Structural Changes in Energy System
Key-Factors in Reducing Environmental Burden

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1. SYNOPSIS

Structural changes like introduction of district heating and cogeneration are efficient in reducing environmental burden. Also nuclear energy and hydropower should be taken into account.

2. ABSTRACT

The main environmental problems of energy systems are caused by emissions to the atmosphere. Emissions of SO2 and NOx contribute to acidic precipitation that is harmful for forests and lakes. Emissions of CO2 contribute to the threat of global climate change. There are, of course, other environmental impacts of energy systems, like ambient air quality, land use and treatment of solid wastes, but they are more or less local. They do not pose a threat to sustainable development.

There are three guidelines for sustainable energy policy. Firstly: energy efficiency, secondly environmental technology and thirdly structural changes in energy economy. Energy saving is not motivated by depletion of energy sources. There are huge reserves of cheap fossil fuels for many generations. The reason that energy saving is important is the fact that environmental risks associated to burning of fossile fuels are too great. By using efficient flue gas treatment it is possible to reduce acidic emissions of fossil fuels. By advanced technology like IGCC plants it is possible to reduce the specific CO2 emissions.

The potentials of structural changes in energy system have not been fully utilised in many countries. These potentials include introduction of district heating networks to major cities, enhanced utilisation of cogeneration in connection with district heating and in industrial back-pressure power. It is also important to recognise the value of nuclear energy and hydropower in reducing environmental burden. The problems related to these alternatives are of political nature rather than being real threats to sustainable environment.

3. INTRODUCTION

Sustainable development is a challenge for the whole mankind. There are several global problems that may create threats to human life on the earth: uncontrolled population growth, environmental destruction, depletion of natural resources and military confrontations. In the United Nations Conference of Environment and Development (UNCED) in 1992 these problems were discussed and a global action plan for sustainable development called Agenda 21 was adopted. Sustainable development means that this generation should be able to satisfy its needs so that the possibilities are conserved for the future generations to fulfil their needs. In particular three important conclusions can be made concerning industrial activity: (1) environmental burden of production processes should be kept as low as to ensure natural reproduction and biodiversity, (2) in the long run production processes should be based on renewable or practically inexhaustible natural resources and recirculation, (3) sustainable development is a global challenge and cannot be achieved without cooperation with the developing countries.

4. SUSTAINABLE DEVELOPMENT AND ENERGY

Energy production and use is responsible for many environmental burdens threatening sustainable development. Global energy resources are very large and they do not pose limits to energy use. The commercial resources allow increasing use of energy for many decades, even centuries according to the statistics in the World Energy Council 1992. In the 1970's the limited oil resources were among the most important arguments for energy saving. Today it is obvious that oil could be substituted by other energy sources. Even in the traffic sector oil could be substituted by synthetic fuels. There may emerge disturbances in international energy market and energy saving is a good strategy in reducing the consequent economic risks. However, energy saving has become even more important because of environmental problems. More precisely: fossil fuels must be saved because of their detrimental environmental effects.

4.1. Cathegories of environmental impact of energy system

Environmental impact of energy production and use can be put in three cathegories according to the scale of the impact and the nature of the problem: (1) wide-spread international environmental problems, (2) local or regional environmental problems, (3) problems of social acceptance. The cathegories are shown in Figure 1.

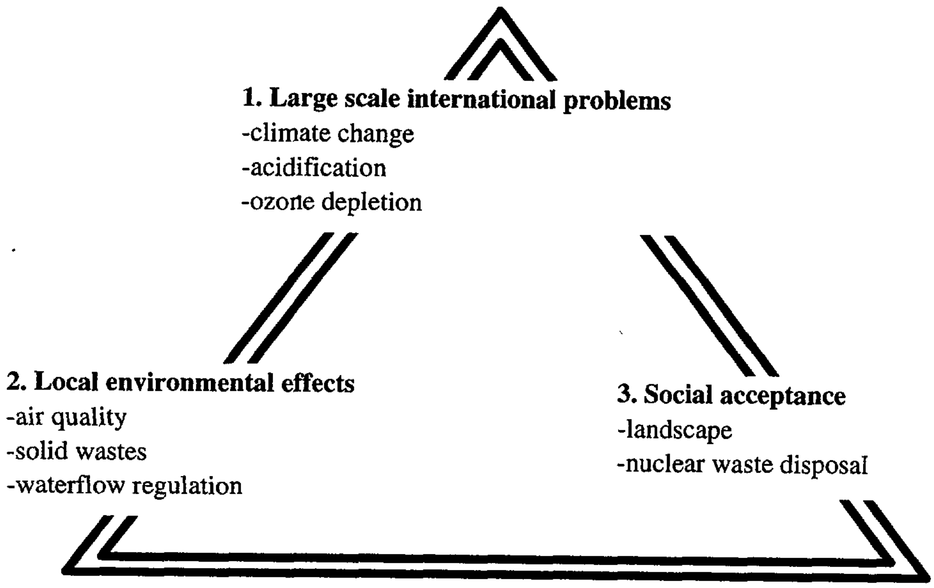

Figure 1. *Cathegories of Environmental Impact of Energy System*

Local or regional environmental problems arising from the production and use of energy are well known. Burning of fuels has a negative impact on ambient air quality. Power plants and oil refineries occupy considerable land areas and further restrictions of land use are due to terminals, fuel storages and distribution network. Extraction of fuels yields waste heaps and consequent effects on surface water quality in nearby waterways. Construction of hydropower involves dams and regulation of water flow. These have effects on fish population and biological systems especially near the continuously changing shoreline.

Local or regional environmental problems can be solved by adequate environmental technology and corresponding investments. Air quality can be improved by flue gas treatment and traffic planning. Waste waters can be purified. Fish population can be compensated by implantation. River banks can be reinforced and shorelines protected. Solid wastes can be collected, contained, recycled or disposed of properly. All this needs careful environmental management. Local or regional environmental problems can't be totally eliminated, but it is important to notice that they do not pose a threat to sustainable development.

Problems of social acceptance are difficult because they can't generally be solved by environmental technology, no matter how strict the applied standards are. The problem is formally very simple: to build something or not. These problems are traditionally solved by political desicion making. In spite of the formal and technical simplicity, the problems may be politically very difficult and sensitive (e.g. building a final repository for nuclear waste). One important procedure to help the decision making is environmental impact assessment including public hearings.

4.2. INTERNATIONAL ENVIRONMENTAL PROBLEMS OF ENERGY SYSTEM

Energy production and use contribute directly to two serious environmental problems of international dimensions: (1) risk of global climate change, (2) acidification of soil and lakes. There is a third global problem which is, however, indirectly connected to energy use namely depletion of stratospheric ozone layer. The connection to energy use is obvious: chloro-flouro-carbons that destroy ozone layer are used in insulation materials, refrigerators, air-conditioning equipment and heat-pumps.

International environmental problems differ from the local and regional problems in that they may be real threats to sustainable development. Global climate change may transfer agricultural land to deserts and acidic precipitation may lead to permanent forest destruction, loss of fresh drinking water and fish. Depletion of ozone layer exposes people to more intensive ultra-violet radiation form the sun thus promoting eye-illnesses and skin cancer. Ultra-violet radiation is also harmful for many plants and may decrease crops.

4.2.1. Risk of climate change

The increase of greenhouse phenomenon and the risk of global climate change may be a real threat according to the climate models used by Intergovernmental Panel on Climate Change (IPCC). How serious the consequences are and what are the regional effects in different parts of the world, can't be assessed quite well by present knowledge. The worst predictions indicate rising sea level, increasing rainfalls in the northern arctic regions and drought in the southern and middle continental areas. If the wide agricultural production areas are dried, starvation may lead to mass destruction of people.

Carbon dioxide emissions of energy production and use is the most important single contributor to the increase of carbon dioxide concentration in the atmosphere. The other important factor is the destruction of forests and desertification. It is a paradox that while the use of biomass in energy production in the industrialised countries is one way of reducing net carbon dioxide emissions, it is often increasing erosion and desertification in developing countries. By international cooperation destruction of rain forests should be reduced and desertification stopped in the developing countries. This means construction of the necessary physical infrastructure: among other things power plants and energy distribution networks. In many developing countries there are considerable potentials of hydropower.

4.2.2. Acidification

Acidification is caused by atmospheric emissions of sulphur dioxide and nitrogen oxides. Sulphur dioxide is emitted from combustion of coal and oil. Nitrogen oxides are formed in all combustion processes, especially in engines of motor vehicles. The gases react with rainwater forming acidic compounds. Acidic precipitation has contributed to forest damages in Central Europe, in Eastern Europe and in the Kola Peninsula. Acid rain may be transported in the air hundreds of kilometres thus causing transboundary effects. Indeed, very many lakes in Scandinavia have lost all fish because of the acidic precipitation originally from Central European emission sources. Also emissions from Eastern Europe are transported across borders. This is why international cooperation is needed to start the necessary investments in the Eastern and Central European countries on environmental technology and flue gas treatment systems.

One special problem is related to nitrogen precipitation: saturation of soil by nitrogen. This may lead to increased concentrations of nitrates in the groundwater. After nitrate contamination, the groundwater poses a public health risk if used as drinking water.

5. GUIDELINES FOR SUSTAINABLE ENERGY POLICY

Reducing the environmental burden of energy production and use can most efficiently be realised by studying three different guidelines shown in Figure 2. Firstly: energy efficiency (including policy and technology); secondly: environmental policy and technology and thirdly: structural changes in energy system. It must be emphasised that all three approaches can and should be employed simultaneously in formulating energy policy for a sustainable environment. The approaches illustrated in Figure 2 are discribed in more detail in chapters 5.1.--5.3.

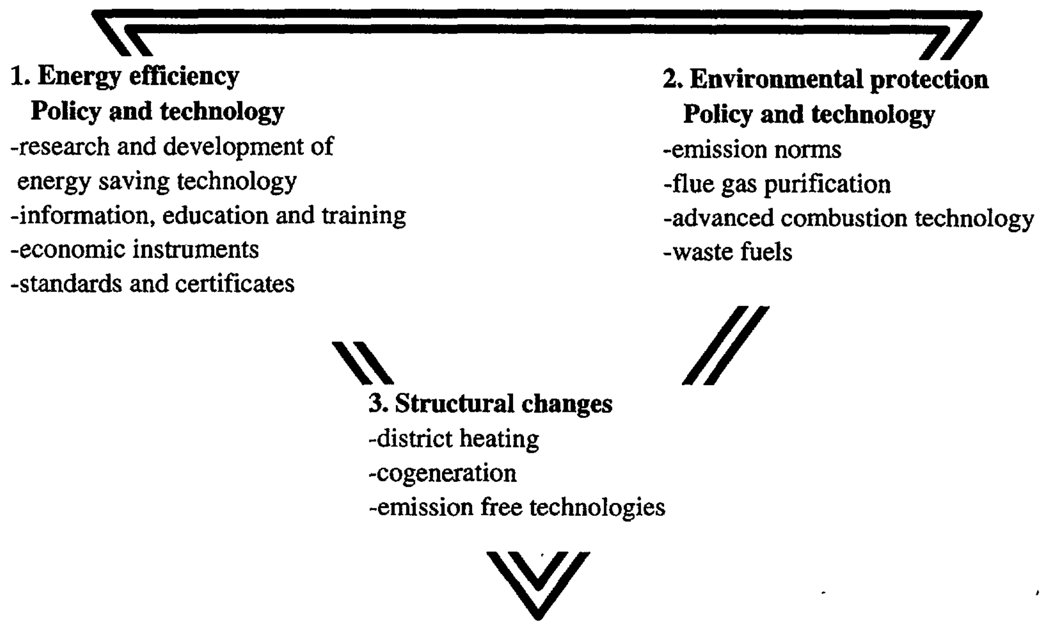

Figure 2. *Guidelines for Sustainable Energy Policy*

5.1. Energy efficiency

Energy efficiency and energy saving programmes constitute a major part of energy policy in many European countries today. Besides the positive effects of reducing environmental burden, energy saving increases performance and competitiveness of national economies and for many countries saves foreign currencies spent in energy import.

There are four approaches generally found efficient in energy saving: (1) research and development, (2) information, education and training, (3) economic instruments, (4) standards and certificates. By research and development new more efficient energy saving technologies can be brought to the market. Specific energy consumption will be reduced, when these technologies replace the old ones. New products also create new market and new jobs. This way research and development benefits the whole society. Information, education and training is needed in order to spread the results of research and development in enterprises, industries and households. In this phase energy audits and technical consultation are needed. Economic instruments may include special energy saving funds for risk capital in order to commercialise new technology. Energy and environmental taxes should be used with caution, because of their adverse effects on industrial production and household expenses. In any case taxes should be internationally harmonised. Standards and certificates should be used to enhance competition, not to block it. Consumption norms for household appliances should therefore be prepared also in international cooperation.

Energy saving programme in Finland (Ministry of Trade and Industry 1994a) includes a voluntary agreement with the Finnish industry. In the agreement objectives are set for reducing specific energy consumption both in process industry and in small and medium size industry. Process industry is committed to reducing specific consumption of heat by 12 % from 1990 level by the year 2005. Corresponding reduction in specific electricity consumption is set to 8 %. Similar agreement has also been designed for Finnish communities aiming at lower energy consumption in public buildings, schools, hospitals and swimming halls.
Because energy is a significant cost factor in Finnish industry, processes are generally quite well optimised. Also houses are well insulated in Finland, because of the severe climate conditions. Three-fold window glazing is required for new houses. The specific annual energy consumption in Finnish new small houses is around 48 kWh/m3 including heating, warm water and electricity. The largest potentials for saving energy have already been utilised in Finland. In the energy saving programme in Finland (Ministry of Trade and Industry 1994a) the goal is to reduce specific heat consumption of houses and buildings in the service sector by 10 % from 1990 level by the year 2005.

5.2. Environmental technology

All major environmental problems related to the energy system are caused by fuel combustion. Harmful emissions can be reduced by flue gas treatment systems but also to a certain extent by advanced combustion technology.

In large boilers and power plants flue gas treatment systems are economically and technically possible solutions for particulate, sulphur dioxide and even nitrogen oxides emission reduction. The smaller the boiler, the more expensive flue gas treatment becomes. For adequate nitrogen oxides emissions in small and medium size boilers, also low NOx - technologies are available. The largest potentials in reducing nitrogen oxides emissions are, however, in the traffic sector. Catalytic converters and lead free petrol are already used widespread in Europe. Also diesel technology has been improved to reducing nitrogen oxides emissions of heavy vehicles.

International agreements have been signed within Economic Commission for Europe (ECE) in order to reduce both sulphur dioxide and nitrogen oxides emissions. The next step in Western Europe is to reduce the emissions so that acidic precipitation could be lower than critical loads in every country. It is evident that this goal could be achieved, if emission reduction measures required in Western Europe would be adopted in the whole continent.

The obsolete industries, inefficient physical infrastructure and old power plants with high emissions in Central and Eastern European countries will make it difficult to meet the goal in the future, because of transboundary effects. Very often investments in emission abatement in Central and Eastern European countries is many times more cost-effective than further investments in the West. The obvious reason is that the starting point for these investments is quite different: it is much cheaper to install the first sulphur reduction system in a power plant than to improve an existing one. In order to get desired results in European environmental protection, like reducing acidic precipitation below the critical loads, it is important to get the necessary environmental investments started in Central and Eastern European countries. These investments need financial arrangements like soft loans from Western European countries. Energy investments and environmental protection
should have a high priority in projects supported by European Bank for Reconstruction and Development (EBRD).

For carbon dioxide purification there are no practical solutions. The gas volumes to be treated are so large that carbon dioxide separation may be possible only in special conditions: e.g. power plants on natural gas fields. Instead there are some combustion technologies by which efficiencies may be increased: pressurised gasification of coal and other solid fuels, pressurised combustion and integrated gas turbine combined cycle power plants. Efficiencies in power production may be over 50 %. Specific emissions of power production are lower than by conventional technologies. In small and medium size boilers fluidised bed combustion gives some advantages: low grade solid fuels can be used with high efficiency and low emissions. In spite of these technologies the most difficult problem of fossil fuel combustion remains essentially the same: high emissions of carbon dioxide.

5.3. Structural changes in energy system

When formulating energy policy for a sustainable environment, key-factors are the structural changes in energy system. End users of energy have many alternatives to choose from to meet their energy needs. Depending on the specific application, energy needs may be satisfied by direct use of fuel, electricity, district heating or process steam, sometimes even by solar energy or windpower. Which alternatives are available for consumers, is very much a political matter.

District heating of urban areas save energy, lead to smaller emissions and much better ambient air quality compared to separate central heating of buildings. District heating enables the use of large boilers and thereby high fuel efficiency. In large boilers the formation of noxious substances like carbon monoxide, dust and hydrocarbons is negligible compared to central heating owens. Large boilers are equipped with flue gas treatment and high stacks. These factors have improved ambient air quality in all cities that have shifted to district heating. Sulphur dioxide concentration in urban air is a good indicator of air pollution caused by space heating. The positive effect of district heating on air quality is visible in Figure 3, where annual mean sulphur dioxide concentrations in urban air is shown in two Finnish cities: Turku and Helsinki. In Turku, large scale district heating started in 1982 (Imatran Voima Oy 1993). In Helsinki the district heating network has existed from the 1960s. Today annual mean concentration in both cities is well below the World Health Organisation recommendation of 40 micrograms per cubic metre.

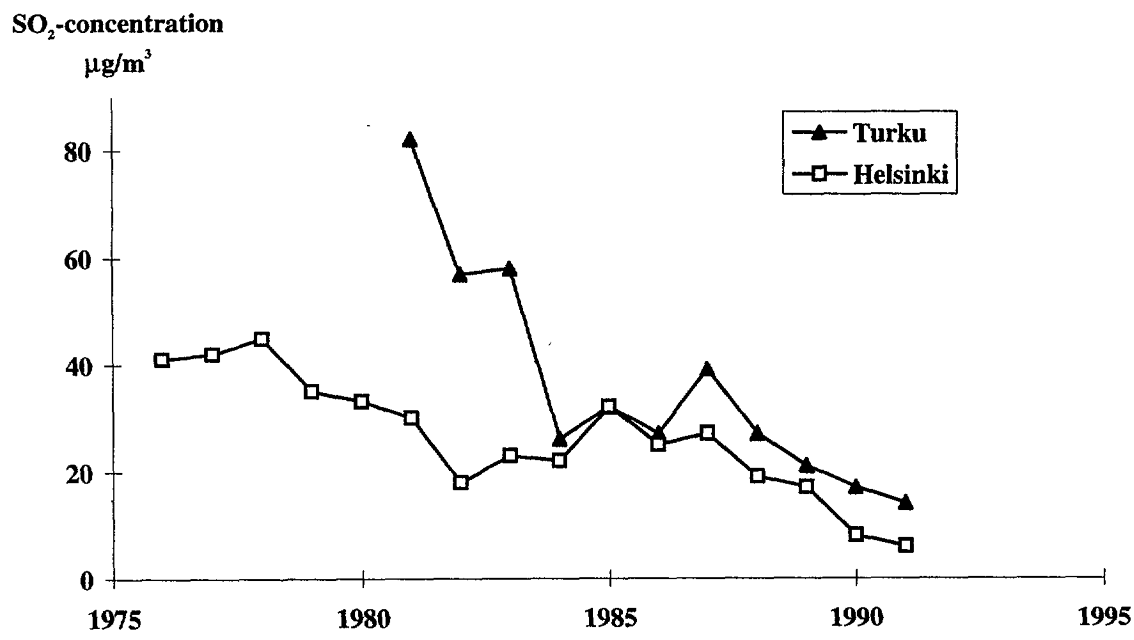

Figure 3. *Annual Mean Concentrations of Sulphur Dioxide in Urban Air in the Cities of Turku and Helsinki (Imatran Voima Oy 1993)*

District heating is an example of a structural change in energy supply system that yields both economic and environmental benefits. When heat loads are large enough centralised energy production gives another benefit, namely cogeneration of heat and power. Overall efficiencies of cogeneration plants are in the range of 80...85 % which is very high compared to separate condensing power production. The same advantage can be utilised in industrial processes by using back-pressure power in connection with steam production.

Because the overall efficiency in cogeneration is high, the specific emissions i.e. emissions per useful energy are correspondingly low. Large boilers have flue gas treatment systems for reduction of particulates, sulphur dioxide and nitrogen oxides emissions. In connection with paper and pulp industries waste wood and black liquor are used in energy production. This kind of industrial back pressure power is based on renewable wood and thus there are no net carbon dioxide emissions. Of course the advantage of using waste wood and black liquor is limited to the sites of forest industry. On the other hand, one can imagine that renewable energy may be used also in the back end of paper's life-cycle. Waste paper could be collected in Central European cities and utilised in district heating and cogeneration plants. Life cycle analyses show that this is a competitive alternative to recirculation and certainly better than dumping (Ministry of Trade and Industry 1993). Waste paper used in district heating in fluidised bed boilers saves fossil fuels and does not yield net carbon dioxide emissions.

The availability of different energy sources for power production varies in European countries considerably. In many countries there are no potentials for hydropower, in some countries people are afraid of nuclear energy and local authorities may be suspicious against district heating. Wide-spread international environmental problems are connected to using of fossil fuels. External costs caused by climate change are not yet well known, but the potential risks associated to the phenomenon are great (European Commission 1994). In this respect structural changes in energy systems should aim at reducing flue gas emissions of fossil fuels; especially net emissions of carbon dioxide into the atmosphere should be avoided.

In all power production systems base load power and short term regulation power are needed. An ideal power production structure would consist of capacity that does not yield large volumes of harmful flue gas emissions, especially carbon dioxide emissions. In practice this means that base load power should be produced by nuclear energy or hydropower if possible (instead of coal power), regulation power should be produced by hydropower (instead of gas turbines) and seasonal changes compensated by cogeneration plants. In cold periods both the consumption of electricity and heat increase simultaneously. Specific emissions of cogeneration plants are relatively low, as mentioned before. New combustion technologies, like pressurised combustion and gasification will reduce the emissions further. Also the use of biomass (where available), waste fuels and waste paper is possible by modern technologies. Waste fuels and waste paper are usually available in urban regions, where also district heating is needed. In practice waste paper can be regarded as a renewable energy source that does not yield net carbon dioxide emissions. Other renewables like wind power and solar energy may be locally important, but in European energy structure they can have only a marginal role in the foreseeable future.

There are many reasons that make it difficult to construct the "ideal" power production structure in Europe. Anyway, we must recognise that the challenge of a sustainable environment and reduction of detrimental flue gas emissions demand the utilisation of all possibilities, including nuclear power and hydropower (where potential is available). Externalities of fuel cycles have been estimated by European Commission in "Externe" project (European Commission 1994). When assessing external costs of coal fuel cycle the project concluded that damages due to global warming are probably the largest. Some cathegories of environmental impact of coal fuel cycle cannot be valued and others require assumptions which can produce widely differing results. Reported costs with discount rate of 3 % for impact that will affect future generations varied from 2,2 mECU/kWh up to 770 mECU/kWh. These values should be compared to the corresponding externalities reported for nuclear fuel cycle with the same discount rate: 0,0952 mECU/kWh (European Commission 1994). External costs of hydropower are very much site specific. Estimates given in the European Commission "Externe" project report (European Commission 1994) show that they are very small compared to coal fuel cycle: 0,0135 mECU/kWh or less depending on impact cathegory.

Nuclear energy and hydropower do have environmental effects but the impact is more or less local. These local problems can be solved by careful environmental management and appropriate technology. There are no scientific or technical obstacles against safe disposal of all nuclear wastes. The costs of nuclear waste management have been estimated in direct disposal option at 0,56 mECU/kWh and 1,1 mECU/kWh (OECD/NEA 1994). These values should be compared to the front-end costs of nuclear fuel cycle, which are around 3,48 mECU/kWh. Consequently nuclear waste management costs are 16--32 % from the fuel costs of nuclear power. Also the decommissioning costs have been estimated to be around 10 % of the construction costs of a nuclear power plant.

From the point of view of total costs of fuel cycles the nuclear fuel cycle is very competitive. This conclusion is valid both for internalised costs and for estimated external costs of the nuclear fuel cycle. The external costs of hydropower are even smaller than those of nuclear. The problems related to the extended use of hydropower and nuclear energy in Europe are essentially political.

6. STRUCTURAL FEATURES OF THE FINNISH ENERGY SYSTEM

In Finland 70 % of primary energy is based on import (Statistics Finland 1994). Because of this dependence on import, Finnish energy policy has been targeted to using many different energy sources. The most important source of primary energy is oil. The share of oil has, however, been reduced significantly after the beginning of 1970s. In 1973 over 55 % of primary energy consumption was based on oil and today its share is only 29 %.

After the oil crisis the growth rate of primary energy consumption has been reduced to 0,5...2,5 % per year due to economical situations and energy conservation measures. Oil dependence has been reduced by introducing new energy sources i.e. nuclear energy and natural gas and increasing the use of domestic biomass especially peat.

Over 55 % of electricity in Finland is produced without atmospheric emissions by nuclear energy and hydropower (Statistics Finland 1994). Biomass is important especially in cogeneration of heat and power in forest industry, where energy wood is obtained as a by-product. The share of biomass is 16 % in electricity production, 10 % is based on waste wood the rest being peat. The share of oil in power production is only 3 %.

Biomass is favoured in Finnish energy policy, because it is indigenous and wood is renewable. In April 1994 Finnish government adopted a ten year programme for enhancing the use of biomass (wood and peat) by 25 % from the present level by the year 2005 (Ministry of Trade and Industry 1994b). This means an increase of 1,5 Mtoe/a. The programme includes government subsidies of ECU 85 million (FIM 500 million) per year mainly on peat and fuel wood production and boiler plant investment aid.

In forest industry practically all waste and black liquor from pulp industry is utilised in energy production. Because of widespread district heating and industrial back pressure power in Finland, the share of cogeneration of heat and power (CHP) is the highest in the world, over 30 % of the electricity production. Since the overall efficiencies of CHP are high, the efficiency of fuel use in Finnish power system is also very high as can be seen from Figure 4 (Economic Commission for Europe 1992).

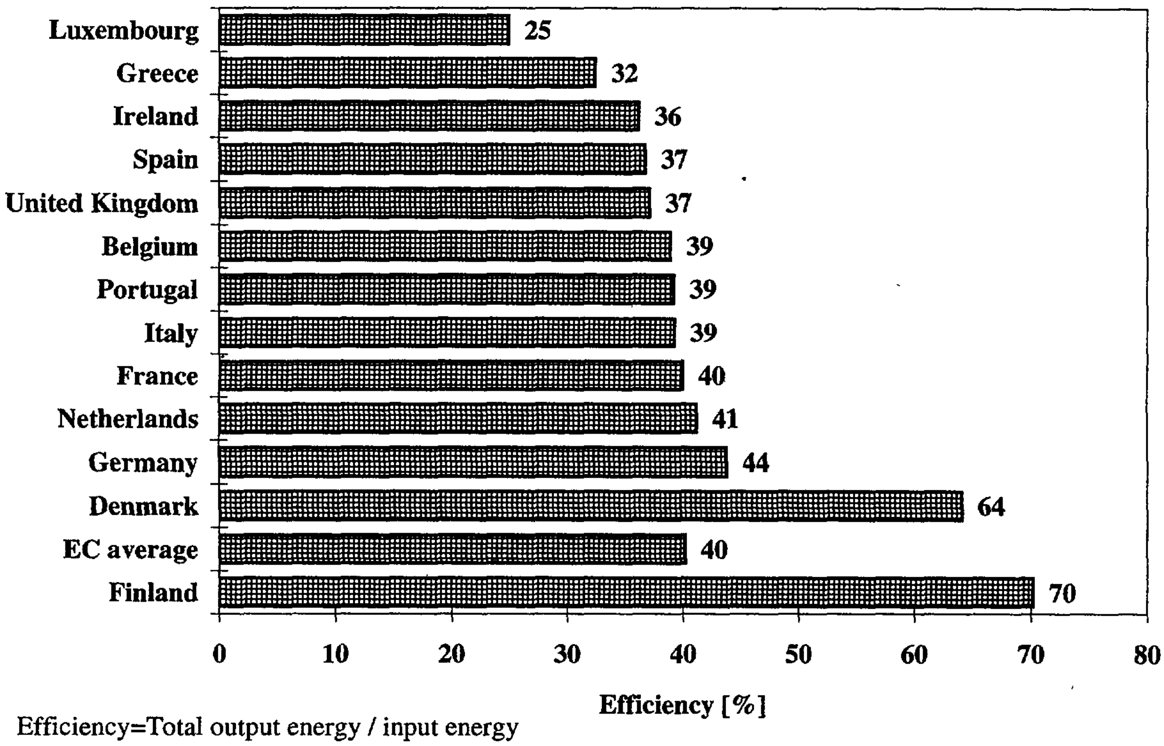

Figure 4. *Total Efficiency of Fuel Use in Power Plants in 1990 (Economic Commission for Europe 1992)*

The favourable structure of power production combined with flue gas cleaning systems have contributed to small specific environmental emissions, such as carbon dioxide, nitrogen oxides and sulphur dioxide. Specific emissions of electricity production in Finland is among the lowest within European Union as is shown in Figure 5. The emissions data are obtained from Commission of the European Communities 1992.

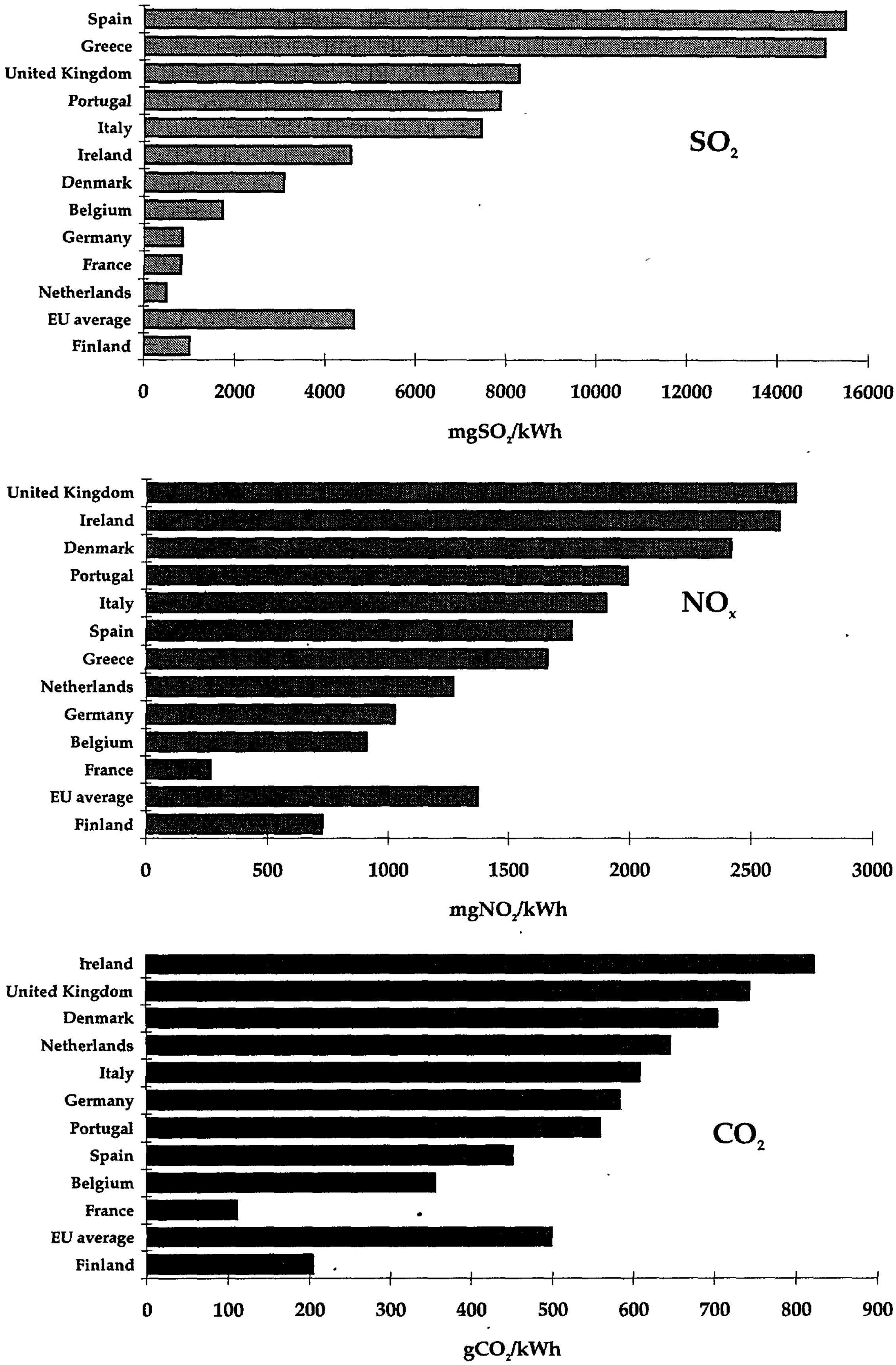

Figure 5. *Average Specific Emissions in Power Production in 1990 (including hydropower and nuclear energy; Commission of the European Communities 1992)*

The role of structural changes is clearly seen, when total emissions of sulphur dioxide and carbon dioxide emissions of Finland are studied. Between the year 1977...81 four nuclear units were taken into operation. They substituted coal power in base load power production and the emissions dropped respectively. Annual sulphur dioxide emissions decreased by 100 000 tonnes (27 % of total emissions in 1984) and carbon dioxide emissions by 13 million tonnes (30 % of total emissions in 1984).

In 1993, Finnish parliament rejected the positive decision of the government to build more nuclear power. As a result, more fossil-fired power, likely coal power, must be build for base load production. This means somewhat higher production costs and more importantly, environmental implications of the negative decision are clearly unfavourable. In spite of best available environmental technology, specific emissions of sulphur dioxide and nitrogen oxides in power production are bound to increase. Of course the worst development is expected in the emissions of carbon dioxide as can be seen in Figure 6 (Ministry of Environment 1994). Finnish forests are absorbing increasing amounts of carbon, because the growth rate of biomass overwhelmingly exceeds the use of wood. This is the reason, why net emissions of carbon dioxide may be stabilised in accordance with the Rio de Janeiro Climate Convention signed in 1992.

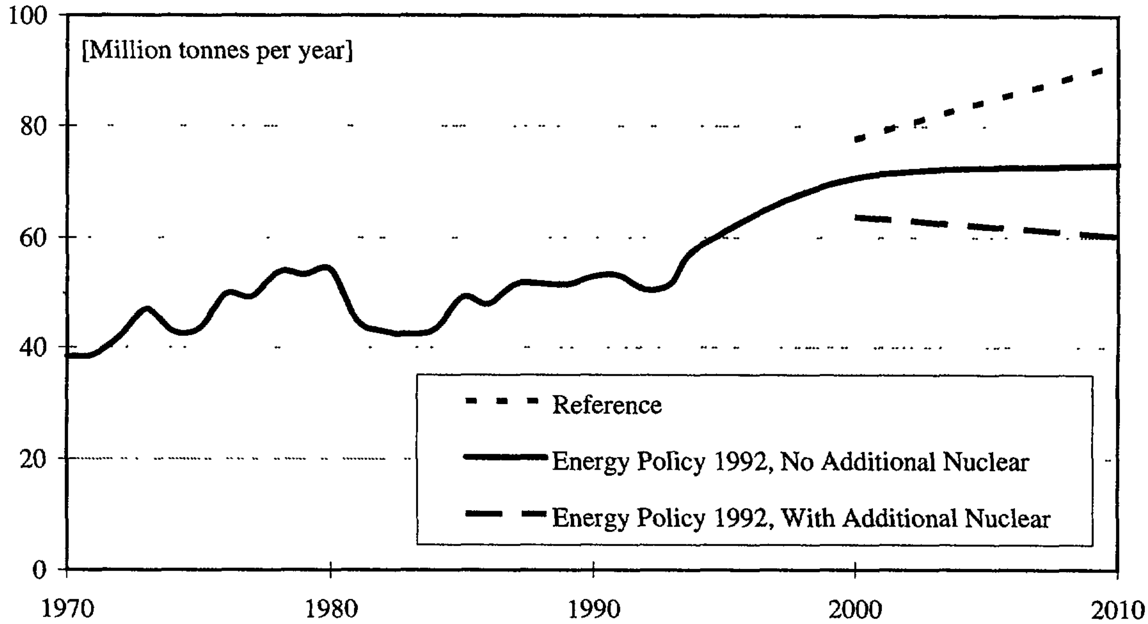

Figure 6. *Carbon Dioxide Emissions in Finland (Ministry of Environment 1994)*

Energy Policy scenarios in Figure 6 include the energy saving programme (Ministry of Trade and Industry 1994a) discussed earlier in chapter 5.1. The Reference scenario shows the situation without energy saving programme. It can be seen that in order to achieve reduction in carbon dioxide emissions, both energy saving and nuclear energy are needed simultaneously.

7. CONCLUSIONS

The major threats to sustainable environment are posed by atmospheric emissions of fossil fuels. Energy policy should include three guidelines at the same time in order to reduce environmental burden most efficiently: (1) energy saving, (2) environmental technology and (3) structural changes in energy system.

In many European countries there are special programmes for promoting energy efficiency and renewable energy like biomass. Also efficient flue gas treatment systems are widely used for reducing the emissions of sulphur dioxide and nitrogen oxides. If the emission standards adopted in Western Europe for acidic emissions were introduced also in Central and Eastern European countries, acidic precipitation could be reduced below critical loads in Europe in the future. This fact is important when considering financial arragements for investments on power plants and environmental protection in Central and Eastern European countries.

Carbon dioxide emissions can't be practically purified from flue gases. To a certain extent specific emission can be reduced by new combustion technology like Integrated Gasification Combined Cycle plants. The key-factors are, however, structural changes in energy system. Finnish experience in application of district heating in urban areas and cogeneration is very good. Energy efficiency is high, imported energy is saved, emissions are lowered and ambient air quality improved.

Also in power production, structural changes are more efficient in reducing environmental burden than energy saving alone. Cogeneration matches very well the seasonal variation of out-door temperture and so does the consumption of electricity. In addition, base-load power is needed as well as short term regulation power. It is important to take full advantage of emission free nuclear energy in base load power production and hydropower in regulation power production. It is in the best interests of European Union that promoting these alternatives is also taken into account when desinging action plans for a sustainable environment and competitive economy.

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