COMPARING ENERGY OPTIONS
THE INTER-AGENCY DECADES PROJECT

BY HANS-HOLGER ROGNER AND ARSHAD KHAN

Supplying adequate and affordable energy services is an essential element of sustainable development. The challenge is to develop those energy services that best support development and improve the quality of life, especially in developing countries, while simultaneously minimizing health and environmental impacts of anthropogenic activities.

The need to design and implement sustainable strategies in the electricity sector has been repeatedly stressed during international fora. Cases in point are the Senior Expert Symposium on Electricity and the Environment (Helsinki, 1991), the United Nations Conference on Environment and Development (UNCED, Rio de Janeiro, 1992), the 16th Conference of the World Energy Council (Tokyo, 1995), and, most recently, the Third Conference of Parties to the United Nations Framework Convention on Climate Change (December 1997 in Kyoto, Japan).

Agenda 21, adopted by UNCED, emphasizes that environmental and development concerns should be integrated into the decision making process. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) emphasizes that mitigation options for alleviating the risks of global climate change should be comprehensively assessed and adequate policies be implemented to promote the installation of the most environmentally benign energy conversion technologies.

At the Kyoto Conference, States adopted a Protocol to the Climate Change Convention that aims to lower overall emissions of a group of six greenhouse gases by the years 2008-2012. The Protocol will entail industrialized countries reducing their collective emissions of greenhouse gases by 5.2%.

In the early 1990s within this global context, the IAEA and eight international partners initiated an inter-agency project, called DECADES. *(See box, page 4.)* It aims to enhance databases and methodologies for comparative assessment of different energy sources and conversion technologies.

This article highlights the project's progress to date, providing some illustrative applications of its computer tools and overviews of comparative case studies that have been carried out in IAEA Member States.

COMPUTER TOOLS

Databases and software developed in the DECADES project have been effectively applied in a number of comparative assessment studies.

Comparison of Power Plants. The net generating efficiency values of several types of power plants (conventional as well as those under development) were compared. (*See graph, next page.*) It may be noted that while significant improvements in the generating efficiency may be obtained for the conventional technologies based on gas, the expected efficiency improvements for the other conventional technologies appear to be only marginal. However, new technologies, with different combustion processes and advanced power cycles, will eventually surpass the best performance of current technologies.

The generating efficiency data are strongly influenced by the characteristics of the fuel used, maintenance of the power plant, and other local conditions. Plant efficiencies vary from country to country and in many countries are lower than the values presented here for electricity generation technologies fueled by coal, oil, and gas.

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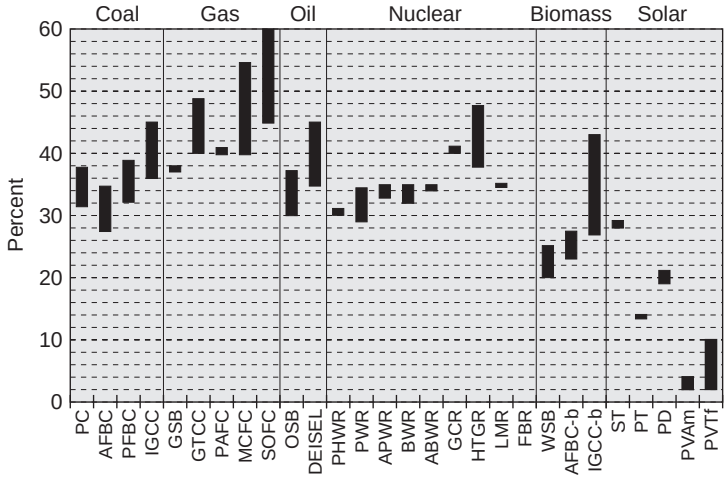
Also compared were the CO_2 emission factors for various types of fossil-fuelled power plants. The power plants have the same size (500 megawatts) and the coal-fired plants use similar coals. The highest CO_2 emissions result from the coal-fired options. These technologies display a considerable range of CO_2 emissions as a result of variations in the efficiency of power generation.

The CO_2 emissions depend on the fuel's carbon content (highest for coal, lowest for natural gas), generating efficiencies, pollution control measures included in different designs, and other factors. The emission factors assume the use of the best available technologies and good quality fuels. Similar comparisons can be carried out for other pollutants, including SO_2, NOx, and particulates.

Economic comparative assessments carried out at the power plant level using the DECADES database show that nuclear power is a competitive option for generating electricity in many countries. The total capital requirements were compared for different types of plants in several countries. *(See graph next page.)* As expected, the total capital requirements per unit capacity vary from country to country, but the range is not large for similar technologies.

Comparison of Energy Chains. Maximum and minimum greenhouse gas emissions were compared for solid, liquid, gaseous, hydro, nuclear, wind, solar and renewable electricity generation pathways. Taking into account the entire up-stream and down-stream energy chains for electricity generation, nuclear power emits 40 to 100 times less carbon dioxide than currently used fossil-fuel chains. *(See graph page 5.)* Greenhouse gas emissions from the nuclear chain are due mainly to the use of fossil fuels in the extraction, processing, and enrichment of uranium and to fuels used in the production of steel and cement for the construction of reactors and fuel cycle facilities. These emissions, which are negligible relative to those from the direct use of fossil fuels for electricity generation, can be reduced even further by energy efficiency improvements. Such improvements at the enrichment step include, for example, replacing the gaseous diffusion process by less energy-intensive processes such as centrifugation or laser isotope separation. Among the fossil fuel chains, natural gas has the widest uncertainty, mainly due to different assumptions concerning methane releases to the atmosphere during drilling, extraction, and transportation of natural gas.

It may be pointed out that in the case of nuclear power, the costs arising from ensuring safety, and for radioactive waste management and decommissioning of facilities, are internalized. This means that they are included in the price of electricity generated by nuclear power. On the other hand, the costs arising from the adverse environmental and health impacts of other electricity



Fossil Fuels: **PC**=Pulverized Coal **AFBC**=Atmospheric Fluidized Bed Combustion **PFBC**=Pressurized Fluidized Bed Combustion **IGCC**=Integrated Gasification Combined Cycle **GSB**=Gas Steam Boiler **GTCC**=Gas Turbine Combined Cycle **PAFC**=Phosphoric Acid Fuel Cell **MCFC**=Molten Carbonate Fuel Cell **SOFC**=Solid Oxide Fuel Cell **OSB**=Oil Steam Boiler **DIESEL**=Diesel Engine

Nuclear Power: **PHWR**=Pressurized Heavy Water Reactor **PWR**=Pressurized Water Reactor **APWR**=Advanced PWR **BWR**=Boiling Water Reactor **ABWR**=Advanced BWR **GCR**=Gas Cooled Reactor **HGCR**=High Temperature GCR **LMR**=Liquid Metal Reactor **FBR**=Fast Breeder Reactor

Biomass & Solar: **WSB**=Wood Steam Boiler **AFBC-b**=Atmospheric Fluidized Bed Combustion using Biomass **IGCC-b**=Integrated Gasification Combined Cycle using Biomass **ST**=Solar Thermal **PT**=Parabolic Trough **PD**=Parabolic Dish/Sterling **PVAm**=Photovoltaic Amorphous **PVTf**=Photovoltaic Thin Film

generating pathways remain to be fully internalized, in part because of the difficulty in their quantification.

Power System Expansion. DECADES computer tools can be used to determine environmentally sound least-cost expansion plans for electricity generation systems or to analyze whether a particular project fits into the robust long-range least-cost development plan for a country or region. It can also be used in an iterative manner to investigate least-cost methods to reduce environmental burdens (e.g., minimum system costs to meet targets for reducing SO_2 or greenhouse gas emissions).

The optimization of the expansion plan is performed taking into consideration the capital investment costs, the operation and maintenance cost, the fuel cost, the fuel inventory cost and the cost of energy not served. Once the optimum expansion plan has been developed, the software allows for the calculation of air emissions, land requirements and production of solid wastes, year-by-year and step-by-step, for every energy chain included in the system, so that the totals for the entire electricity system are calculated.

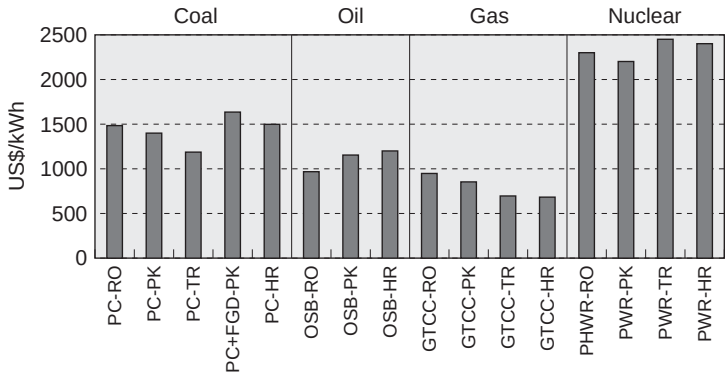
CASE STUDIES

In the first phase of the DECADES project, 22 country case studies on comparative assessment of alternative strategies and policies for the electrical power sector were carried out, supported by the IAEA through a coordinated research project (CRP).

The case studies sought to identify electricity generation strategies that would meet the objectives of environmental protection, in particular reduction of atmospheric emissions at acceptable cost. A broad range of issues have been addressed. They include assessing the potential role of nuclear power in reducing the greenhouse gas emissions; effects of CO_2 taxation and/or emission constraints on the future generation mix; and the impact of privatization and deregulation of the electricity sector on electricity system expansion strategies.

Significant reductions of emissions and other environmental burdens can be obtained by improving the efficiency of existing facilities at different levels of the energy chains. The rehabilitation of existing power plants, in particular by adding pollution control technologies, was often found a cost effective measure for mitigating local air quality and regional acidification impacts. Improving the overall efficiency of energy systems by promoting co-generation was identified as a cost-effective option in many countries, especially where heat

INVESTMENT COSTS AT POWER PLANT LEVEL

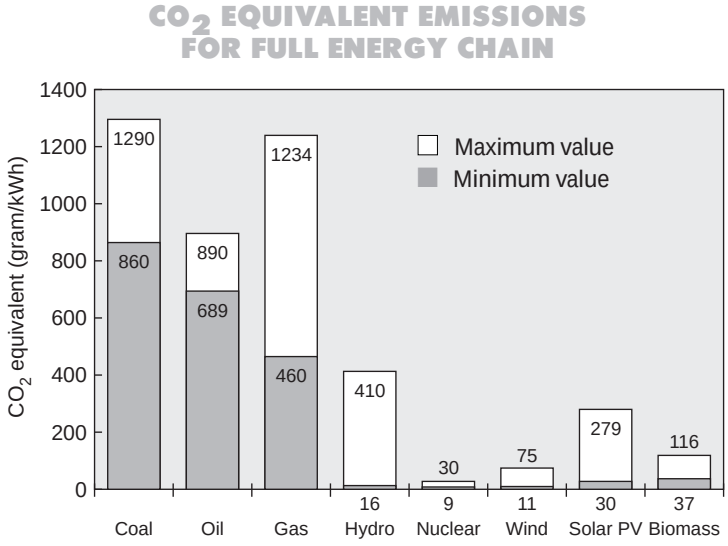


Note: RO=Romania; PK=Pakistan; TR=Turkey; HR=Croatia

For abbreviations of technologies, see note for graphs on page 3. *Source: CSDB*

JOINING FORCES FOR

Nine international organizations joined together in 1992 to launch the inter-agency project on Databases and Methodologies for Comparative Assessment of Different Energy Sources for electricity generation, in short DECADES. They are the IAEA, the European Commission (EC), United Nations Economic and Social Council for Asia and the Pacific (ESCAP), Institute for Applied Systems Analysis (IIASA), World Bank (IBRD), Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA), Organization of Petroleum Exporting Countries (OPEC), United Nations Industrial Development Organization (UNIDO), and World Meteorological Organization (WMO). The project's aim is to facilitate the development of sustainable energy strategies as an integral part of planning and decision making in the electricity sector. The project has established technology databases, developed analytical tools, and provided training and support to developing countries in conducting comparative assessment studies. The



distribution networks already exist for district heating.

In most of the studies addressing capacity expansion, nuclear power proved cost-effective for reducing emissions of SO_2, NOx, and CO_2 and other greenhouse gases. In Romania, for example, the case study examined a gas expansion scenario versus a nuclear expansion scenario. The study found that a large reduction of CO_2 emissions may be obtained by using nuclear power plants in the power system expansion without any significant increase in the total system expansion cost. For the gas scenario, although the CO_2 emissions are reduced in comparison with coal-dominated scenarios, they are significantly increasing over the study period. SO_2 emissions decrease in both scenarios but, in the nuclear expansion scenario, the decrease is approximately 30% more than in the gas scenario.

ENERGY PLANNING

DECADES computer cools consist of databases and analytical software. They can be used for evaluating the always existing trade-offs between technical, economic and environmental features of different electricity generation technologies, chains and systems at the national, regional and international levels.

Two types of technology databases were developed: the Reference Technology Database (RTDB) and Country Specific Databases (CSDBs). The RTDB provides a comprehensive, harmonized set of technical, economic and environmental data for energy chains that use fossil fuels, nuclear power, and renewable energy sources for electricity generation. It contains data for about 300 technologies, characterized according to their level of maturity. The CSDBs store data on electricity generation technologies for various countries or regions for the purpose of carrying out case studies with the DECADES analytical software or other national planning tools. More than 25 countries have developed a CSDB, containing a total of more than 2500 technologies.

Some studies also showed that, although CO_2 emission reduction targets could be achieved without nuclear power, its use would lead to significantly lower costs. It may be pointed out that the implementation of environmental protection measures and policies are likely to increase the cost of electricity from fossil-fueled power plants that will have to comply with these regulations. Furthermore, global climate change concerns are leading many countries to consider policies, such as carbon taxes, that would affect the competitiveness of fossil fuels for electricity generation. In the Romanian case, CO_2 abatement costs based on the accelerated use of nuclear power are approximately US$5/ton CO_2 or US$18/ton-carbon, which is at the bottom end of the range (US$0 to US$120/ton-carbon reported in the IPCC Second Assessment Report).

In most of the case studies, power plants using the natural gas combined cycle — which are very attractive from the point of view of generating efficiency (55% or higher), capital requirements, and short construction periods — were considered as candidates for electric system expansion. Other factors also need to be taken into account when considering this option. These factors include security of supply for countries relying on imports, the potential for gas price fluctuations, and the contribution to greenhouse gas emissions from carbon dioxide during combustion and methane during gas production and transmission.

The cooperation that has been established through this CRP — involving experts hav-

ing different scientific backgrounds and coming from different countries — has proved extremely valuable and effective.

In particular, the cooperation and exchange of information and experience between different teams that are confronted with similar difficulties — such as data collection, technology description, fuel chain definition and comparison, and electric generation system analysis — resulted in identifying and implementing common approaches for solving such problems. The participation of experts in the fields of electricity system analysis, macro-economics and environmental impact assessment led to a recognition of the need to reconcile various concerns and priorities — for example, alleviating local and global environmental impacts and addressing economic, social and security of supply issues — within a comprehensive assessment of alternatives.

DECADES PHASE II

The second phase of the DECADES project (1996-2000) focuses on disseminating the current computer tools, providing user training in their application, supporting country studies, and developing new analytical capabilities.

The DECADES computer tools will be extended to address more comprehensively the issues of impact assessment and integration of impact indicators in the decision-making process. Enhancements currently under way include an improved representation of the health and environmental damages as well as external costs, enhanced capability for regulatory analyses, demand-side management options, multi-fuel units, and combined heat/power systems.

The comparative assessment of comprehensive source-to-service pathways of different energy sources and conversion technologies is key to the development of sustainable energy supply strategies. The DECADES project provides the necessary methodology and tools for performing such assessments, and the dissemination of activities and results to IAEA Member States is an ongoing process. Interregional workshops on the use of the DECADES computer tools were held at Argonne National Laboratory in the United States (1995 and 1996), in Poland (1996) and in Brazil (1997). Also, seminars and workshops were held in Canada, the United States, the United Kingdom, Brazil, and the Republic of Korea. The high interest manifested by institutes, organizations, and universities in Member States participating in these events is a good indicator for the usefulness of the DECADES approach.

The comparative assessment studies based on DECADES show that nuclear power can be economically competitive with other baseload generation options and that it generates significantly lower emissions of SO_2, NOx and CO_2 than any fossil-sourced option. In countries having the right infrastructure in place, natural gas is the preferred option for electricity option, even if the gas is imported. In the case of coal-fired power plants, they may be attractive in countries having access to inexpensive sources of supply. However, their economic competitiveness might become questionable in the context of more stringent environmental protection regulations and standards requiring the implementation of pollution control devices and limitations to greenhouse gas emissions. Most renewable energy sources offer interesting prospects for environmentally friendly electricity generation systems. However, their potential role for large-scale electricity generation, other than conventional hydropower, may be limited by physical constraints in some regions. Moreover, they are unlikely to be economically competitive with fossil fuels for baseload electricity generation and nuclear power in the short and medium term.

To assist more countries interested in conducting their own studies, the Agency intends to strengthen its capacity for objective analysis in the area of comparative energy assessments. Foreseen is closer cooperation with other organizations in the energy field, including the Nuclear Energy Agency, European Commission, World Bank, Organization of Petroleum Exporting Countries, and the International Energy Agency, among others. The Agency also will continue to work within the UN system on an objective examination of all energy options.

Based on results of its comparative assessment analyses, the IAEA plans to participate actively in the preparation of the Third Assessment Report of the IPCC. During the next two to three years, the report will provide an important scientific platform for policy approaches to the issues of climate change and the mitigation of greenhouse gases. ❐