Electricity, health & the environment: Selecting sustainable options

At an international symposium on comparative energy assessment, experts reviewed key issues facing decision-makers

by Leonard Bennett and Malik Derrough

Demand for energy, and notably electrical energy, will grow significantly, especially in developing countries, as the world's population increases. Which energy options are selected will significantly affect the world's achievement of sustainable social, economic, and environmental development.

In many countries, energy planners and decision-makers are facing difficult questions about their nation's energy futures, and they must assess a number of options and energy strategies taking many factors into account. Many of the major issues were addressed at an international symposium convened in Vienna by the IAEA and nine other international organizations in late 1995. *(See box.)*

In opening the symposium, IAEA Director General Hans Blix surveyed the overall global energy scene. He noted that fossil fuels are expected to continue to dominate global energy supply, with solar power, wind power, biomass and other renewables projected to play valuable yet minor roles. Nuclear power's contribution, which now stands at about 7% of the world's commercial energy and 17% of its electricity, is projected to remain significant.

He further pointed out some of the complexities facing today's energy planners and decision-makers, particularly in the electricity sector. They must take into account a range of factors related to the entire fuel cycle of the energy source — including their technical and economic performance and their impact on health and the environment. While costs remain a key factor, they must be measured in many comparative ways — including assessing the costs for those countries suffering from a chronic *under-supply* of electricity.

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The types of analysis now required, he said, require the design of approaches that incorporate all relevant elements into a comprehensive comparative assessment of different options and strategies, and to develop enhanced databases, analytical methodologies, and other decision-aiding tools upon which policy makers can rely to support their decisions. International organizations have an important role to play in helping to meet these challenges, he pointed out.

As part of its efforts to assist national energy authorities in analyzing and planning their energy and electricity systems, the IAEA is conducting a programme covering comparative assessment and methodologies that will objectively support decision-making processes. This article reviews efforts in the context of the major electricity and related issues addressed at the 1995 international symposium. It includes highlights of keynote addresses and selected major points addressed during six technical sessions.

Highlights from keynote addresses

Dr. E. Andreta, European Commission. He stressed the importance of understanding the linkages between electricity, environment, and the economy (the E3 linkages). The relationships are very complex, and it is not possible to manage the whole electricity system without very reliable and efficient technologies, on one side, and without comprehensive management and planning tools on the other side. The EC has developed a large set of energy models for planning sustainable development of energy and electricity supplies. The databases and models developed within the inter-agency DECADES project initiated by the IAEA are another positive contribution, one that points out the necessity of global co-operation in this field. *(See box.)*

Dr. R. Stern, World Bank. Primary energy consumption in developing countries is expected

to equal that in OECD countries by the year 2000, and by the year 2030 to be 2.5 times greater than OECD consumption. The World Bank estimates that the investment needs of the electric power sector alone will be of the order of US $150 billion per year. Financing this investment will require a mix of national resources and international capital. The World Bank recognizes that the appropriate mix of policy mechanisms and technology choices will depend on the situation of each country, its resource endowment, and the inevitable trade-offs required to achieve economic and environmental objectives.

For many countries, natural gas is a very attractive fuel. The difficulty is that gas is not always available where it is needed; hence, gas trade via pipelines or as liquefied natural gas (LNG) is essential. This will require large investments, a great deal of international co-operation, and a long time for development. Dr. Stern noted that the burning of natural gas produces relatively low amounts of CO_2 compared to the burning of coal. However, the greenhouse gas effect of unburned natural gas (methane) is some 30 times greater than that of CO_2; therefore, roughly a 5% leakage rate in a gas pipeline would negate the benefits in CO_2 abatement achieved by substituting gas for coal in a power plant.

Ms. J. Aloisi de Larderel, Industry and Environment Department of the United Nations Environment Programme (UNEP). While electricity is available to virtually 100% of the population in industrialized countries, an estimated 2 billion people in developing countries have no access to electricity. Thus, there is still a huge potential for electrification in developing countries. Electricity provides the possibility of clean and efficient energy use in households, transport, and industry. However, the massive provision of electricity to growing populations with increasing standards of living and expanding industries introduces the risk of potentially serious environmental impacts. Therefore, UNEP's primary role in the area of energy is to foster environmental awareness and to encourage greater incorporation of environmental issues into energy planning and policy.

Dr. A. Tcheknavorian-Asenbauer, United Nations Industrial Development Organization (UNIDO). UNIDO estimates that the industrialization process in developing countries — where 60% of the world's projected population growth will take place — will require a tripling of energy supplies by the year 2025.

Cost-effective improvements in the existing equipment using energy, and the application of good housekeeping measures in industries can result in efficiency gains of up to 40%, and this can be achieved with small to moderate investments. Process improvements, although much more capital intensive, can achieve energy savings of more than 50%. Thus, decision makers need to examine all available options for energy conservation and efficiency in terms of their potential for helping to meet the country's economic and environmental goals.

About the International Symposium

The Symposium on Electricity, Health and the Environment: Comparative Assessment in Support of Decision Making was held 16-19 October 1995, in Vienna, Austria. It was organized jointly by the IAEA and nine other international organizations: the European Commission (EC), the Economic and Social Commission for Asia and the Pacific (ESCAP), the International Bank for Reconstruction and Development (IBRD), the International Institute for Applied Systems Analysis (IIASA), the Organization of Petroleum Exporting Countries (OPEC), the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA), the United Nations Environment Program (UNEP), the United Nations Industrial Development Organization (UNIDO), and the World Meteorological Organization (WMO). Some 200 experts from 53 countries and 16 different organizations took part.

The Symposium was convened as part of the inter-agency project called DECADES, which the IAEA and its partner organizations are sponsoring. The project focuses on databases and methodologies for comparative assessment of different energy sources for electricity generation. Its main objective is to strengthen information sharing and co-operation between interested and affected parties in the field of electricity demand analysis and supply planning, aiming towards implementing sustainable policies in the power sector, taking into account economic, social, health and environmental aspects. Sessions addressed the following topics: key issues in the decision making process; assessment of health and environmental impacts; integrated framework for comparative assessment; implementation of comparative assessment; country case studies; and comparative assessment in decision making. A closing roundtable focused on challenges for global co-operation aiming towards implementation of sustainable electricity policies. In addition to the main sessions, poster presentations illustrated results from comparative assessment studies carried out in different countries, and software demonstrations provided opportunities for participants to gain information about state-of-the-art computer tools, databases, and analytical models used in decision support studies.

Proceedings of the Symposium are being published by the IAEA.

New and renewable energies, such as solar power, biomass, and small hydropower should be examined as options for decentralized supply of electricity to rural areas, which, due to the low population density, are expensive to supply from the central grid. Dr. Tcheknavorian stressed the important role that biomass, particularly wood, represents as an energy resource for rural populations and also for local industries. She noted that biomass provides over 50% of the industrial energy in Africa. However, the use of biomass is often associated with inefficient conversion processes and the collection of fuel wood can lead to deforestation.

Also, industrialized countries should assist developing ones by transferring technologies that are well adapted to the needs and situations in developing countries. In order to assess and compare various energy systems, decision makers need to define technology transfer as a strategic component of an energy programme. Thus, the extent to which various technologies can be absorbed, and the time and cost needed for that process, need to be examined. Finally, the main lesson that UNIDO has learned through its experience in developing countries is that, in order to contribute to sustainable socio-economic development, decisions on energy systems must take into account the specific situation in the country in which they will be implemented.

Dr. L. Olsson, World Meteorological Organization (WMO). In presenting a keynote address on behalf of Prof. Obasi, Secretary General of WMO, he reviewed issues related to energy and climate change. Production and use of energy has a complex impact on the environment, including an impact on climate, and the need for energy is normally directly related to climate and weather. Also, many energy-related activities, e.g. production of energy from biomass, hydropower, and other renewable sources, are based on resources that are extremely sensitive to climate. Global concern over potential climate change has increased the need for environmental impact assessments. In order to ensure a fair judgement of various energy systems, it is of utmost importance to make available relevant information, and it is essential to take a non-biased attitude in assessing scientific, technological, and socio-economic development. The DECADES project is making an important contribution towards this objective.

Highlights of technical sessions

Session 1: Key Issues in the Decision-making Process. Chaired by Dr. Rajendra Pachauri, Director of the Tata Energy Research Institute in India, the session focused on the wide range of issues of concern to decision makers in various regions. Papers illustrated that there may be greatly different priorities according to the level of social, economic, and industrial development in a given country. Presentations included those by Dr. K. Leydon, of the EC; Dr. H. Khatib, speaking on behalf of the World Energy Council's Committee on Energy Issues in Developing Countries; Mr. L. D. Ryabev and Mr. Y.F. Chernilyn of Russia; Ms. J. Ellis and Mr. S. Peake of the International Energy Agency of the OECD; and Mr. R. Lanari, Canada. A number of important points were addressed.

- Member countries of the European Union are dependent on imports for 50% or more of their energy, and this likely will rise to about 70%, Dr. Leydon noted. The challenge to any economist is how to meet the environmental goals and, at the same time, avoid raising the cost of energy as a factor in production. He stressed that it will be no easy task in an evolving geopolitical situation to develop new energy services in response to changing needs; to harness energy efficiency; and to develop new technologies and products. The decision-making framework has to properly reflect the complexity of the choices to be made.
- Developing countries, particularly those in the low income category, are concerned about cost more than anything else, Dr. Khatib said. Therefore, they try to utilize available local fuels, irrespective of their quality, whenever possible. Also, priority is given to technologies requiring low investment, which may lead to the use of local technologies having less efficiency than state-of-the-art technologies. In most instances, these countries cannot afford the extra investment to install pollution abatement systems. However, developing countries are becoming increasingly concerned with environmental questions, and they are trying to reduce pollution, in particular where it is causing local impacts.
- The two largest developing countries, China and India, have populations of 1175 million and 900 million, respectively; a combined population of 2075 million which is almost half the total of all developing countries, Dr. Khatib noted. The growth potential of electricity supply in both countries is very high, and both have large coal reserves. Therefore, both countries will continue to depend on coal as their major fuel for electricity generation for decades to come. Indeed, all developing countries with reasonable levels of commercially viable coal reserves will favour coal as their main fuel for electricity generation. To minimize the environmental consequences of more coal burning, clean coal technologies need to be promoted in developing countries.

The DECADES Project: Progress Report

At the symposium, Dr. B.A. Semenov — who until January 1996 served as IAEA Deputy Director General and Chairman of the Joint Steering Committee for the DECADES Project — reviewed the project's three major areas of work.* These cover databases, methodologies, and training and support for implementing comparative assessments.

Databases. A Reference Technology Data Base (RTDB) has been established, which runs on personal computers. It contains numerical, textual and visual information on the main characteristics of electricity generation technologies at different levels of production chains using fossil fuels, nuclear power, and renewable energy sources. Several hundreds of technologies are characterized by a detailed set of parameters, covering technical performance, costs, atmospheric emissions, wastes, and other environmental burdens. In parallel with the RTDB, some 15 countries have been assisted in implementing Country Specific Data Bases (CSDBs), using the RTDB computer system to store information about their electricity chain facilities. The CSDBs cover more than 1000 technologies.

Methodologies. Two main tasks had been undertaken on methodologies: 1) the preparation of a report describing already available computer tools for comparative assessment of electricity generation options and strategies; and, 2) the development of a new software package for electricity system analysis and planning (DECPAC).

The report on computer tools is based upon information provided by software developers from different countries and international organizations. The new software package, DECPAC, was developed with financial support from the United States and provides enhanced capabilities for integrating technical, economic, health and environmental aspects into electricity system expansion planning. It is linked with the RTDBs and CSDBs and enables analysis of costs, airborne emissions, solid wastes, and other health and environmental burdens of different electricity generation strategies. Some 12 teams from different countries are testing DECPAC for case studies, and their initial experience has shown that it is very useful to analysts and planners in the power sector, and that it meets a real need.

Training and Support. Training workshops are being organized at national, regional or interregional level. They involve users groups that have been established to promote exchange of information between users and the software developers. Work was started late in 1994 on a reference book integrating economic, social, health, and environmental issues into policy making for the power sector. The book's preparation is being led jointly by the IAEA and the World Bank, with important contributions by other DECADES organizations and national experts. It addresses issues such as integrated resource planning, external cost valuation and internalization, and multi-criteria analysis and decision-aiding tools. Expected to be completed by mid-1996, the book is intended to help policy makers in designing a comparative assessment framework adapted to specific requirements and objectives and in selecting appropriate computer tools for carrying out decision support studies.

Case studies. Dr. Semenov pointed out that more than 20 country case studies have been done on comparative assessment of alternative strategies and policies for the electrical power sector through the IAEA's Co-ordinated Research Programme (CRP). Participating in these studies are experts in the fields of electricity system analysis, macro-economics, and environmental impact assessment. The CRP has led to an increased recognition of the need to reconcile various concerns and priorities; for example, alleviating local and global environmental impacts and comparatively addressing economic, social, and security of supply issues.

Encouraging Results. Results obtained so far through DECADES are encouraging, Dr. Semenov said, and demonstrate the effectiveness of joint efforts by international organizations and national experts and institutes. High interest in the project has been shown by national experts, in particular from developing countries and countries in transition. While the project's first phase focuses on the comparison of different electricity supply options, some new directions have been identified, notably concerning demand-side technologies. Information on these technologies might be added to the databases, and an analysis of demand-side options might be incorporated into the DECPAC model. In this regard, Dr. Semenov noted that there has been close co-ordination with the project on establishing an "Environment Manual for Power Development", which has been managed by the World Bank. The results from this project could provide a basis for further enhancing DECADES tools.

Another area of greater future emphasis concerns comparative analysis of health and environmental impacts. The IAEA has done some work on establishing a database on Health and Environmental Impacts of Energy Systems, but more work is required to produce a tool that can be used in the comparative assessment process. The European Commission, in co-operation with national research institutes, also has done work on the external costs of energy systems. Also useful would be national studies using tools that have been developed to examine high-priority issues, such as the cost-effectiveness of different energy systems and measures for mitigating greenhouse gas emissions and other environmental burdens.

For an earlier report, see "Electricity, health, and the environment: The Decades Project", by Evelyne Bertel, *IAEA Bulletin*, Vol. 37, No. 2 (June 1995).

● Electricity's share in OECD energy use is expected to increase from 18% to over 21% by the year 2010. Electricity is an important source of CO_2 emissions in the OECD, accounting for 33% of total energy-related CO_2 emissions in 1993. Thus, in spite of the commitments taken in relation to the Framework Convention on Climate Change, total emissions from electricity production in OECD countries are expected to grow, since electricity demand is projected to increase by some 2.1% per annum up to 2010. However, the emissions will depend on the fuel mix, which differs greatly among OECD countries at present. Norway, for example, currently generates 99% of its electricity from renewable energies; Denmark uses coal for 87% of its electricity and the United Kingdom, United States, Australia, and Germany also rely on coal for the majority of their electricity generation. France, on the other hand, relies on nuclear power for some 75% of its electricity supply, while Italy generates the majority of its electricity from oil.

● In Canada, indigenous populations are being involved in the planning of a hydro-electric project. Through a process of intensive consultation with the indigenous Inuit populations, it was possible to identify a number of measures that could help to meet their concerns about potential impacts of the project. Also, the consultative process gave community members a measure of confidence and a feeling of control over the project, which they otherwise would not have felt. This process showed the importance of involving interested and affected parties as active participants in the decision-making process, and not merely as passive spectators.

Session 2: Assessment of Health and Environmental Impacts. Chaired by Prof. Mohan Munasinghe from Sri Lanka, this session examined the ongoing development of tools for assessing health and environmental impacts of energy chains for electricity generation. Presentations included those by Prof. B. Sørensen of Denmark; Prof. A. Markandya, Harvard University, United States; Dr. N. Pop-Jordanova, Former Yugoslav Republic of Macedonia; Ms. D. Lin, China; Ms. N.P. Villela, Brazil; and Dr. S. Morris, World Health Organization Collaborating Centre on Health and Environmental Effects of Energy Systems, Brookhaven National Laboratory, United States. Major points were made on various issues.

● Several papers stressed the continuing need to improve databases and analytical tools so that uncertainties in data and results can be reduced. Putting monetary values on health impacts from energy systems is a difficult task and many problems still must be resolved. However, the monetary valuation of impacts can assist in the decision-making process, both in the selection of fuels and technologies and in the location of power plants.

● The standard approach of analyzing direct health effects caused by exposure to physical and chemical agents should be extended to include consideration of psychological effects (e.g. stress, anxiety, fear), Dr. Pop-Jordanova suggested. Her research showed there is a great difference between the real and perceived health effects from energy systems. Objective and transparent information from comparative assessments could help to reduce this difference.

● All energy technologies involve some degree of health risk. Dr. Morris noted that despite many studies on the relative health effects of different methods of generating electricity, the results do not appear to have affected actual investment choices. However, due to the increasing public concern about health and environmental aspects of power generation, it may be expected that such studies would have a greater influence on future decisions. It is thus important that the comparative assessment approaches are capable of providing decision-makers with scientifically correct and understandable information.

● Scientists and analysts still have a long way to go in order to provide the type of comprehensive information that is needed by decision-makers, Prof. Munasinghe stressed in his concluding remarks. More has to be done in investigating comprehensively transboundary and global issues such as greenhouse gas emissions and impacts; assessing long-term effects that might arise from chemical and radioactive waste disposal for example; and exploring all potential impact pathways. The uncertainties that still prevail in data and in results from modelling studies make it impossible to give definitive answers to all questions. Thus, there is a need for more co-operation and exchange between analysts and decision-makers to transfer adequate information and useful results from analytical studies to those responsible for policy making.

Session 3: Integrated Frameworks for Comparative Assessment. Chaired by Mr. Kurt Yeager, Electric Power Research Institute, United States, this session included presentations by Prof. P. Capros of Greece; Mr. N.J. Eyre and Ms. J.E. Berry on the ExternE Project of the EC and the US Department of Energy; Prof. M. Munasinghe of Sri Lanka; Dr. S. Hirschberg of the Paul Scherrer Institute in Switzerland; Dr. Y. Uchiyama, Central Research Institute of the Electric Power Industry, Japan; Dr. I.F. Vladu of the IAEA; Prof. M. Chadwick, Stockholm Environment Institute, Sweden; and Dr. R. Wilson, Harvard University, United States. Selected highlights are featured here.

● The ExternE project has shown that it is difficult to achieve full comparability between different fuel cycles, since each one has unique impacts and the assumptions adopted in the quantification can affect their comparison. Some fuel cycles have very long-term impacts, notably global warming impacts from fossil fuel cycles and the radiological impacts of long-lived isotopes from the nuclear fuel cycle. Both the monetary values and the methodology for weighting the distribution of risks to the population and over time and space remain controversial, which adds to uncertainty. Despite some unresolved issues, the study has made important advances in: evaluating damages over very long time and space scales; reporting them in a consistent manner for different energy cycles; identifying the remaining uncertainties; and highlighting important parameters in the decision-making process.

● A life-cycle analysis of electricity generation chains in Switzerland showed that nuclear power emits some 100 times less greenhouse gases than hard coal chains and 10 times less than solar systems. For fuel cycles other than fossil, the power plant contributes only a minor amount to greenhouse gas emissions, while the other steps of the chain are responsible for the major share of emissions, owing to energy consumption and material production in these steps. In the Swiss context, expected technological improvements will reduce greenhouse gas emissions by some 30% for the coal-fired and nuclear systems; and by a factor of five for solar systems with the introduction of amorphous silicon panels.

● A life-cycle analysis of greenhouse gas emissions from electricity generation and supply systems in Japan found that coal, oil, and gas systems emit respectively some 270, 190, and 180 grams of carbon per kWh of electricity generated. On the other side, hydropower, nuclear power, and solar photovoltaic power emit respectively some 5, 6, and 35 grams of carbon per kWh. Technological improvements are expected to reduce significantly the greenhouse gas emissions from electricity systems. Combined cycle gas turbine plants fuelled with liquefied natural gas (LNG) will emit 140 grams of carbon per kWh as compared to 180 grams per kWh with currently used natural gas fired plants. The progress is expected to be even more significant for nuclear power and photovoltaic systems. Advanced nuclear reactors with a closed fuel cycle will emit some 2 to 3 grams of carbon per kWh (versus 6 grams per kWh with current nuclear technology) and photovoltaic systems using amorphous silicon cells will emit 8 grams of carbon per kWh (versus 35 grams per kWh with photovoltaic power plants now in operation).

● All approaches to environmental risk assessment have difficulties in regard to quantitative estimation; not only are the environmental effects not readily quantified but there is no general agreement on what should be quantified, Prof. Chadwick noted. A number of methods have been proposed in order to overcome this problem and a number of possible approaches have been taken to comparative environmental risk assessment. However, more work needs to be done to reach some level of agreement on the approach which is most useful in the decision-making process, and he recommended that this could be a fruitful area of work for the next phase of the DECADES project.

● Four issues dominate public concerns about energy sources, although the magnitude of the risk of each is controversial, either because the experts do not agree or the public does not trust the experts, in the view of Dr. Wilson. The four are the probability and effect of a severe nuclear power accident; the health impact of particulate air pollution; the global climate effect of increased CO_2 emissions from burning fossil fuels; and wastes from the nuclear fuel cycle. Dr. Wilson stressed that severe accidents can and do happen in energy systems, and that overall nuclear power's safety record is excellent. The effects of fossil fuel use on public health are primarily those of air pollution, especially from emissions of very small particles and sulphates. He noted that many studies show that it seems likely that CO_2 concentrations in the earth's atmosphere will rise to two or three times the historical levels within the next century. Although there remains considerable controversy about what the effects will be, it generally is agreed that we are making a large change in an important climate parameter (CO_2) which could affect the entire earth. Nuclear power, whose CO_2 impact is negligible, has the potential to replace at least a significant share of fossil fuels for electricity generation.

With regard to wastes from energy systems, Dr. Wilson noted that many experts are of the opinion that nuclear power is the only energy system for which society has any idea of a sensible long-term solution. Coal wastes are not perceived by the public as a major problem, yet these wastes contain radioactive materials with half lives comparable to long-lived nuclear wastes. Furthermore, the volume or weight of wastes from coal production and burning dwarfs that from the nuclear fuel cycle. In the United States, for example, about 800 million tons of coal are mined in the country each year, producing some 120 million tons of ashes and 20 million tons of sulphur compounds when it is burned for electricity generation.

Session 4: Implementation of Comparative Assessment. Chaired by Prof. Zhou Dadi of China, this session included presentations by Mr. L. Bennett *et. al.* of the IAEA; Prof. T. Lefevre, Economic and Social Commission for Asia and the Pacific (ESCAP); Mr. T. Herberg and Mr. U. Fritsche, Germany; Mr. M. Amann, International Institute for Applied Systems Analysis (IIASA); Mr. R.. Campo, Colombia; and Dr. C. Heaps *et. al.*, Stockholm Environment Institute (SEI)-Boston Centre, United States.

- Results were reported from some 20 comparative assessment case studies sponsored by the IAEA as part of the DECADES project. The studies sought to identify electricity generation strategies that would meet the objectives of environmental protection, in particular reduction of atmospheric emissions at acceptable cost. Overall results showed that 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, including the fuel conversion and transportation steps. The rehabilitation of existing power plants, in particular by adding pollution control technologies, is often a cost-effective measure for mitigating environmental impacts. Improving the overall efficiency of energy systems by promoting co-generation is identified as a very cost-effective option in many countries, especially where heat distribution networks already exist for district heating.

In those studies where it was considered, nuclear power appeared to be cost effective for reducing emissions of SO_2, NO_x and CO_2. For example, some studies showed that, although CO_2 emission reduction targets could be achieved without nuclear power, its use would lead to significantly lower costs. In general, the studies showed that the possibilities for CO_2 emission reduction in the electric power sector would be very limited without the use of nuclear power.

- ESCAP has carried out Energy Environmental Planning (EEP) case studies in the framework of the Programme for Asian Co-operation on Energy and the Environment. Prof. Lefevre stressed that, although sustainable development now is widely embraced as a key societal goal, it is clear that the specification of sustainable policies for the energy sector is a complex task that poses serious dilemmas for many Asian countries. Developing countries of Asia are striving to increase energy production and/or imports to keep up with desired energy consumption. Because the countries are developing rapidly and energy production capacity must be added quickly, emphasis has been placed on minimizing capital costs, with relatively little concern for environmental consequences. However, these countries increasingly are feeling pressure, from multilateral lenders and donor countries, to pay more attention to the environment and to sustainable development. Also, as many of the countries have become more prosperous, their citizens are becoming less willing to sacrifice environmental quality (including public health) for cheap energy. As a consequence, the countries are seeking technical and scientific information, as well as state-of-the-art methodologies and tools for energy-environmental analysis to help them make informed decisions about their energy development strategies.
- Under the SEI/UNEP Fuel Chain Project, two countries (Venezuela and Sri Lanka) have used the project's software and database to examine fuel and technology options across a range of fuels and energy sectors. The two case studies showed that fuel chain analysis can be useful in highlighting trade-offs between local and global environmental impacts. For example in Venezuela, the analysis found that while compressed natural gas (CNG) would be favoured over diesel in terms of local air pollution resulting from the power plant, the use of CNG could result in higher global emissions of greenhouse gases.

Session 5: Implementation of Comparative Assessment: Country Case Studies. Chaired by Dr. Cesar Cordoba-Salazar of Colombia, this session included presentations by Dr. T. Larsson *et. al.*, Sweden; Dr. A. Khan *et. al.*, Pakistan; Dr. A. Popescu *et.al.*, Romania; Dr. A. Das, India; Dr. M. Vielle, France; Dr. J. Geidl and Dr. S. Kanhouwa, United States; and Ms. S. Messner, IIASA in Austria.

- Studies in Sweden have compared the effect on CO_2 emissions from three different policies on energy taxes and subsidies. The main differences were between the tax systems introduced in 1990 and 1994, as well as some difference in the policies on subsidies for the energy sector. The results showed that the 1994 changes in energy policy would lead to CO_2 emissions being reduced in 2005 to 20% below what they would have been if the 1990 policy were still in use. However, beyond 2005, i.e. from the start of the planned nuclear phase-out and beyond, CO_2 emissions will rise drastically regardless of which policy (1990 or 1994) would be in effect.
- In Pakistan, a study carried out under the DECADES project involved two possible paths of development of electricity generation, one that envisaged a reasonable growth in nuclear power capacity and the other postulating a moratorium. The two cases were compared in terms of their associated emissions of pollutants such as SO_2, NO_x, CO_2, methane, radioisotopes, taking into account the full energy chain of each supply

option. The study showed that the increased use of nuclear power in Pakistan would not only be cost effective but also would be helpful in reducing environmental impacts from electricity generation in the country.

- In Romania, a comparative assessment of alternative electricity supply strategies showed that the least-cost plan for expansion of the electricity generation system would use combined cycle natural gas-fired power plants. The case with expanded use of nuclear power showed total costs (up to 2015) that were some 2.6% higher than the least-cost plan; however, the use of nuclear power would allow emissions of CO_2 and NO_x to be reduced by 70% and 80%, respectively, up to 2015, relative to the least-cost case.
- In India, a study examined different CO_2-abatement measures, such as accelerated development of hydropower, increased use of renewable energies, and increased use of clean coal technologies. The power sector is the single largest contributor of CO_2 emissions in India, and electricity demand is expected to grow at 6% to 7% per year. If the current domination of coal in electricity generation continues, then CO_2 emissions from the electricity sector would triple by the years 2011-2012. The study showed that the lowest cost strategy involved the accelerated development of hydropower. It would not only lead to lower costs but also would reduce CO_2 emissions in 2011/2012 by some 12%. The study also examined an "abatement scenario" which assumed a 25% reduction of CO_2 emissions up to 2011/2012. This scenario included both the accelerated development of hydro and the introduction of clean coal technologies. Results showed that this scenario would be some 7% more costly than the business-as-usual scenario.
- In France, a study examined nuclear power's economic and environmental impacts. It found that if France had not developed its nuclear power programme, the price of electricity would be some 15% higher than what exists today, and would be highly sensitive to fluctuations in the price of imported coal. Sulphur dioxide emissions would be 18% higher that the current levels, and other atmospheric emissions would be higher by an even greater amount.
- A IIASA research project is examining long-term options and strategies for sustainable energy development, in particular by assessing the potential for reducing energy use and the carbon intensity of energy worldwide. The project has led to an inventory of technologies for reducing CO_2 emissions and the data's application in a number of studies. The database contains information on over 1400 technologies, with more than 70% of the entries being for electricity generation and cogeneration technologies.

Session 6: Comparative Assessment in Decision Making. Chaired by Dr. Nengah Sudja of Indonesia, the final technical session included presentations by Ms. B. Reuber of Canada; Prof. R. Dutkiewicz, South Africa; and Dr. D. Martinsen and Dr. A. Voss *et. al.*, Germany. A number of important points were addressed.

- In Canada, Ontario Hydro has included comparative assessment as an integral part of its decision-making process. Externality values (i.e. social costs, such as health effects, that are not always fully reflected in the price of electricity) have been established for Ontario's fossil-fired power stations and for the full life-cycle of its nuclear power stations. Preliminary data show that for the fossil power stations, the externality values ranged from a low of 0.06 Canadian cents per kWh to a high of 1.66, with an average of 0.40. For nuclear stations, the estimated externality costs ranged from a low of 0.0015 to a high of 0.12 cents per kWh.
- A comprehensive study in Germany analyzed possible paths for the future development of the national energy system, with the objective of identifying strategies for reducing CO_2 emissions by 30% up to the year 2005 and 50% up to the year 2020. The possible role of nuclear power as a mitigation measure was analyzed by four separate 50% CO_2 reduction scenarios, including one with a build-up of nuclear capacity. The study concluded that a 50% CO_2 reduction by the year 2020 is feasible, and that it can be attained with technologies that are already available or known to become available in the next 30 years. The 50% CO_2 reduction target could be achieved without the use of nuclear energy as a carbon-free energy carrier, although at considerable cost. The expanded use of nuclear energy would allow the target to be reached with significantly lower costs of energy supply.

Future directions

The international symposium underscored the importance of comparative assessments in support of decision-making in the electricity sector. It further identified a number of areas where greater global co-operation is needed to improve the base of information and the analytical tools and methodologies for conducting comparative studies.

Through its programmes and activities, the IAEA is continuing to examine areas in which its expertise and support can best be applied to assist national policy- and decision-makers in objectively and comprehensively assessing their energy systems and strategies. ❐