater benefits or costs.

Another feature of following the WRE emissions trajectory over the S Series lies in the fact that the WRE emissions trajectories are tractable with emissions mitigation proposals advanced under the Berlin Mandate discussions. Consider, for example, a protocol in which Annex I nations agree to return emissions to 1990 levels in 2010 and continue reducing emissions at 0.75%/yr until emissions are 50% of 1990 levels. We can subtract this emissions trajectory from both the S Series and WRE trajectories and impute potential non-Annex I emissions. These calculations are shown in Figures 7a and 7b along with non-Annex I emissions in the IS92a scenario.

In Figure 7a, non-Annex I emissions lie everywhere below the IS92a trajectory for all stabilization ceilings below 750 ppmv. In fact, for many years, the S Series trajectory requires Non-Annex I percentage emission reductions to exceed those of Annex I. In contrast, Figure 7b shows that with the WRE trajectory, for long periods of time allowable non-Annex I emissions exceed IS92a emissions. Thus, it would be possible for Annex I to provide emissions allowances to non-Annex I nations in excess of their anticipated emissions, a potential mechanism for extending participation in a protocol.

This vein of research has given rise to the realization that there are significant economic benefits associated with allowing flexibility in determining when emissions mitigation occurs.

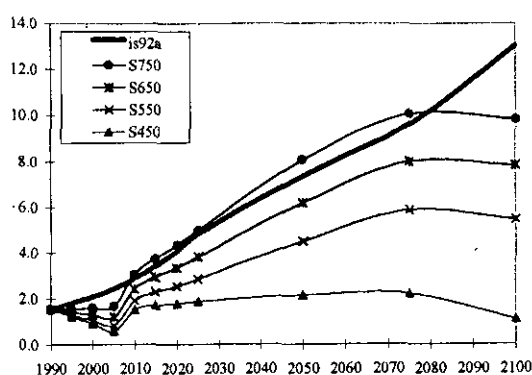


Figure 7a: Allowable Non-Annex I Emissions With S Series Emissions Trajectories and Hypothetical Protocol

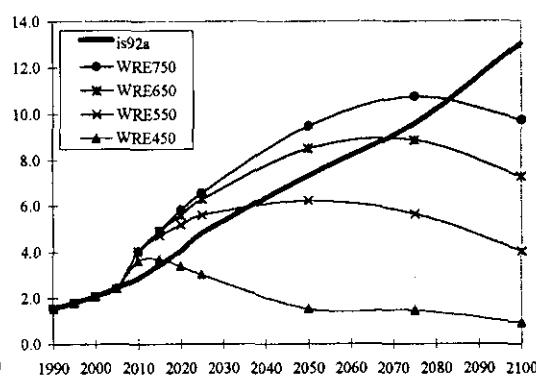


Figure 7b: Allowable Non-Annex I Emissions With WRE Emissions Trajectories and Hypothetical Protocol

“Where” Flexibility

There are opportunities to reduce the cost of emissions mitigation in providing flexibility in where emissions are reduced as well as in when they are reduced. Cost differences can be large between strategies which allow trade in emissions allowances and those which do not.

A simple exercise was performed by the Energy Modeling Forum to explore the ability of where and when flexibility to control costs. This exercise created a hypothetical commitment on the part of OECD nations to return emissions to 1990 levels in the year 2000 and reduce 20% further by the year 2010 (Richels et al., 1996). Four modeling groups participated in the exercise, which computed the cost with and without flexibility. When regions were required to reduce emissions independently, present discounted costs were estimated to be between two and eight trillion dollars ($\$2 \times 10^{12}$ to $\$8 \times 10^{12}$). Most of the costs were accrued by OECD nations, but some were experienced in other regions, particularly those which were energy exporters and those with important links to the international economy through trade.

An alternative case was constructed in which emission mitigation was allowed to be purchased by nations from other OECD and non-OECD nations. This flexibility reduced the cost of meeting the mitigation targets by 70%. Similarly, when no flexibility in where emissions reductions were taken but nations could undertake emissions mitigations whenever

it was cheapest, as long as cumulative emissions were identical in 2050 as they would have been in the "No Flex Case," costs were reduced 40%. When both where and when flexibility were allowed, total costs were reduced an average of 85% in model runs.

The implication of these analyses is that a great potential exists to lower the cost of meeting emissions targets when flexibility is introduced, with the greatest cost reductions occurring when the global economy is mobilized to achieve an emissions reduction goal.

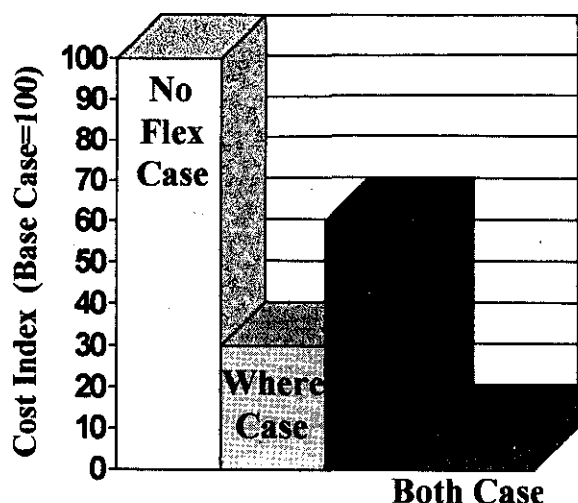


Figure 8: Global Costs Under Four Alternative Cases

Edmonds et al. (1996) examined the implications for atmospheric CO₂ concentrations of efficient and inefficient policy instruments. They found that, without trade in emissions rights, the cost of the above protocol was about the same as would be experienced if an efficient global effort were mounted to stabilize the atmosphere at 500 ppmv, Figure 9. Yet the OECD-only emissions reductions would not stabilize the atmosphere and would only marginally lower atmospheric CO₂ concentrations from levels that would be anticipated without policy intervention.

The Mechanisms of Technological Change

The degree to which technology changes and the manner in which technology changes have profound effects on the estimated cost of achieving any objective. In Figure 4, for example, Goldemberg et al. (1987) show the effect of introducing advanced energy technologies with wide market penetration; the effect is to decrease to zero the cost of reducing emissions 50% relative to the reference case.

The modeling approach employed by Goldemberg et al. is to introduce changes in technology exogenously. Most models employ this same approach. Depending on the model, technologies are either specified explicitly or are covered by a "blanket" assumption: Explicit technology descriptions provide the cost and performance characteristics for a particular piece of capital equipment, such as for example a combined cycle gas turbine, employed in a particular setting. This technology may or may not change over time. This approach is often employed in the energy supply and transformation sectors, where a large share of energy passes through a small set of technologies.

In much of the economy, the set of technologies in use is broad and diverse. There are many types of lighting applications. There is an even larger set of industrial technologies that employ energy to transform materials. And while these technologies may be classified into broad categories of steam raising, heating, mechanical drive, and direct electric applications, the variety of technologies and circumstances makes specification of individual technologies far into the future a risky undertaking. To make matters worse, the changes in the composition of industrial sectors can dramatically affect energy intensity for industry as a whole, without any changes in the underlying technologies.

As a consequence, an aggregate rate of change for energy intensity for large sectors such as industry, residential, commercial and transport, are assumed. This rate often goes under the title: AEEI (Autonomous Energy Efficiency Index), though the acronym is something of a misnomer in that it measures changes in energy *intensity* rather than energy *efficiency*. Energy intensity is a combination of many effects, including changes in energy efficiency, changing composition of underlying activities, and a changing regulatory environment.

The AEEI concept is not a natural, observable quantity. It is a residual value which each model needs to calibrate to the historical experience. As a consequence, values for AEEI may be different for different models, and yet they may have similar performance. For example AEEI in the Global 2100 is 0.5%/yr, while in the Edmonds-Reilly-Barns (ERB) model it is 1%/yr. Yet these models generate very similar forecasts of future energy and carbon emissions, and are characterized by highly similar emissions mitigation costs. The reason each model uses a different AEEI value can be traced to differences in their internal model structures. The ERB employs an income elasticity of demand for energy services greater than unity outside OECD regions, while Global 2100 employs a constant unitary income elasticity. Thus, each model needs a different AEEI value to reflect a common historical record.

Recently there has been interest in models in which the rate of technological change is determined endogenously. Researchers such as the Goulder (1996), Nakicenovic (1996,1991), Messner (1995), Messner and Nakicenovic (1992), Kim and Lau (1992), Grubler (1991), and Frisvold (1991) have recently looked at the problem of determining technology within the model itself.

Several approaches have been adopted. One exploits the "learning curve" effect. Here the cost of a technology depends on cumulative production. Thus, increased production leads to lower costs and therefore greater market share. The implication is similar to the "infant industry" argument in international trade. Early subsidies can be helpful in accelerating the development and deployment of a technology which will ultimately be profitable. The problem with this framework from the perspective of modeling is that the modeler must know which technologies will ultimately be profitable if sufficient cumulative production is acquired, and which lack the potential to gain significant market share at maturity. Goulder (1996) showed that, depending on the specific model parameters, "learning curve" models could either tend to imply greater or lesser near-term mitigation efforts in a program of atmospheric CO₂ concentration stabilization.

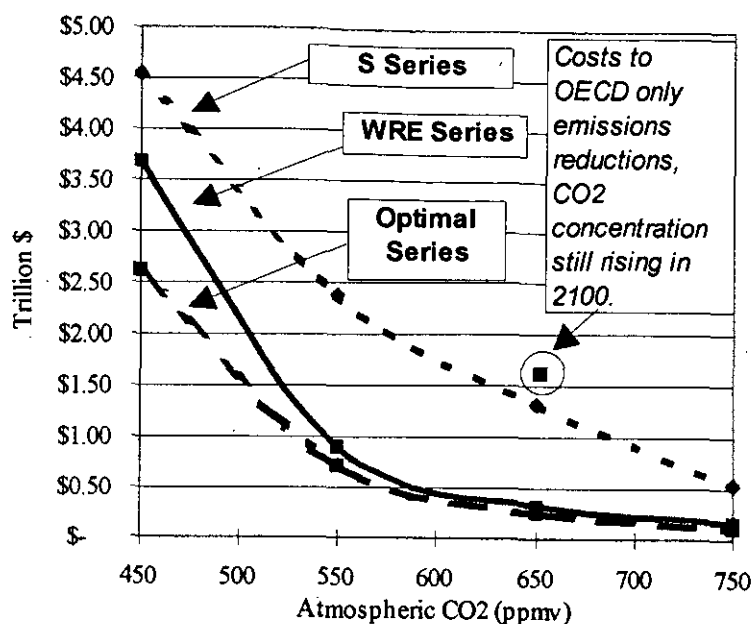


Figure 9: MiniCAM 2.0 Costs of Stabilize the Atmospheric CO₂ Concentration at Levels Ranging from 450ppmv to 750 ppmv for Three Alternative Sets of Emissions Trajectories (S, WRE, and Optimal) and One Non-Stabilization Case.

Another model of endogenous technological change focuses on the role of R&D. In this model, technology is a produced good, and like other produced goods can be increased in supply by the application of resources. Mitigation efforts lead to a shift in the production of R&D production toward activities which produce the mitigation. Goulder (1996) showed that the existence of endogenous R&D tended to reduce the degree of near-term mitigation efforts in a program of atmospheric CO₂ concentration stabilization. The fact that R&D resources could be used to accelerate the development of mitigation cost saving measures meant that delay had little cost.

While some progress has been made in modeling endogenous technological change, the problem remains daunting and the solution elusive.

THE VALUE OF TECHNOLOGY

While the mechanisms by which technology changes are not well understood, the value of developing and deploying advanced energy technologies is enormous. Edmonds et al. (1995) computed the cost of stabilizing the concentration of CO₂ at various levels using the WRE trajectory, with complete flexibility in where emissions mitigations were undertaken, for three alternative classes of technology assumption:

Technology Case 1: **IS92a (1990Tech)** -- Technologies are frozen at 1990 levels. No energy technology improvements of any kind were considered.

Technology Case 2: **IS92a (Tech+)** -- IPCC Technologies from the IS92a scenario were assumed to become available. This case assumes significant energy technology improvements in both fossil and non-fossil energy technologies over the course of the next century.

Technology Case 3: **Advanced Technology** - In addition to the technologies available in Technology Case 2, a suite of advanced, non-carbon emitting technologies are developed which are efficient and cost effective. These technologies have been described in, for example, Ishitani et al. (1996).¹

The cost estimates developed here must be viewed as a lower bound on the actual costs that would be experienced. But the pattern they show is revealing. Figure 10 shows the costs for different CO₂ concentration ceilings. The difference between stabilizing the concentration at 550 ppmv with 1990 technologies, and the technology advances in the IS92a scenario, is an order of magnitude.

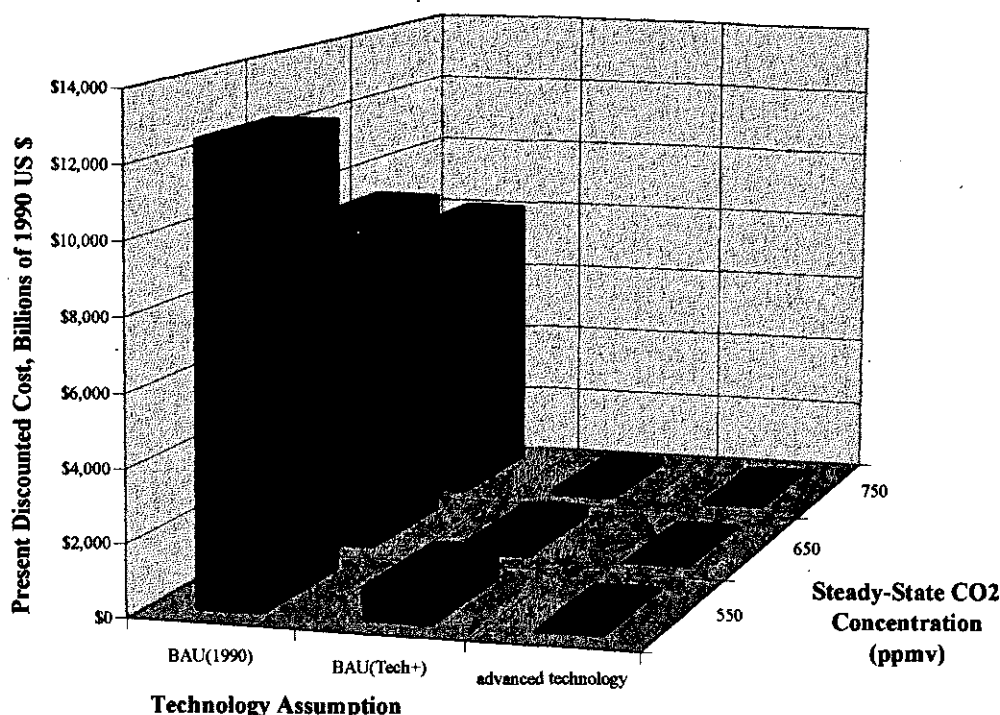


Figure 10: The Relationship Between Technology and Minimum Cost of Stabilizing the Atmosphere Below Various Ceilings

The cost of stabilizing the atmosphere at 550 ppmv with 1990 energy technologies exceeds \$12 trillion² or more than 1.5% of GDP, even with full flexibility in where emissions are reduced. In contrast the introduction of IS92a assumptions lowers costs to approximately one trillion dollars or only 0.12% of GDP, and if advanced, non-carbon, energy technologies could be made widely available by the year 2020, these costs virtually disappear.

Technology reduces costs by lowering the required emissions mitigations. To stabilize the atmosphere at 550 ppmv, the WRE analysis requires that global fossil fuel CO₂ emissions be reduced to 6.5 PgC/yr in the year 2100. With 1990 technology, global fossil fuel CO₂ emissions grow to more than 67 PgC/yr by the year 2100 in contrast to 20 PgC/yr in the IS92a scenario and only 9.5 PgC/yr with advanced technologies. While different models would yield different estimates of costs, even with the same technology assumptions, and the assumed complete flexibility in where emissions mitigations occur may not actually be achievable, the importance of energy technology in shaping the cost of achieving any climate goal is a robust qualitative result.

CONCLUSIONS

Socio-economic modeling of fossil fuel carbon emissions has proceeded for at least two decades. That rather large body of work indicates not only that emissions are likely to grow, but that much of that growth in emissions will be associated with the development of presently economically poor nations, and a transition from conventional oil and gas to coal-based, high-value fuels, liquids, gases, and electricity. Great uncertainty surrounds the details

of these three general findings. The rate of global and non-Annex I emissions growth, and the date of energy system transition, are all highly uncertain.

Socio-economic models are at a similar place regarding the cost of emissions mitigation. Nevertheless, the general conclusion is clear, that the greater the required relative emissions reduction, the greater the cost. Furthermore, flexibility in where and when emissions mitigations are undertaken can reduce costs.

Technology has a profound effect on emissions mitigation costs. The present discounted value of moving from 1990 technologies to the technology set assumed in the IPCC IS92a scenario can be more ten trillion dollars even if full where and when flexibility is employed. Costs can be reduced to very modest amounts with the development and deployment of advanced energy technologies.

If done efficiently, stabilization of the concentration of atmospheric CO₂ can be relatively inexpensive, costing less than a percent of world GDP for ceilings of 550 ppmv or above, but if done inefficiently, costs can much greater, and the atmosphere will not be stabilized.

END NOTES

¹The advanced technology case examines technologies which might be introduced in the future, but which are not presently available. These technologies include: advanced liquefied hydrogen fuel cells; hydrogen transformation from natural gas, biomass, or electrolysis; non-fossil fuel electric power generating technologies including solar photovoltaic, nuclear fusion, and wind, and commercial biomass energy production. Mean potential costs for the non-carbon electric technology set is assumed to decline to a cost of \$0.04/kWh by 2020 and decline 0.5%/yr thereafter. Biomass energy is assumed to be available at costs ranging from the \$1.40/GJ to \$2.40/GJ.

²Costs are denominated in 1990 United States dollars, computed as the present discounted sum of all years costs discounted at 5%/yr.

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