TECHNOLOGY AND CLIMATE CHANGE

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The Framework Convention on Climate Change (FCCC), calls for stabilization of atmospheric greenhouse gases concentrations. Carbon dioxide is the most important of the anthropogenic sources of greenhouse gases because it has the highest atmospheric concentrations, the highest total global warming potential and a very long life time in the atmosphere. Furthermore, it is also very pervasive being associated with almost all human activities. The most important sources of carbon dioxide emissions are energy related.

The Intergovernmental Panel on Climate Change (IPCC), in the draft second assessment report of Working Group I (WGI), has identified ranges of possible future carbon dioxide emissions that would be consistent with the stabilization called for in the FCCC. Figure 1 shows the historical and possible future global energy-related carbon dioxide emissions in Gigatons of carbon (Gt C). The shaded area indicates the emissions range from the WGI concentration stabilization exercise at 450 ppm. Future emissions are shown for three global scenarios that lead to stabilization below 500 ppm. The highest trajectory is from the World Energy Council Commission Report, Energy for Tomorrow's World, Ecologically Driven Scenario C (WEC-C). The middle trajectory is from a scenario developed at IIASA that describes a transition to a methane economy and eventually to zero carbon energy system (CH4-zero C Economy). The lowest trajectory is from a scenario developed by the IPCC WGIIa for the second assessment report, called LESS, which describes the effect of technological mitigation options in a world based on sustainable use of biomass and other renewable energy sources. All of these three scenarios are consistent with the objectives of the FCCC. However, none of them would be easy to reach since they all imply radical changes both in the energy system and in energy end-use by assuming high degrees of energy efficiency improvements, high levels of decarbonization and vigorous diffusion of new technologies.

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Figure 2 shows energy intensity expressed as energy consumption divided by GDP (MJ/US$1980) for a number of countries. Many of the OECD countries have comparatively low energy intensity compared to the reforming economies of the former Soviet Union (FSU) and two developing regions shown in the figure, centrally planned Asia (CPA) and South Asia (SAS). For the reforming and developing countries, GDP is expressed in both market exchange rates (mexr) and in terms of purchasing power parity (ppp). The figure shows that these regions have energy intensities today that are comparable to those prevailing in the OECD countries 50 to 100 years ago. During the last century, energy intensity has decreased in the shown OECD countries, typically at about 0.9 percent per year. A part of the reduction in the energy intensity during the early phases of industrialization is due to the substitution of non-commercial, and often unsustainable and inefficient, energy use by commercial energy sources. Such and even higher rates of energy efficiency improvement might be possible in the developing parts of the world as similar replacement occurs.

Compared to this historical development of energy efficiency improvement as captured by energy intensity levels, Figure 3 shows possible future energy intensity improvements as an index compared to the base year 1990 (100 percent). The figure shows the intensity improvements for the three scenarios (WEC-C, CH4-zero C Economy, and LESS WGIIa). In addition, the Figure shows the range of the IPCC scenarios from the 1992 Supplement report (IS92 range) and with the wider shaded region, the range of non-IPCC scenarios available in the literature. The three mitigation scenarios that lead to stabilization at below 500 ppm imply energy intensity improvements in excess of two percent per year during the next century, or more than twice as high compared to the historical improvements during the last century.

Figure 4 shows the historical decarbonization of energy in the world expressed in tons of carbon per unit energy. The global decarbonization rate was, on average, about 0.3 percent per year. It is calculated by accounting for all of the primary energy consumption in the world, including non-commercial energy, and determining total carbon content of consumed energy. Decarbonization has occurred because of the gradual replacement of carbon intensive sources of energy by those of low and even zero carbon content. The global decarbonization of energy resulted from the substitution of the unsustainable use of fuelwood and coal by oil and natural gas, and to a lesser degree by hydro power, nuclear energy and the sustainable use of biomass.

In contrast, Figure 5 shows the possible future decarbonization rates expressed as an index compared to the base year 1990 (100 percent) for the three stabilization scenarios, the IS92 IPCC range of scenarios, and for the other non-IPCC scenarios from the literature. It is interesting to note that some of the non-IPCC scenarios anticipate a trend reversal of the historical decarbonization toward increases in the carbon intensity of energy use, largely due to replacement of oil and gas by coal. Most of the other scenarios, including the IS92 range, lead to gradual decarbonization. Moreover, the three stabilization scenarios imply decarbonization rates of up to two percent per year. This corresponds to more than up to six times the historical rates. It is evident, therefore, that the three scenarios imply unprecedented rates of replacement of fossil energy sources with high carbon content, by the less carbon intensive ones, such as natural gas, and eventually a complete transition to zero carbon options, such as renewables, nuclear and solar energy. The key question is what policy measures are required to bring about vigorous diffusion of carbon mitigation technologies to realize the three stabilization scenarios.

Figure 6 shows the historical substitution of primary energy sources in the world expressed in terms of market shares of each energy source in the total global energy consumption. In the middle of the last century, fuel wood contributed more than 70 percent but was then replaced by coal, which achieved maximum market shares approaching 80 percent during the 1920s. Coal was then gradually replaced by oil and natural gas, and to a lesser extent hydropower and nuclear energy. This substitution process also explains the gradual decarbonization of global energy. It is important to note, however, that the diffusion of new primary energy sources lasted many decades. On the global scale it took almost one hundred years from the time coal and oil were introduced before they became the dominant energy forms. Adding to that the few decades usually required for the commercialization of new technologies, the whole diffusion process from innovation to market dominance can take over a century on the global level.

Figure 7 shows the future structure of primary energy supply of the three stabilization scenarios in the years 2020 and 2100. By the end of the next century, all three scenarios are virtually non-fossil with approximately 90 percent energy supplied by zero carbon technologies, such as solar, biomass, other renewables and nuclear power. The three scenarios differ in the relative importance of different zero carbon technologies by the end of the next century, but all agree that the primary energy mix will be reversed from the current reliance on fossil energy to non-fossil energy. Therefore, all three are consistent with the historical dynamics of primary energy substitution shown in Figure 6. At the same time they also imply that stabilization at less than 500 ppm is only possible through continuous and vigorous diffusion of mitigation technologies throughout the energy system and end use.

A major conclusion from this assessment of the three stabilization scenarios, compared to the historical rates of energy efficiency improvements, decarbonization and diffusion of new technologies, is that the gradual improvement of current technologies and practices is unlikely to be sufficient to achieve global stabilization of atmospheric concentrations of greenhouse gases. While these gradual improvements are important and necessary, what is required in addition is rapid market penetration of mitigation technologies. Over the next ten to 20 years, efficiency improvements can indeed help offset some of the emission increases, but in the long run the reliance on fossil energy needs to be replaced by zero carbon options. Assuming that economic growth in the world continues at the rate of two to three percent per year in view of at least a doubling, if not tripling, of global population by the end of the next century, the historical rates of decarbonization and energy intensity improvement of jointly about 1.3 percent per year, are certainly not sufficient to stabilize emissions. Yet, emissions need to be reduced to less than half of the current levels to achieve atmospheric stabilization (see Figure 1). The assessment of the three stabilization scenarios indicated that decarbonization and energy intensity have to improve jointly at rates of up to four percent per year or more. This would be feasible only assuming dedicated long term research and development efforts required for the commercialization of new mitigation technologies and energy options during the next two to three decades and thereafter hopefully their diffusion under prevailing market conditions.

Table 1 lists some of the important economic and institutional factors required for the diffusion of new technologies. Many of them are related to the learning processes and experiences, human networks, market mechanisms and regulatory frameworks, performance of new technologies, investments and costs. Many of these factors cannot be determined ex ante so that forecasting technological diffusion processes is a notoriously difficult undertaking. In order to facilitate the comparison of mitigation technologies documented in the literature, a technology inventory, called CO2DB was developed at IIASA. The inventory includes estimates of technical performance, costs and investments, environmental characteristics and diffusion prospects of mitigation technologies. The assessment of the mitigation potentials achievable by the foreseeable development of new technologies, based on the data compiled in the CO2DB, confirms the results of many studies that indicate the possibility of concentration stabilization. For example, Figure 8 shows a number of energy chains from CO2DB for producing light. This starts from primary energy conversion to electricity in a power plant culminating in the delivery of an energy service, i.e., light from an end-use device, either an incandescent or florescent light bulb. Some of the fossil power plants are also assumed to be equipped with carbon removal (scrubbing) facilities. The figure shows that a high degree of mitigation is, in principle, possible (expressed as grams of carbon emitted per lumen) with, in comparison, relatively modest variations in cost. This raises one of the fundamental problems in the assessment of the local, regional and global mitigation potentials and technology diffusion rates. On the one hand, claims are made that large mitigation potentials exist at low or even negative mitigation costs (free lunch), and on the other hand, that mitigation is extremely costly and therefore associated with a loss of economic growth.

The CO2DB mitigation inventory now contains more than 1,000 technologies with a particular emphasis on developing countries so that it allows derivation of empirical cost curves for future technologies from the various estimates in the literature. For example, Figure 9 gives three histograms for the investment costs of biomass, nuclear and solar energy from the CO2DB. The histograms show the frequency of investment costs distribution for many observations, ranging from 31 for biomass to 45 for solar power. All three histograms have relatively long tails on the high investment side, indicating that the number of estimates are quite pessimistic concerning the possibility of reducing investment requirements in the future. At the same time, it is also interesting to observe that the highest consent is shown for biomass followed by nuclear energy, and the lowest for the investment requirement for solar power. This kind of assessment of future costs and performance of new technologies provides a fundamentally new approach to estimating mitigation potentials and diffusion rates of new technologies. Empirical distribution functions can be developed from the histograms and used in the mitigation and diffusion assessments. This kind of analysis can also help refine research and development, as well as the regulatory policies, to aid in accelerating market introduction, penetration and contribution of new technologies in the reduction of carbon emissions.

Figure 10 suggests that this might be feasible with adequate policies. The diffusion of primary energy sources at the global level were shown to last about one hundred years (see Figure 6). However, an energy system is complex and each energy chain from a particular primary energy source to a given energy service, consists of numerous technologies and interrelated systems. For a successful market penetration, a whole family of new technologies has to be developed. Figure 10 shows the histogram of diffusion rates based on two comprehensive technology assessments of 117 and 265 cases, respectively, ranging from infrastructures to end-use devices. The diffusion rates are measured as the time elapsed between successful market introduction and market dominance (Δt).[2] The frequency distribution of the histograms indicates

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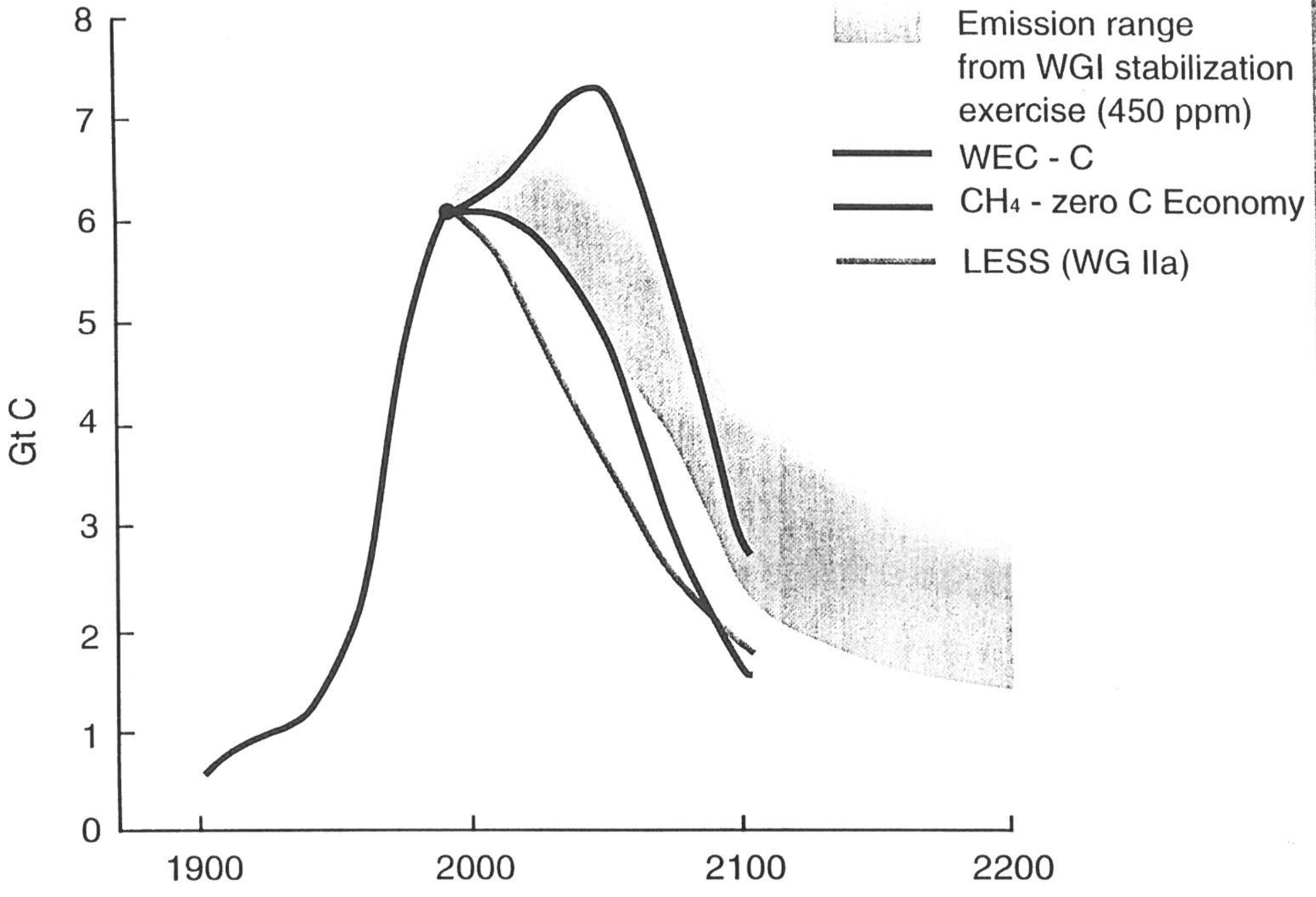
[2] Strictly speaking, Δt is measured as the time that elapses between the achievement of ten and 90 percent of saturation level. For example, saturation might represent the ultimate technology performance or market share. This measure is almost identical to the time required to go from one to 50 percent of the saturation level.

a number of diffusion processes with a duration in the range of 100 years as was observed for the substitution of primary energy sources in the world. Most of the diffusion processes, however, last about 15 to 60 years with the bulk centered around 30 years. Typical technologies which diffuse over a period of three decades include vehicles and many energy conversion processes. End-use devices often need three decades to diffuse but the processes can be substantially faster.

All this means that within the next 30 to 60 years, the current vintage of technologies can be expected to be replaced by completely new ones. Only infrastructures, such as roads and settlements, can be expected to take longer. In other words, by the middle of the next century, most of the energy system components will be new. And, by the end of the next century, virtually the whole energy system will consist of new technologies. Thus, it is of fundamental importance whether research and development policies are directed at enhancement of mitigation innovations, and market and regulatory ones at their rapid diffusion after commercialization. Since the duration of this whole process will probably last 50 years or more, long term policies are required. No doubt efficiency improvements, conservation and gradual technology modifications will help offset some of the emissions increase over the next ten to 20 years, but in the long run the development of new technologies and their successful introduction is necessary to implement FCCC.

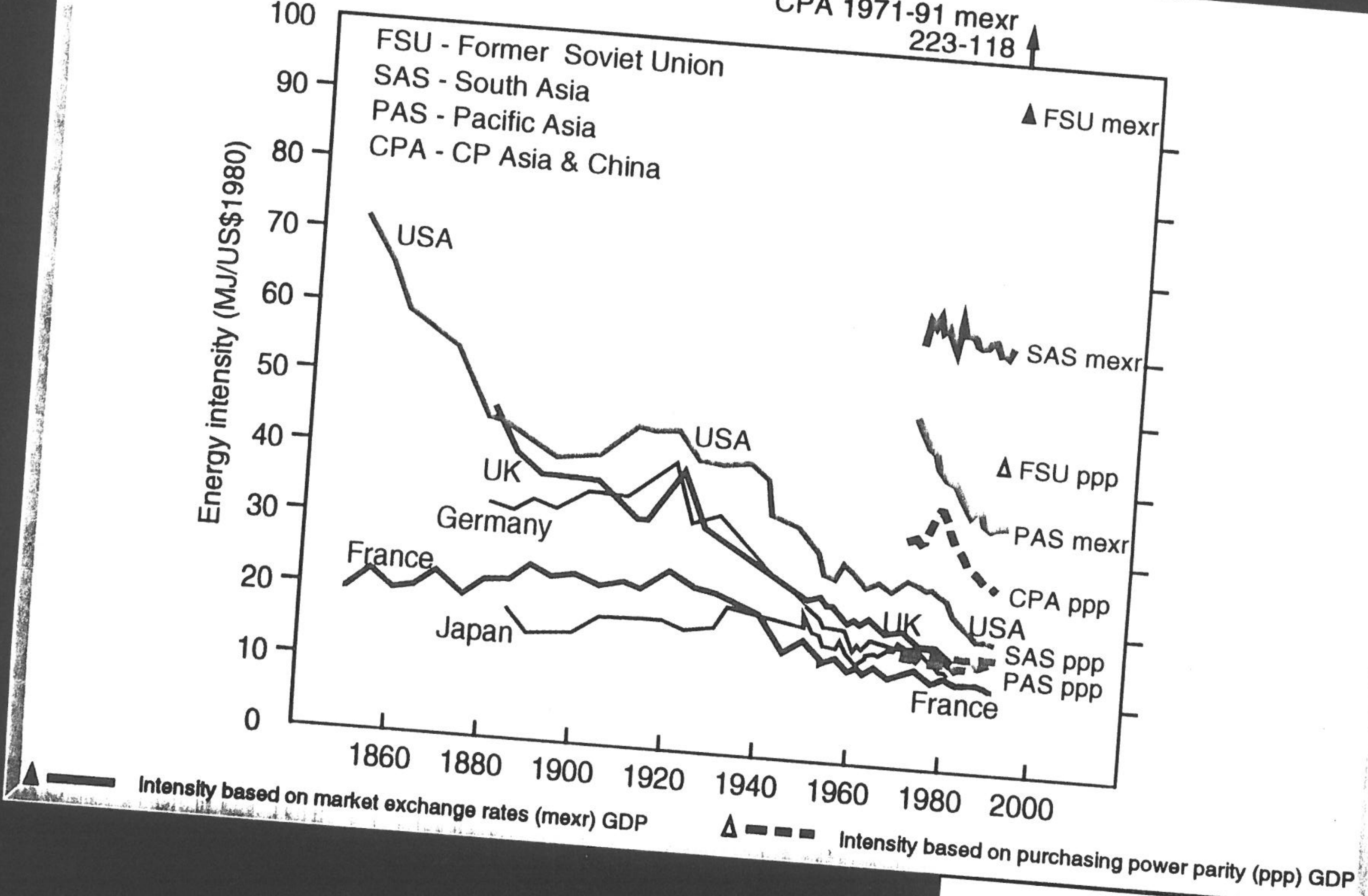
INDUSTRIAL CARBON EMISSION PROFILES

For stabilization below 500 ppm



N. Nakicenovic – Figure 1

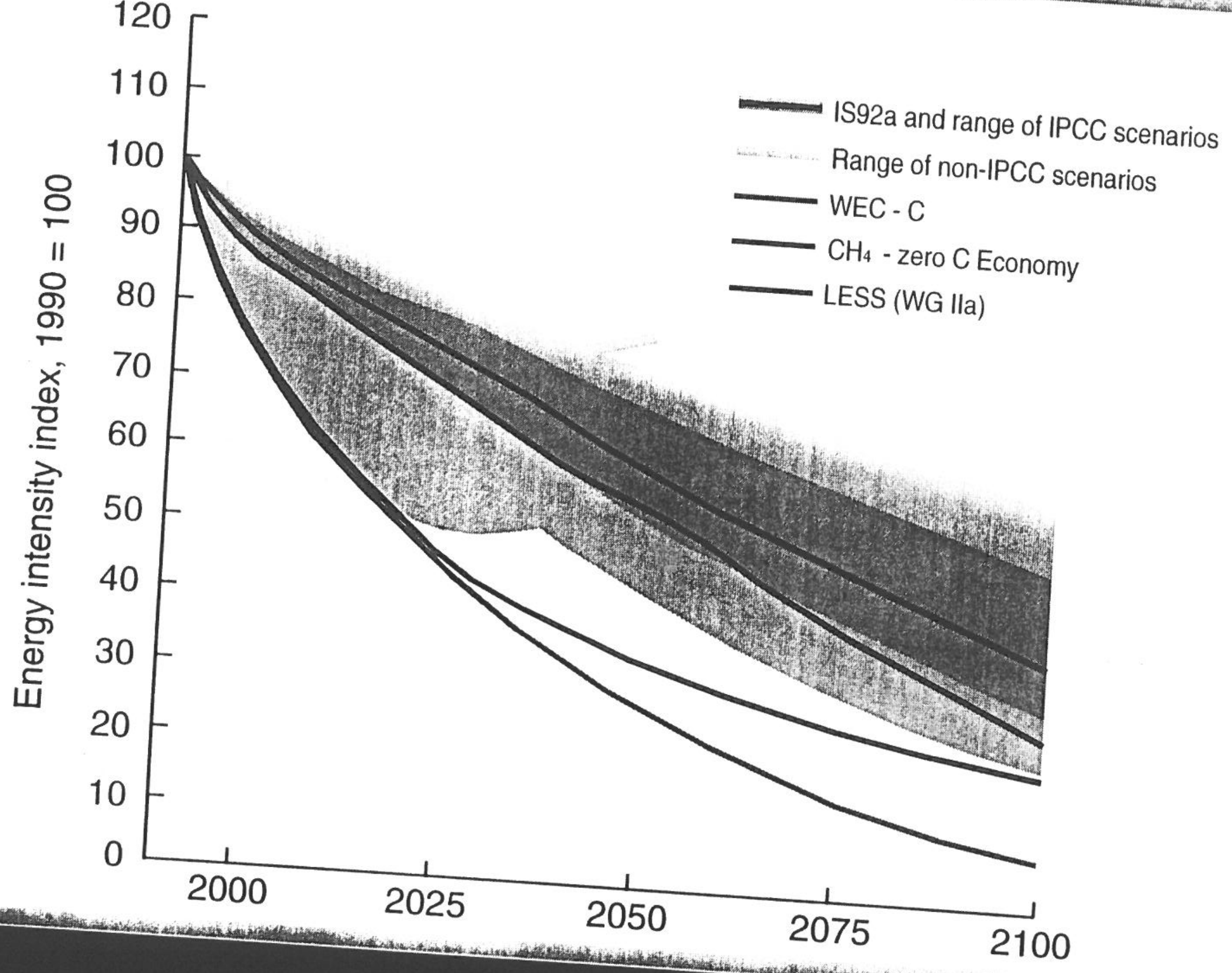
PRIMARY ENERGY (INCL. WOOD) PER GDP
(in constant US$1980)



N. Nakicenovic - Figure 2

ENERGY INTENSITY (PE/GDP)

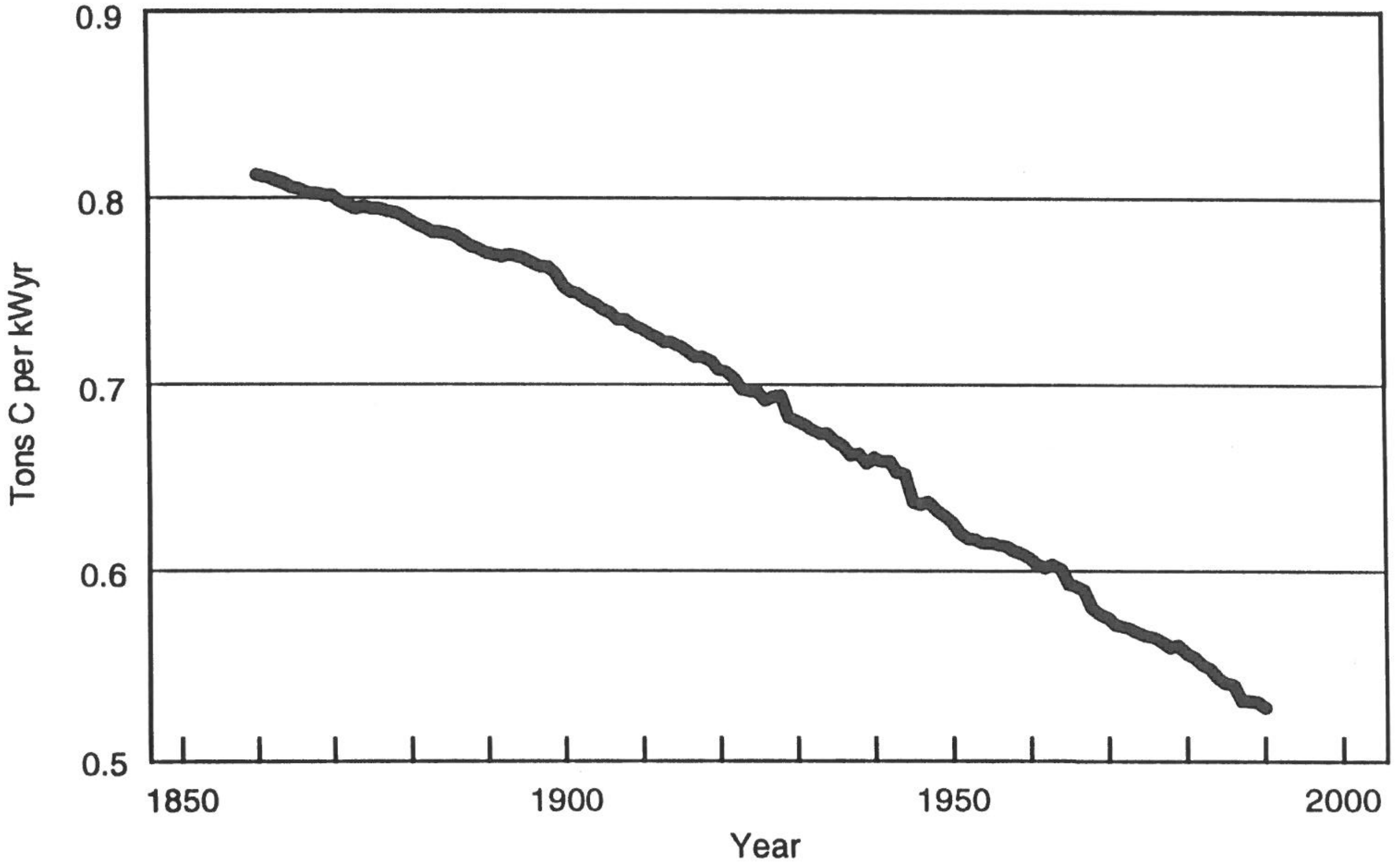
Range of reference ("no controls") scenarios and three stabilization, scenarios
(< 500 ppm)



N. Nakicenovic - Figure 3

CARBON INTENSITY OF PRIMARY ENERGY

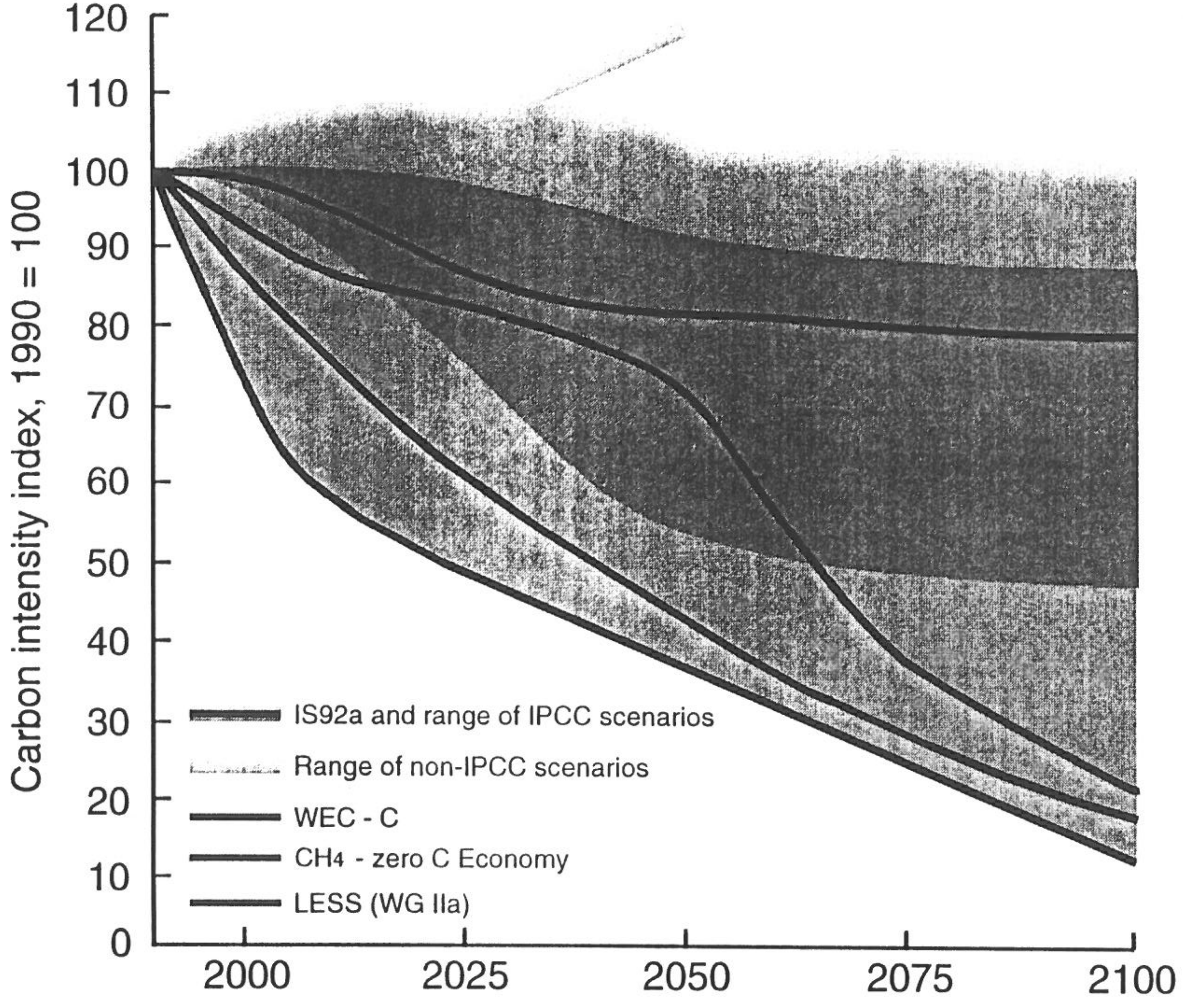
World



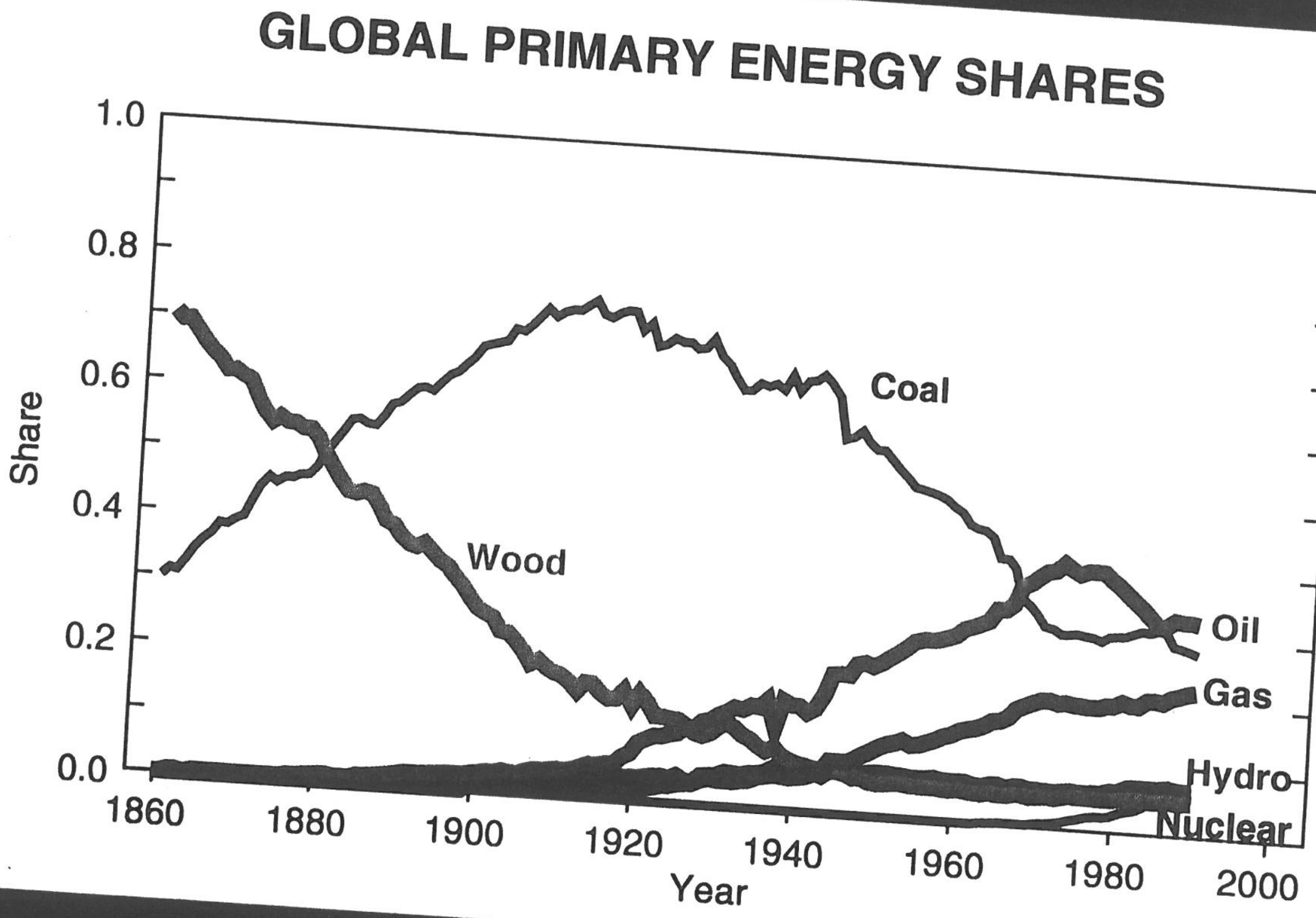
N. Nakicenovic - Figure 4

CARBON INTENSITY (C/PE)

Range of reference ("no controls") scenarios and three stabilization, scenarios
(< 500 ppm)



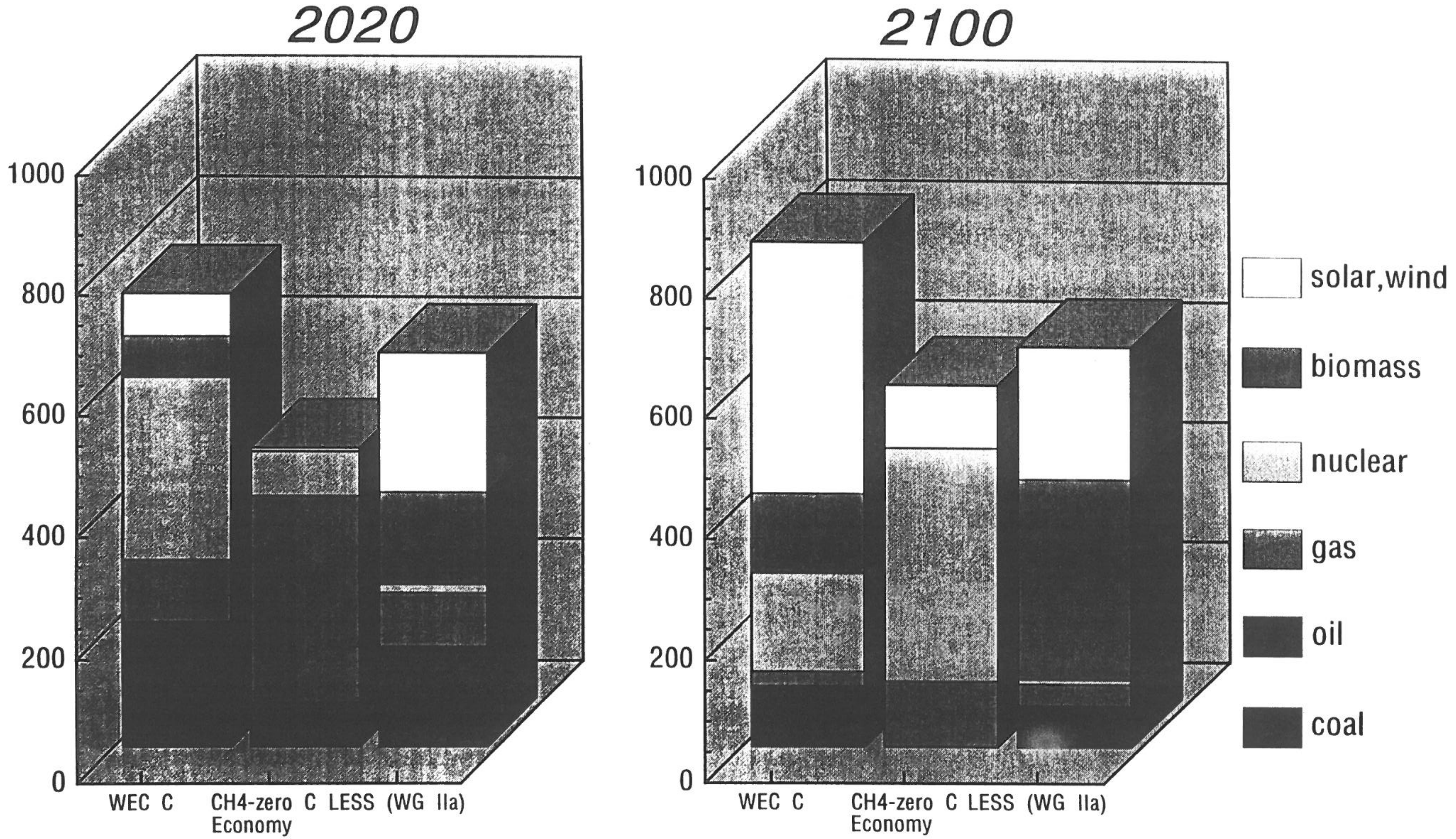
N. Nakicenovic - Figure 5


GLOBAL PRIMARY ENERGY SHARES

N. Nakicenovic - Figure 6

PRIMARY ENERGY SUPPLY (EJ)

THREE STABILIZATION (<500 ppm) SCENARIOS



2020

2100

N. Nakicenovic - Figure 7

ECONOMIC & INSTITUTIONAL FACTORS IN THE DIFFUSION OF NEW TECHNOLOGIES

Determinants of Diffusion (Rate & Level)	Interpretation in Economic Theory	Institutional & Policy Dimensions
Relative advantage	Profitability (ex ante) Size of investment	Macro-economic & price signals, taxes, subsidies
Compatibility	Network, externalities infrastructure requirements	Niche markets, public infrastructures
Market size	Demand pull	Purchase programs, export promotion
Technology dynamics	Learning by doing & using, experience curves, technology push	R&D, local adaptation, capacity building
Appropriability	Sources of innovation, transaction (information) costs, "technology transfer"	Information campaigns "diffusion agents", innovation & demonstration centers

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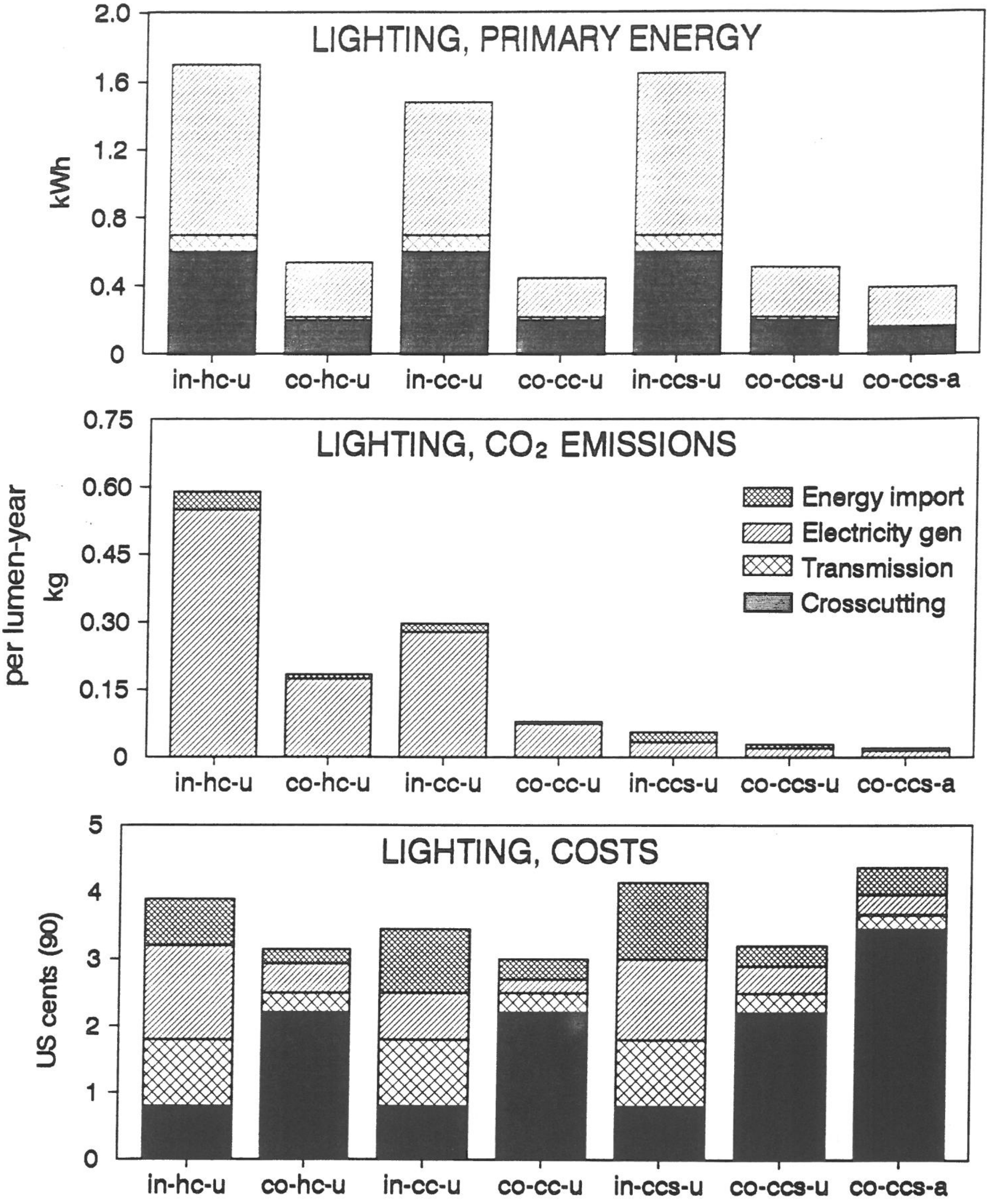
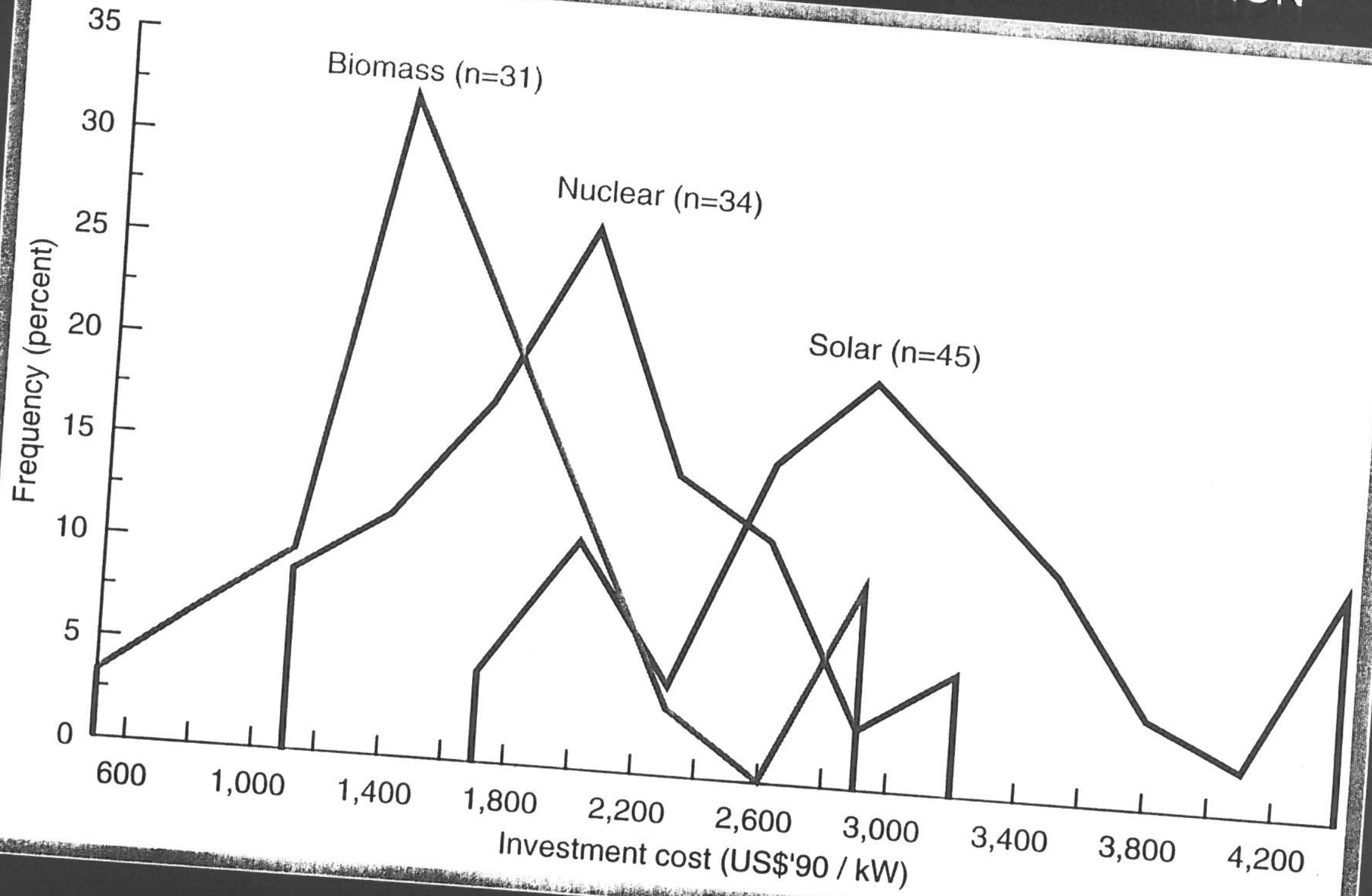
N. Nakicenovic - Table 1



	End-use:		Energy supply:		Region:
in	Incandescent light bulb	hc	Hard Coal power plant	u	USA
co	Compact fluorescent bulb	cc	Combined Cycle natural gas	a	Austria
		ccs	Combined Cycle natural gas with carbon Scrubbing		

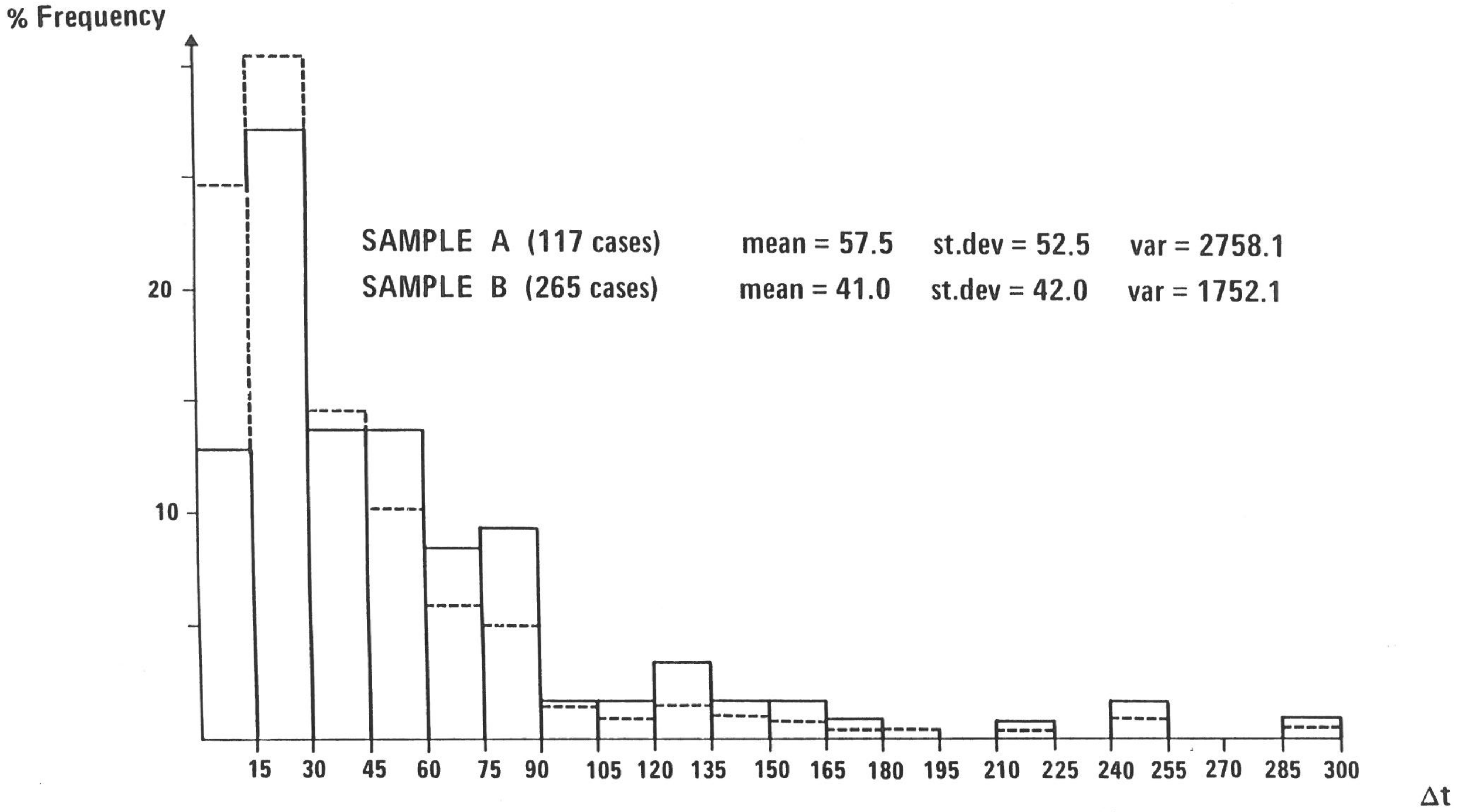
N. Nakicenovic - Figure 8

RANGE OF INVESTMENT COST DISTRIBUTION FROM IIASA [illegible] BIOMASS, NUCLEAR, SOLAR ELECTRICITY GENERATION



N. Nakicenovic - Figure 9

HISTOGRAM OF DIFFUSION RATES
$(\Delta t = t_{0.9F} - t_{0.1F})$



N. Nakicenovic - Figure 10