Sustainable Energy for the 21st Century

IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessments

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This brochure is intended for decision makers and technical experts in IAEA Member States, who are interested in energy and nuclear technology planning and in related support available from the IAEA.

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Executive Summary

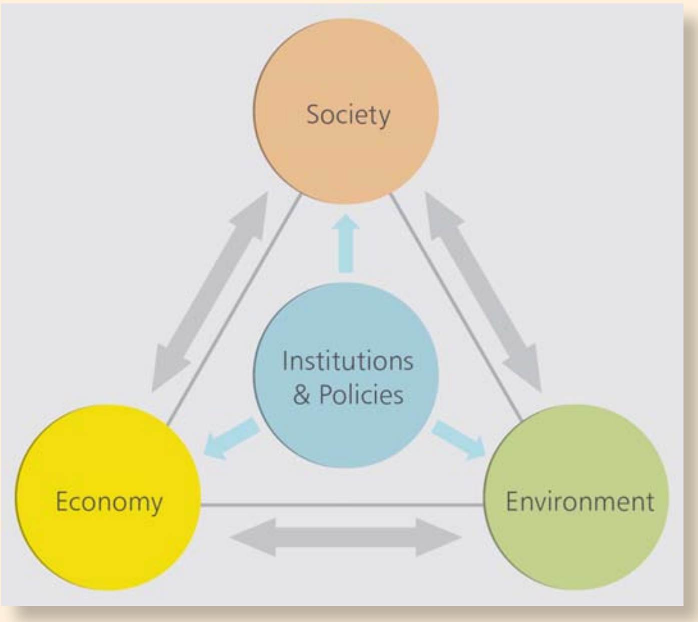
Energy is essential for all human activities, and its availability is critical to economic and social development. Energy is the engine for the production of goods and services across all economic sectors. It is vital to the provision of basic civic services in education, health care, clean water supply and sanitation, and also for wealth creation.

Lack of energy is a contributing factor to the poverty of individuals, communities, nations and regions. While not an end itself, energy, jointly with appropriate technologies and infrastructure, generates the services modern societies demand (transportation, lighting, air conditioning, information exchange, etc.). Meeting the United Nations Millennium Development Goals can be only accomplished with access to affordable energy services.

Concerns over energy resource availability, climate change, air quality and energy security suggest an important role for nuclear power in supplying energy in the 21st century. Currently there are 436 nuclear power reactors in operation in 30 countries around the world. They account for approximately 14 % of worldwide electricity generation and provide half or more of the electricity in a number of industrialized countries. Another 45 nuclear power reactors are under construction. Nuclear power has low carbon energy emissions and generates electricity in a reliable, environmentally safe and affordable manner.

Energy Planning and Sustainable Development

Energy planning aims at ensuring that decisions on energy demand and supply infrastructures involve all stakeholders, consider all possible energy supply and demand options, and are consistent with overall goals for national sustainable development. The concept of sustainable development encompasses three interdependent and mutually reinforcing pillars: social development, economic development and environmental protection, linked by effective government institutions.



Concept of sustainable development.

The IAEA assists Member States in capacity building in the area of national and regional energy systems analysis and planning, so they can independently chart out their own national energy strategies. Depending on a country's indigenous resource endowment, its stage of infrastructure development and sustainable development objectives, the energy system analyses may or may not conclude that nuclear energy is part of a country's future energy mix.

The IAEA offers a set of computer models and a methodology to:

(1) develop potential and plausible trajectories of energy demand and corresponding energy supply mixes (technologically neutral);

(2) conduct a Nuclear Energy System Assessment (NESA) with particular focus on all things nuclear.

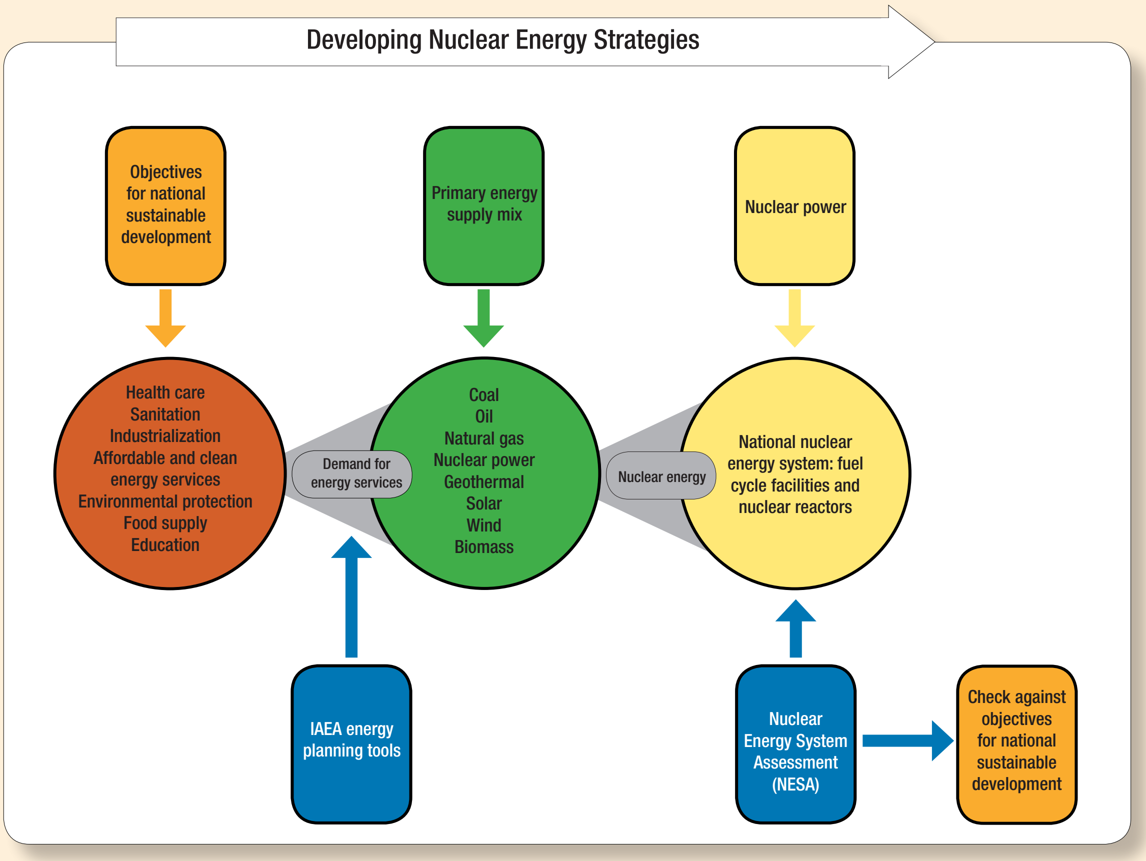
Long range and strategic planning for energy system evolution and the potential role of nuclear energy therein requires a sound understanding of the dynamics of technology change and innovation of energy related infrastructures, social preferences, economic development directions and environmental constraints. In particular, adopting a nuclear power programme has intergenerational implications and obligations extending well beyond 100 years.

Developing Energy Strategies

An energy planning process starts by taking stock of a country's or region's overall energy situation using a set of indicators that encompasses all aspects of sustainable development, and then generating an image of the existing energy system from resource extraction to the provision of energy services consistent with the requirements of the IAEA's energy analysis and planning tools. The IAEA models are then calibrated to correctly reflect the current energy infrastructure and energy flows. The design of future socioeconomic and technology development scenarios[1] is the next step, i.e. charting a possible long term national outlook on social and economic development of a country or region from which demand profiles for energy services are derived. Finally, an evaluation of all present and future energy supply options is undertaken that can meet demand under certain policy targets or constraints.

Once nuclear energy has been identified by a Member State as a desirable component of a country's future energy mix, it may be useful to perform an assessment of the entire nuclear energy system (NES) to raise the awareness of all issues associated with the development and deployment of nuclear energy, support the development of a national strategic plan for nuclear energy, and determine if the proposed nuclear energy system meets sustainable development criteria.

[1] *A scenario is an internally consistent image of a possible future. Since the future is unknown, analysts use a set of scenarios to better understand uncertainties.*



IAEA energy planning tools and methodology support national sustainable (nuclear) energy planning.

A nuclear energy system encompasses all facilities of the nuclear fuel cycle from mining/milling, conversion, enrichment, fuel fabrication, electricity generation or other energy products, through to final end states for all wastes and permanent disposal of high level waste, and related institutional measures including legal framework, regulatory bodies, etc.

To assist a Member State in performing a NESA, the 'INPRO Methodology' was developed by the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) with contributions by some 300 international experts, including those from the Generation IV International Forum (GIF).

Evaluating Options for Long Term Energy Planning and Development

Computer assisted modelling forms the core of the IAEA's approach to energy analysis and planning. National economic and energy statistics provide the input to the calibration of the models to accurately reflect the current energy system as well as its interaction with the principal drivers of energy demand and supply, such as demographics, economic development, technology change, environment policy, etc. Energy planners or policy analysts design future development trajectories of the principal drivers of the energy system 20 to 50 years into the future, and by using the IAEA energy planning tools, derive profiles of energy service demands and optimal supply mixes. Energy planners can then compare these scenarios (different futures) with their ability to support national development objectives and goals. Critical policy and investment aspects of different energy strategies can be defined, undesirable consequences can be identified, and the most cost effective approach to meeting future energy needs can be determined.

The IAEA offers several analytical tools that support energy analysis and planning in Member States:

The **Model for Analysis of Energy Demand (MAED)** evaluates future energy demand based on a set of consistent assumptions on medium to long term socioeconomic, technological and demographic developments in a country or a region. Future energy needs are linked to the production and consumption of goods and services; technology and infrastructure innovation, lifestyle changes caused by increasing personal incomes; and mobility needs. Energy demand is computed for a host of end use activities in three main 'demand sectors': household, services, and industry and transport. MAED provides a systematic framework for mapping trends and anticipating change in energy needs, particularly as these correspond to alternative scenarios for socioeconomic development.

The **Model of Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE)** combines technologies and fuels to construct so-called 'energy chains', making it possible to map energy flows from resource extraction, beneficiation and energy conversion (supply side) to the, distribution and the provision of energy services (demand side). The model can help design long term energy supply strategies or test energy policy options by analysing cost optimal energy mixes, investment needs and other costs for new infrastructure, energy supply security, energy resource utilization, rate of introduction of new technologies (technology learning), and environmental constraints.

The **Wien Automatic System Planning Package (WASP)** is an effective tool for power planning in developing countries. It helps to determine 'optimal' expansion plans for power generation within constraints identified by local analysts, which may include limited fuel availability, emission restrictions and system reliability requirements, among others. WASP explores all possible sequences of capacity additions that are capable of satisfying demand while also meeting system reliability requirements. It accounts for all costs associated with existing and new generation facilities, reserve capacity and un-served electricity.

The **Model for Financial Analysis of Electric Sector Expansion Plans (FINPLAN)** is used for financial analysis of electricity generation projects by taking into account financing sources, expenditures, revenues, taxes, interest rates and weighted average capital costs, etc. Since financial constraints are often the biggest obstacle to implementing an optimal energy strategy, the model is particularly helpful for exploring the long term financial viability of projects by preparing cash flows, income statements, balance sheets and financial ratios.

The **Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS)** estimates and quantifies health and environmental damage costs, so-called 'externalities', of different electricity generation technologies. This tool is particularly useful for comparative analyses of fossil, nuclear and renewable electricity generation, siting of new power plants or cost effectiveness of environmental mitigation policies. A key strength of SIMPACTS is that it already delivers useful results when only limited data are available.

Solar energy – a renewable option.

The **Indicators for Sustainable Energy Development (ISED)** framework provides a flexible tool for analysts and decision makers to better understand their national energy situations and trends, and the impacts of policies and policy changes on the energy system. The indicators reflect the interaction of energy with the economic, social and environmental aspects of sustainable development over time. The ISED can also be used to monitor progress of policies and strategies for sustainable energy development.

Assessing Nuclear Energy Systems

Innovation is key to the future of nuclear energy — as is the need for nuclear energy to be consistent with the sustainable development objectives of those countries which consider including the technology in their future energy mixes or plan to expand its use. Nuclear energy systems are characterized by complex infra-structures and longevity easily extending over several generations. Also, developing or expanding nuclear energy systems requires extensive lead times and resources, especially for the design and commercialization of new and innovative components. It is therefore prudent to assess nuclear energy systems holistically, i.e., from all possible angles including the four dimensions of sustainable development.[2]

[2] *The World Commission on Environment and Development (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and identified four essential dimensions: economic, social, environmental and institutional.*

A Nuclear Energy System Assessment (NESA) is a holistic approach, using an internationally validated tool, the INPRO Methodology, to support strategic decision making in Member States that are planning to establish a new nuclear energy programme or expand an existing one.

More specifically, a NESA evaluates:

- *All nuclear facilities in a given nuclear energy system, from mining through to final end states for all wastes and permanent disposal of high level waste, and all related institutional measures such as legal framework, regulatory bodies, etc.;*
- *The complete lifecycle of the facility ('cradle to grave'), i.e. design, construction, operation and decommissioning;*
- *All assessment areas defined in the INPRO methodology, i.e. economics, infrastructure, waste management, proliferation resistance, physical protection, environment and safety.*

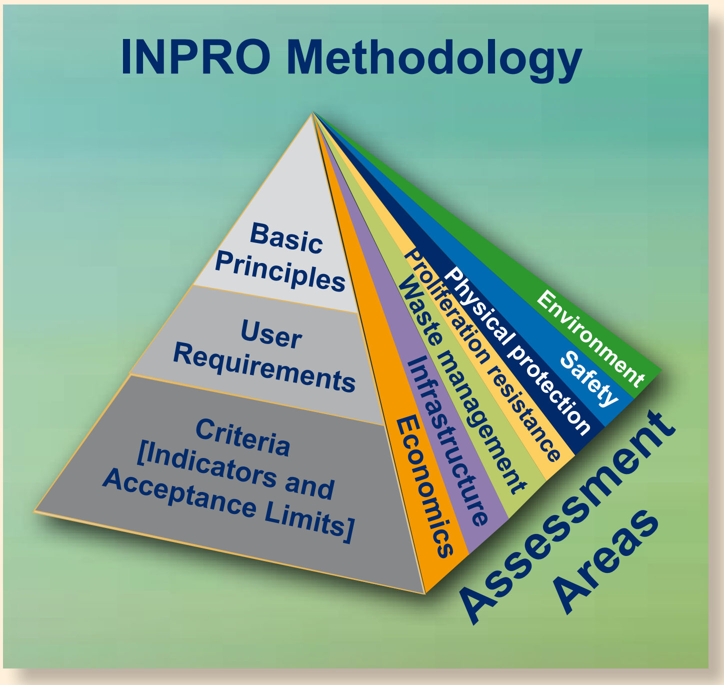
A NESA can be used both by countries with established nuclear programmes, for example to assess the transition from a current fleet of reactors to a nuclear energy system with innovative technologies, and by 'newcomers', wishing to embark on new nuclear programmes. The assessment allows them to consider possible future nuclear systems in a holistic and comprehensive manner to determine whether or not they would meet a country's sustainable development objectives.

The INPRO Methodology — A Tool for Nuclear Energy System Assessments

The INPRO methodology was developed as the tool to undertake national, regional or global NESAs. It comprises a three tier hierarchy of *Basic Principles, User Requirements and Criteria with Indicators and Acceptance Limits*. These elements are used to assess a nuclear energy system in seven areas, which together encompass the dimensions of sustainable development:

- *Economics*
- *Infrastructure (institutional arrangements)*
- *Waste management*
- *Proliferation resistance*
- *Physical protection*
- *Environment (impact of stressors and resource depletion)*
- *Safety of reactors and nuclear fuel cycle facilities.*

If all criteria, user requirements and basic principles are met in the assessment areas, the nuclear energy system represents a source of energy consistent with a country's sustainable development criteria. If not all components are met, a given nuclear energy system may still represent an excellent interim energy supply system, but will need to change and evolve to become sustainable in the longer term. The results of a NESA can be used to guide this evolution.



The INPRO Methodology comprises a hierarchy of Basic Principles, User Requirements and Criteria with Indicators and Acceptance Limits.

IAEA Assistance Aligning to Member State Needs

Each Member State has unique needs in the area of energy and nuclear energy planning. The IAEA offers a range of assistance programmes, particularly for developing countries, to improve their capabilities for performing integrated energy assessments to formulate long term strategies for sustainable energy development, and assessing the possible role of nuclear power in meeting future energy needs.

The tools and methodology described in this brochure are an important contribution to these assistance programmes. The IAEA provides these tools and methodology, documentation and manuals, workshops and training courses, and expert missions to Member States.

Member States wishing to embark on a new nuclear programme should also consider recommendations contained in the IAEA publication *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1).

Regional training course on evaluating energy strategies

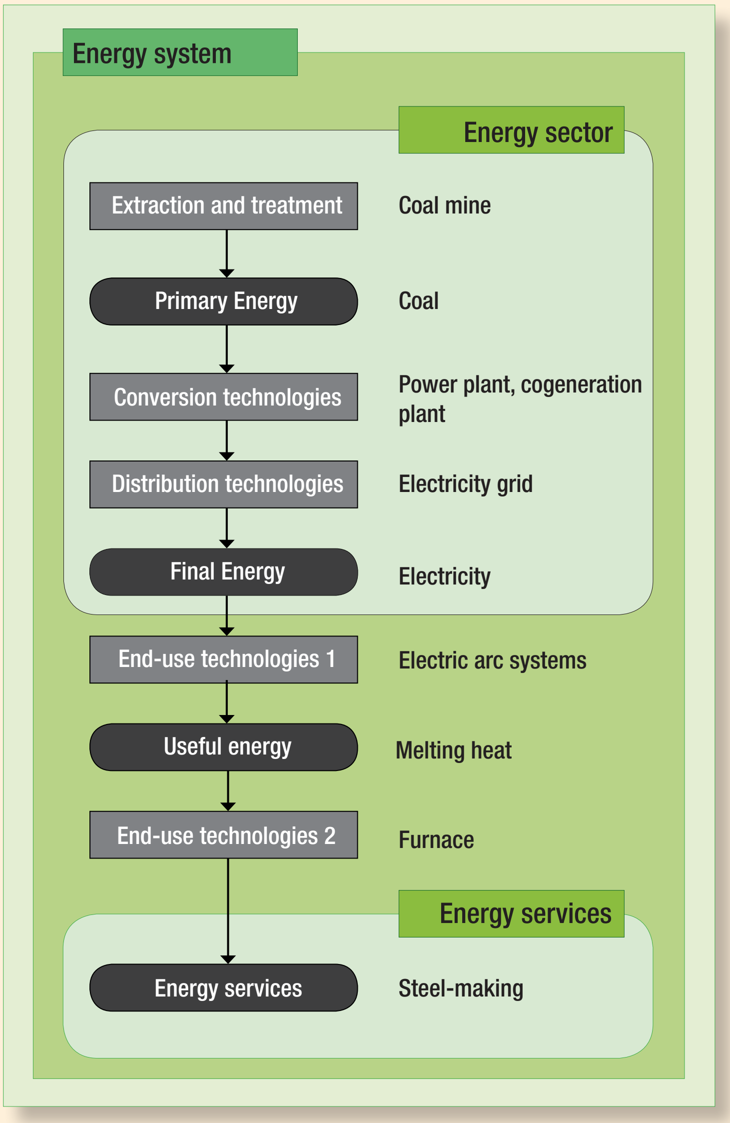
IAEA Workshop on MESSAGE

Energy Planning Tools

Energy System

The energy system is more than the energy sector, which is a part of the energy system. The purpose of the energy system is to deliver energy services such as illumination, comfortable indoor temperatures, refrigeration, transportation, etc. Energy services are also required for virtually every commercial and industrial activity. The energy system is made up of the energy supply sector and energy end-use technologies, e.g. stoves, refrigerators, light bulbs, computers, milling machines, and associated infra-structure that covert the fuels provided by the energy sector into energy services, e.g., electricity for information technology services.

Put differently, the energy system consists of a set of chains – often interconnected – to deliver these services. They begin with the collection or extraction of primary energy that may be converted into fuels, such as electricity, diesel oil or bio-fuels suitable for the provision of the desired energy services via the end-use technologies (the figure to the right illustrates an energy chain that delivers the service 'steel making'). Competition exists between different energy chains, as the same service can often be delivered by more than one chain (see figure on page 8).

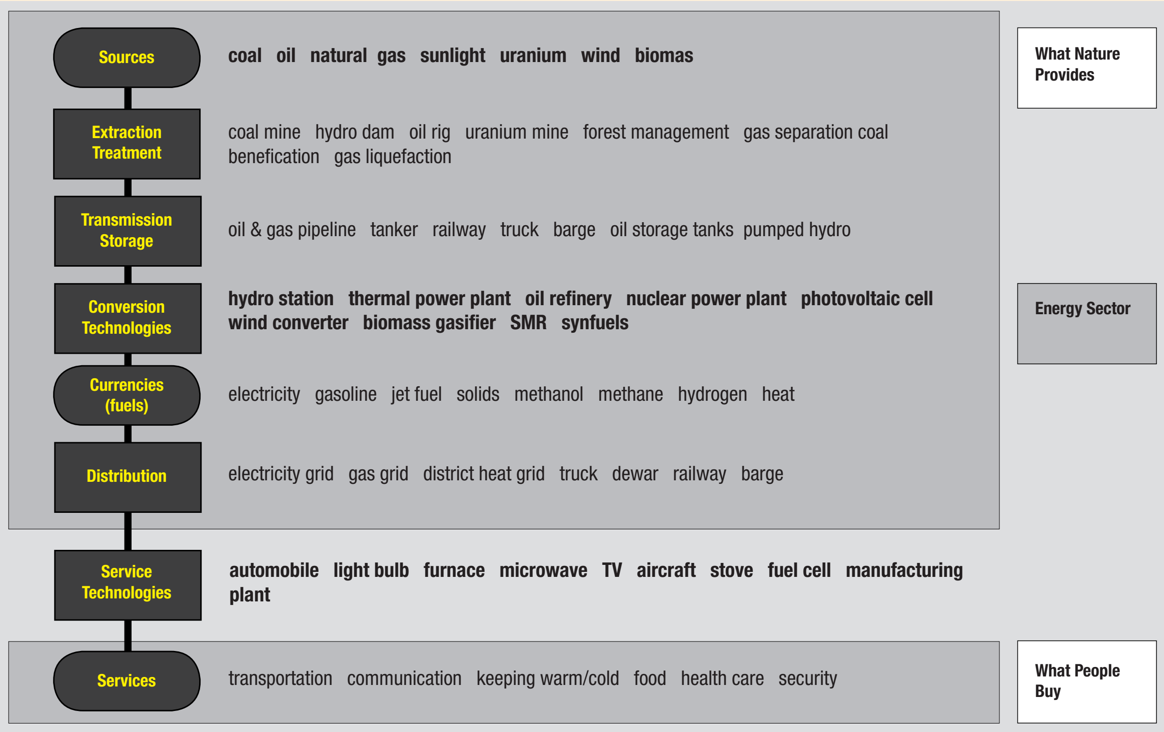


Example of an energy chain (Source: World Energy Assessment, 2001)

Energy services, therefore, are the result of a combination of various technologies, infrastructure (capital), labour (know-how), materials, and energy sources. Each of these inputs carries a price tag, and they are partly substitutable. Each of these inputs is subject to change, especially in the longer run. However, modelling helps to put potential changes into perspective. From the consumer's perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services.

Evaluating Options for Long Term Energy Development

In response to the needs of Member States for capacity building to analyse and design national strategies toward sustainable energy development, the IAEA has developed a set of indicators, energy demand, supply and environmental impact modelling tools, and mechanisms for transferring the tools and the necessary expertise to Member States, in particular to developing countries.



Architecture of the energy system. The examples are illustrative and not intended to be comprehensive (Source: Rogner and Scott, 2000).

Energy planning models cover the entire spectrum of energy issues and provide a consistent framework for developing and evaluating alternative paths for the energy system in a country. They take into account expected changes in demography and life-styles, technological development and innovations, economic competitiveness, environmental regulations, market restructuring, and global and regional developments. The models have the added advantage that they are extremely flexible and can be readily adapted to the often very different national and regional energy system structure, constraints, needs and uses in different countries.

Users of Energy Planning Tools

Energy analysts and planners in energy ministries, electric utilities, and research institutions are the main users of the IAEA's energy planning tools. These tools are instrumental in elaborating sustainable energy development strategies and assessing the potential contribution of various energy options, including nuclear energy, for meeting long term energy needs. The quantitative analyses conducted using these tools generate consistent and coherent information for policy makers to assess the possible impacts of energy decisions and help formulate national energy strategies compatible with long term social and economic objectives of the country.

To date, the IAEA's analytical tools and indicators support energy planning in 115 Member States. The World Bank, the Latin American Energy Organization (OLADE), the European Commission and other international and regional organizations use the models in energy projects in developing countries. Universities and research institutions apply them in academic programmes and research studies.

The emphasis of the indicators for sustainable energy development (ISED) is on national self-examination rather than international benchmarking. The interpretation depends on the state of development of each country, its economy, geography and availability of indigenous energy resources. A critical analysis of underlying conditions is therefore essential. Changes in the value of each indicator over time, properly analysed, can help energy analysts/planners to quantify progress toward selected development goals within a country. Valuable insights can be gained, if the indicators are applied at the beginning of an energy assessment and then again at the end. The indicators then monitor the progress towards sustainable energy development (as defined by the policy maker) of a particular scenario or energy strategy.

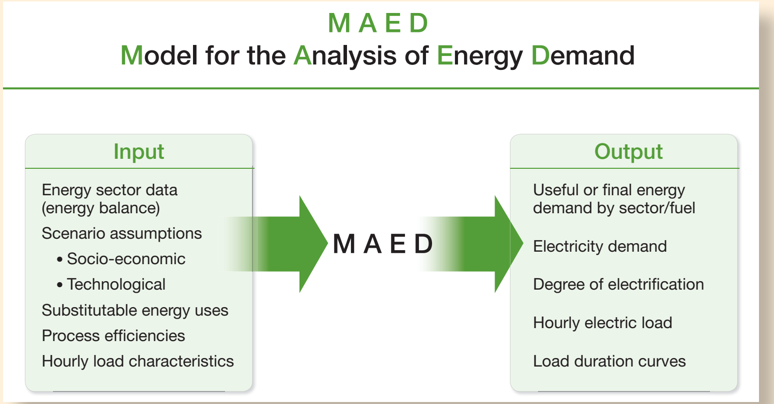
IAEA Models for Energy Planning

Computer supported modelling forms the core of the IAEA's approach to energy planning. More information on the individual models and assistance in their use is available in IAEA publications (see list at the end of this chapter) and at the following web site: ***http://www.iaea.org/OurWork/ST/NE/Pess/***.

Model for Analysis of Energy Demand (MAED)

MAED evaluates future energy and electricity demand based on assumptions of medium to long term socioeconomic, technological and demographic developments in a country or a region. The model systematically relates the specific energy needs for producing various goods and services to the social, economic and technological factors that affect the demand for a particular fuel.

Energy demand is divided into a number of end use categories, each corresponding to a given service or the production of a certain good. The nature and level of demand for goods and services are determined by population growth, number of inhabitants per dwelling, number of electrical appliances used in households, peoples' mobility and preferences for transport modes, national priorities for the development of certain industries or economic sectors, evolution of the efficiency of certain types of equipment and market penetration of new technologies or energy forms. The expected future trends for these determining factors, which constitute 'scenarios' are exogenously introduced.



Major inputs and outputs of MAED

The energy demand for each economic sector can be evaluated when understanding the determining factors mentioned above. The total energy demand for each end use category is summed up into four main energy consumer sectors: industry (including agriculture, construction, mining and manufacturing), transportation, service, and household.

The starting point for using MAED is construction of a base-year energy demand pattern of a given country, followed by development of future scenarios of the social and economic evolution of the country and technological factors, e.g. the efficiency and market penetration potential of alternative energy forms.

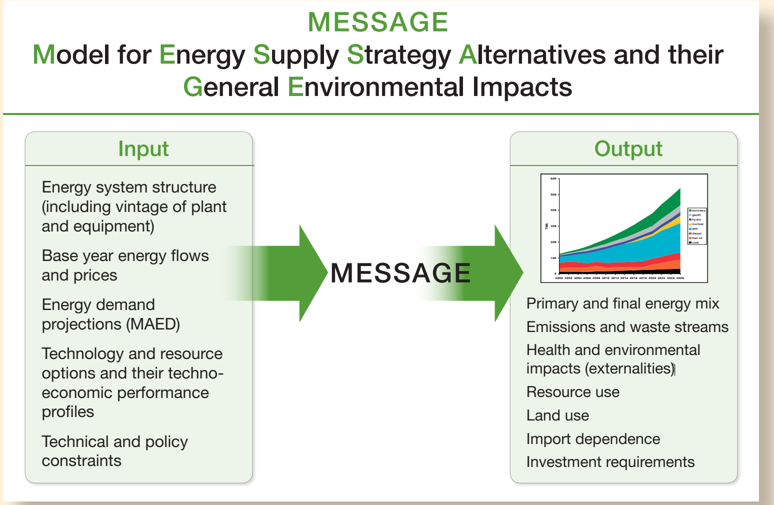
The model focuses exclusively on demand for specified energy services. When electricity, fossil fuels and other forms of energy are competing for a given end use category of energy demand, this demand is calculated in terms of useful energy and then converted into final energy. Non-substitutable energy uses, e.g. motor fuels for cars or electricity for lightening, are calculated directly in terms of final energy. Energy demand is not only calculated annually (as for all other forms of energy) but also hourly. Such calculations serve as input data for further analysis of the energy generating system using the WASP model described below.

MAED provides a systematic framework for evaluating the effect of a change in socio-economic and technical development on energy demand.

Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE)

MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user defined constraints on new investment, market penetration rates for new technologies, fuel availability and trade, and environmental emissions.The underlying principle of the model is the optimization of an objective function (e.g. least cost, lowest environmental impact, maximum self-sufficiency) under a set of constraints. The backbone of MESSAGE is the techno-economic description of the modelled energy system. This includes the definition of the categories of energy forms considered (e.g. primary energy, final energy, useful energy), the fuels (commodities) and associated technologies actually used (e.g. electricity, gasoline, ethanol, coal, district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology).

Technologies are defined by their inputs and outputs (main and by-products), their efficiency and their variability if more than one input or output exists, e.g. the possible production patterns of a refinery or a pass-out turbine. Economic characteristics include investment costs, fixed and variable operation and maintenance costs, imported and domestic fuel costs and estimates of levellized costs and shadow prices.



Major inputs and outputs of MESSAGE

Fuels and technologies are combined to construct energy chains, where the energy flows from supply to demand. The model takes into account existing installations, their vintage and their retirement at the end of their useful lives.

The investment requirements can be distributed over the construction time of a plant and can be divided into different categories to reflect more accurately the requirements of industrial and commercial sectors. The requirements for basic materials and for non-energy inputs during construction and operation of a plant can also be accounted for by tracing their flow from originating industries either in monetary terms or in physical units.

For some fuels, ensuring timely availability entails considerable cost and management efforts. Electricity has to be provided by the utility at exactly the same time it is demanded, and MESSAGE simulates this situation.

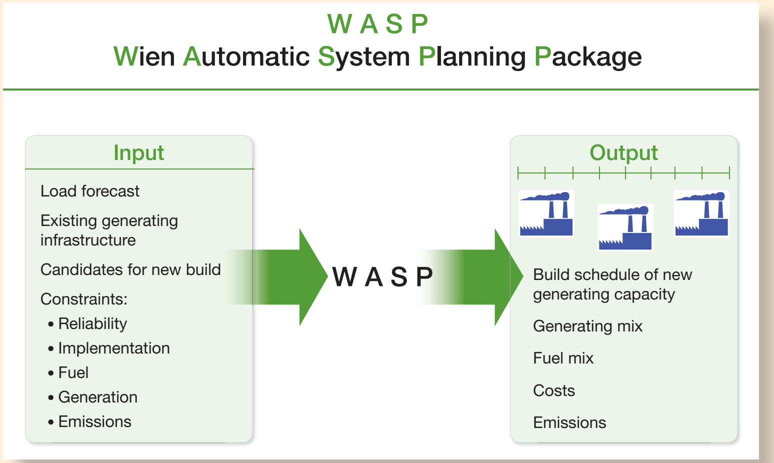
Environmental aspects can be analysed by keeping track of, or limiting, pollutants emitted by various technologies at each step of the energy chains. This helps to evaluate the impact of environmental regulations on energy system development. The inputs and outputs of MESSAGE are depicted in the figure below.

MESSAGE uses the projections of useful or final energy demand from MAED to generate the energy supply system. The most powerful feature of MESSAGE is that it provides the opportunity to define constraints for all types of technology. The user can, among other options, limit one technology in relation to other technologies (e.g. a maximum share of wind energy that can be handled in an electricity network), give exogenous limits on technologies (e.g. a limit on cumulative SO_2 or greenhouse gas emissions), or define additional constraints between production and installed capacity (e.g. ensure take-or-pay clauses in international gas contracts, forcing customers to consume or pay for a minimum share of their contracted level during summer months). The model is extremely flexible and can also be used to analyze energy and electricity markets and climate change issues.

Wien Automatic System Planning Package (WASP)

WASP is the IAEA's long-standing model for analysing expansion plans for electricity generation. Initially developed in the 1970s, it has been enhanced and upgraded over time to match emerging needs and allow analysis of contemporary issues such as environmental regulations and market restructuring, among others.

WASP is an exceptionally effective tool for power planning in developing countries. It permits the user to find an optimal expansion plan for power generation over a long period of time and within the constraints identified by local analysts. This may include limited fuel availability, emission restrictions, system reliability requirements, etc. Each possible sequence of power plants that could be added to an energy system, for example an expansion plan or policy, and which meets selected constraints, is evaluated by a cost function of capital investment costs, fuel costs, operation and maintenance costs, fuel inventory costs, salvage value of investments and cost of energy demand not served.



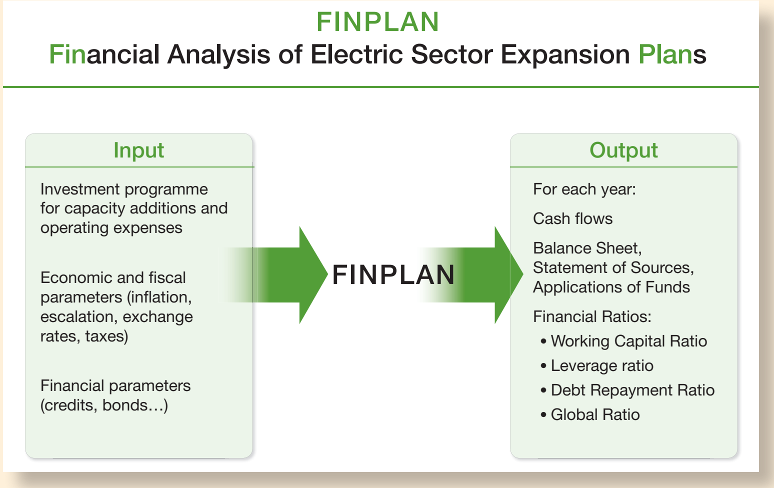
Major inputs and outputs of WASP

WASP requires that the technical, economic and environmental characteristics of all existing power plants in a country's electricity generation system be defined. These characteristics include plant capacities, minimum and maximum operating levels, heat rates, maintenance requirements, outage rates, fuel and operation costs, emission rates, etc. For a given yearly future demand for electricity, the model explores all possible sequences of capacity additions that will match this demand, and at the same time overcome all constraints, for example a certain level of system reliability, availability of certain fuels, build-up of various technologies, or environmental emissions.

Model for Financial Analysis of Electric Sector Expansion Plans (FINPLAN)

FINPLAN evaluates the financial implications of an expansion plan for a power generating system. The model clarifies the feasibility of electricity generation projects by computing important financial indicators while taking into account financing sources, costs, revenues, taxes, etc. It is particularly helpful for establishing the long term financial viability of projects by preparing cash flows, income statements, balance sheets and financial ratios. When an optimal or desired investment programme for expansion of the electric sector has been determined, for example with the help of the WASP model, it should be subjected to various reality checks. If the expansion plan is too ambitious for available resources, even the most efficient configuration may not be realisable. Such financial constraints may require a revision of the economically optimal expansion plan. FINPLAN helps to analyse alternative expansion plans by evaluating their financial consequences.

FINPLAN is designed to consider all power plants in an energy system or owned by a company. It can also be used for financial analysis of a single power plant. If all power plants in a system are analysed, the model evaluates the consequences of adding additional power plants (over a given time period) on the overall financial performance of the company. For a single plant analysis, it evaluates financial viability of the plant under assumed market conditions.



Major inputs and outputs of FINPLAN

For developing countries, arranging funds in foreign exchange is an added difficulty. The model treats all expenditures in a foreign and the local currency. The cash flows for all expenditures in the respective currencies are maintained and the impact of future exchange rate changes is analysed accordingly.

The model is very useful as it helps to analyse the impact of assumed future conditions that affect the financial health of a company.

Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS)

SIMPACTS estimates and quantifies the health and environmental damage costs of different electricity generation technologies. It consists of separate modules for estimating the impacts on human health, agricultural crops and buildings resulting from routine atmospheric emissions of pollutants from energy facilities. It can be used for comparative analysis of fossil, nuclear and renewable electricity generation, siting of new power plants or cost effectiveness of environmental mitigation policies. It estimates physical damages and external costs. A decision aiding module permits comparison of the relative advantages of different technologies. The most significant aspect of SIMPACTS is its simplicity — it is designed for use on a PC with a minimum of input data.

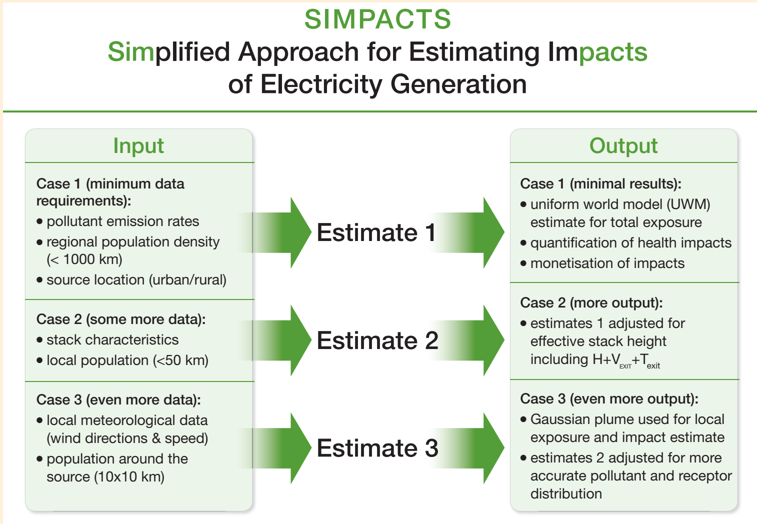
For airborne pollution, whether from fossil or nuclear plants, the model follows the impact pathway approach. The emission source is characterized, and an inventory of airborne releases is prepared. The changes in ambient concentrations of various pollutants are estimated using atmospheric dispersion and deposition models. Then, exposure response functions are used to relate the change in pollutant concentration to a physical impact on the relevant receptors.

For hydropower, the model offers a simplified approach to estimate the loss of land, population displacement, and emissions during construction from hydro dams as well as the impacts from dam failures.

The model allows a user to make a range of external cost estimates ranging from crude to accurate, depending on available data. An approximate estimate can be obtained with input on average population, plant characteristics and emissions. Given the high uncertainties involved in any estimation of external costs, SIMPACTS produces results well within the range of more complex models.

The nuclear assessment module includes impacts of routine emissions of radionuclides through four pathways: (1) direct inhalation of radionuclides in the air; (2) external irradiation from radionuclides immersed in clouds; (3) external irradiation from deposited radionuclides; and (4) ingestion of radionuclides in agricultural products.

The key stages for these pathways are: releases, transport, contamination, human exposure and health effects. The accidental emissions module uses expert judgement about the probability and magnitude of consequences and utilizes an expected risk aversion approach. Monetization of expected consequences gives the external cost.



Major input and output of SIMPACTS

The hydro module considers displaced population, loss of agricultural and forest land, impacts of dam failures, and emissions during construction, etc. The model provides an estimate for future hydro projects even if site specific information is not available. In such cases, it uses different reservoir models based on terrain characterisation to estimate inundated area and potential impacts. It also calculates expected loss of life and economic damage due to dam failure.

With these modules, SIMPACTS covers the major energy sources and most of the associated impacts on human health and the environment. Most important, it provides a simple but accurate tool for estimating external costs associated with electricity generation. The model can be used for comparing and ranking various options in terms of these external costs.

Indicators for Sustainable Energy Development (ISED)

The IAEA developed the framework for ISED in cooperation with the International Energy Agency (IEA), the European Environmental Agency (EEA), the European Commission's EUROSTAT and the United Nations Department of Economic and Social Affairs (UN-DESA) to:

- *Complement the efforts of the UN Commission on Sustainable Development (CSD) on Indicators for Sustainable Development (ISD), by providing a higher resolution to energy issues with a consistent set of energy indicators, and*
- *Assist Member States in capacity building necessary for elaborating sustainable energy strategies.*

Each of the indicators is relevant to the economic, social, environmental and institutional dimensions of sustainable development.

Indicators in the *social dimension* measure the impact that available energy services may have on social well-being. Social ISED describe issues related to accessibility, affordability and disparity in energy supply and demand.

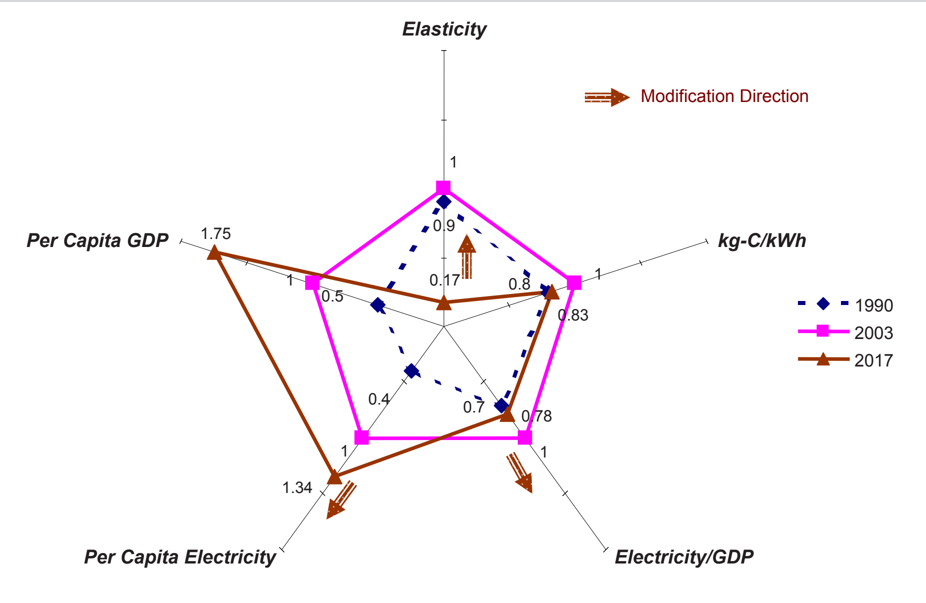
Indicators in the *economic dimension* measure the impact of energy supply and demand and the quality of energy services on the progress in economic development. Economic ISED include energy use, production and supply, energy supply efficiency and end-use energy intensity, energy pricing, taxation and subsidies, energy security, and energy diversity.

Tracing Sustainable Energy Paths

National teams from Bangladesh, China, India, Indonesia, the Republic of Korea, Mongolia, Myanmar, Pakistan, the Philippines, Sri Lanka, Thailand and Viet Nam, participated in an IAEA technical cooperation project on Tracing Future Sustainable Paths through Nuclear and Other Energy Options. The project assisted the countries in:

- *Establishing national indicators for sustainable energy development;*
- *Conducting a national study to assess the role of nuclear power and other energy options in a balanced development of the energy sector; and*
- *Providing policy recommendations to national authorities on response actions consistent with sustainable energy development.*

Each country identified development strategies for energy security, economic efficiency and environment protection. National ISED were used to evaluate whether energy development paths met the sustainability goals defined by the countries.



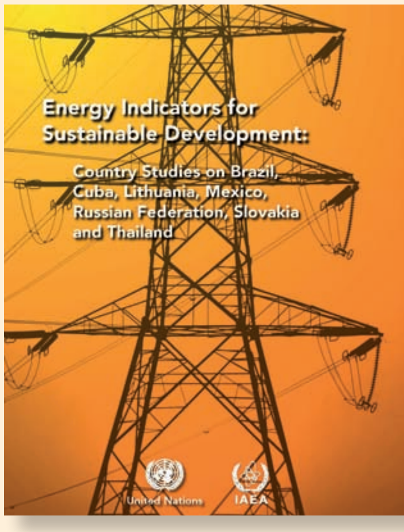
Republic of Korea: Assessment of sustainable energy development in the electricity sector

Indicators in the *environmental dimension* of sustainable development measure the impact of energy systems on the environment such as global climate change, air pollution, water pollution, wastes, land degradation and deforestation.

In addition, indicators in the *institutional dimension* assess the availability and adequacy of the institutional framework necessary to support an effective and efficient energy system. Institutional indicators are useful for linking and addressing the response actions and policy measures designed to influence trends in the social, economic and environmental dimensions despite the fact that they are difficult to measure in quantitative terms.

Experience Gained and Lessons Learned

A great deal of experience has been accumulated in the application of IAEA energy models and indicators for sustainable energy development. Energy analysts and planners in more than 115 countries are using these tools in national and regional studies to assess the potential contribution of nuclear energy in meeting long term energy needs and elaborate sustainable development strategies.



Indicators for sustainable development were developed and refined in a three year coordinated research project involving Brazil, Cuba, Lithuania, Mexico, the Russian Federation, Slovakia, and Thailand. Since then, ISED have been used in regional and national energy studies to analyse and evaluate alternative strategies and their conformity with sustainable development, including in a regional project in Asia, involving Bangladesh, China, India, Indonesia, the Republic of Korea, Mongolia, Myanmar, Pakistan, the Philippines, Sri Lanka, Thailand and Viet Nam.

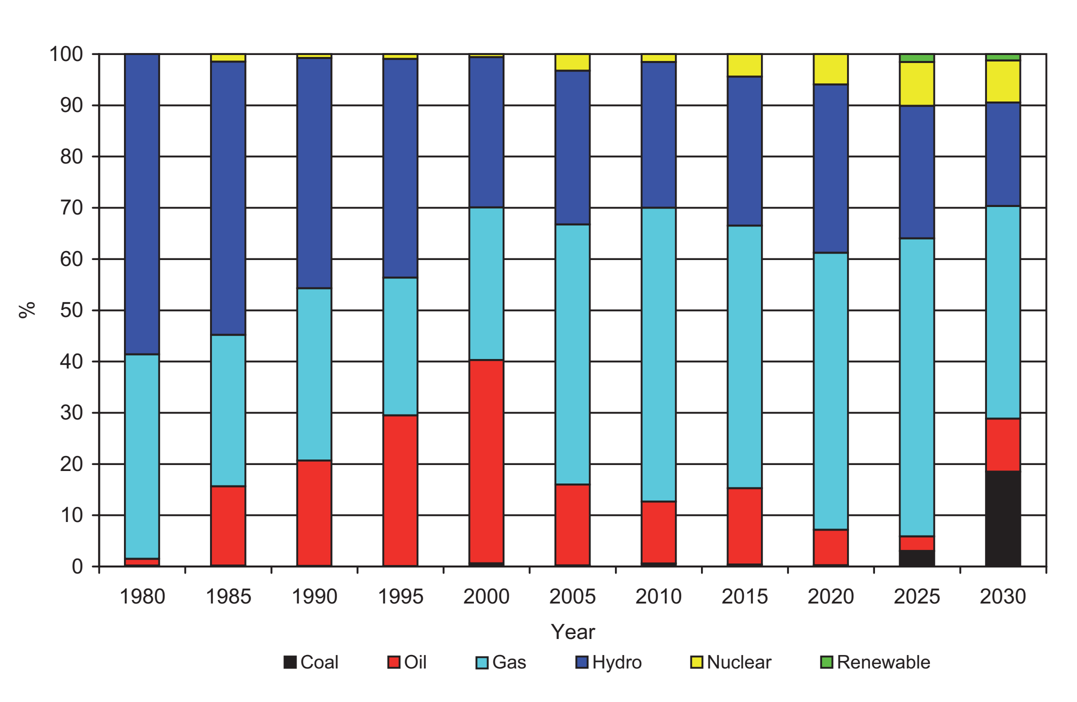
The IAEA has developed an extensive network of users who provide feedback and share lessons learned. This has helped in enhancing and upgrading these tools on a regular basis to meet widely diverse situations in Member States.

A Model Case of the Effective Use of Energy Tools for National Energy Planning

Energy experts in Pakistan used IAEA energy planning tools to carry out a landmark study in support of the Government's Energy Security Initiative.

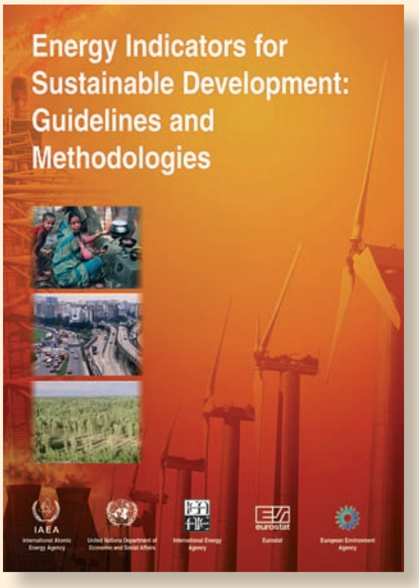
Using base year data of 2000, energy modelling in four different scenarios showed that to keep pace with demand, Pakistan needed to significantly increase net power generation capacity by 2030 — by as much as 147 000 MW. Substantial infrastructure investment was required, and modelling showed that if Pakistan continued to rely primarily on fossil fuels, it would become even more dependent on imported energy and would suffer tremendous environmental impacts.

Modelling 30 years ahead illustrated that expanding renewables, particularly hydro, and building nuclear capacity were the best options to minimize environmental impacts and increase energy security. However, both options have long lead times. In the nearer term, Pakistan's strategy remains oriented toward fossil fuels but with a greater diversity of sources (coal, oil and gas) and of suppliers, e.g. gas pipelines planned from Qatar, the Islamic Republic of Iran and Turkmenistan.



Example of the evolution of energy supply mix in Pakistan.

Related Publications



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Assessing Policy Options for Increasing the Use of Renewable Energy for Sustainable Development: Modelling Energy Scenarios for Sichuan, China, UN-Energy (2007).

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Comparative Assessment of Energy Options and Strategies in Mexico until 2025, Final Report of a Coordinated Research Project 2000-2004, IAEA-TECDOC-1469 (2005).

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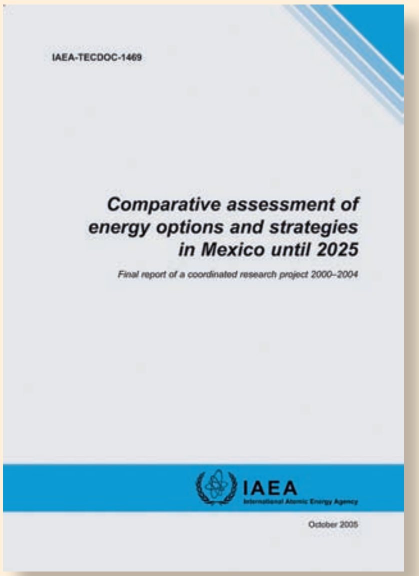

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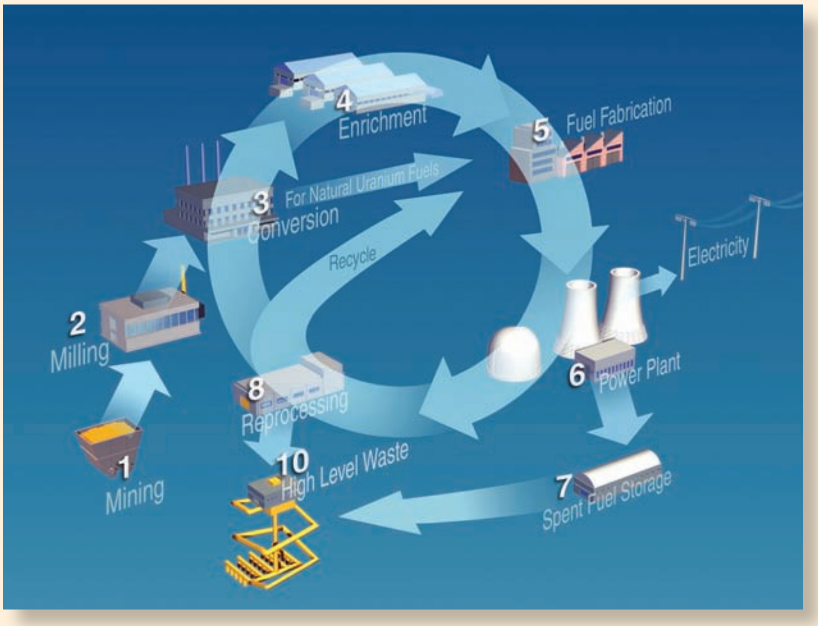
Nuclear Energy System Assessment (NESA) using the INPRO Methodology

Nuclear Energy Systems



Nuclear Fuel Cycle

A nuclear energy system (NES) includes the complete spectrum of the nuclear fuel cycle, i.e. mining, milling, conversion, enrichment of uranium and/or thorium, fuel fabrication, electricity generation or other energy products, e.g. steam or hydrogen, reprocessing to recover fissile material (in a closed fuel cycle), storage of reprocessed fissile material, recycle of fissile materials, waste treatment and stabilization, waste repository and final end states for all wastes, and associated institutional arrangements. These institutional measures may consist of agreements, treaties, national and international legal frameworks or regimes, and conventions, such as the Treaty on the Non-Proliferation of Nuclear Weapons, the Convention on Nuclear Safety, and IAEA safeguards agreements, as part of the national and international institutional infrastructure needed to deploy and operate a nuclear programme.

Nuclear energy systems encompass all systems that position nuclear energy to make a major contribution to global energy supply in the 21st century and may include evolutionary and innovative designs of nuclear facilities. An evolutionary design is an advanced designed that achieves improvements through small to moderate modifications, with strong emphasis on maintaining proven designs to minimize technological risks. An innovative design is an advanced design which incorporates radical conceptual changes in design approaches or system configuration, for example small and medium sized reactors or transportable nuclear installations without onsite refuelling. In addition to electricity generation, such systems may also include plants for other applications, such as high temperature heat production, district heating, hydrogen production, and sea water desalination, to be deployed both in industrialized and developing countries.

Assessing Nuclear Energy Systems

The IAEA supports Member States in strategic planning and decision making on nuclear power programmes. A NESA helps energy planners in Member States make informed decisions on the choice of the most appropriate nuclear system and to determine whether their strategic deployment plan is sustainable. The IAEA offers support in the application of a NESA using the INPRO methodology.

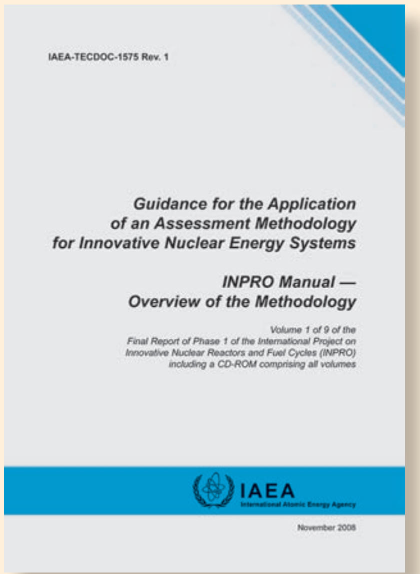
A prerequisite for a NESA is the existence of an energy planning study that defines the role of nuclear in a mix of energy supply on a national, regional or global level, depending on the goal of the assessment. IAEA energy planning models, introduced in the first part of this booklet, assist energy planners in undertaking such studies.

The assessment can be initiated by national authorities in charge of energy or nuclear energy system planning. It requires a team of individuals with cross-cutting expertise in the seven assessment areas defined by INPRO, and adequate knowledge of the nuclear facilities comprising the nuclear energy system. Such assessment teams can:

- *Assess a single nuclear energy system (or its planned deployment) to confirm that nuclear energy will contribute, in a sustainable manner, to the energy supply till the end of the century;*
- *Compare different nuclear energy systems to find a preferred one consistent with the sustainable development objectives of a given country;*
- *Indentify gaps in nuclear power development or installation programmes, leading to follow up actions such as R&D studies;*
- *Study the transition from a current operating nuclear system to a nuclear energy system with significant technical or institutional innovations.*

The INPRO methodology was developed specifically to determine whether or not a given nuclear energy system will contribute, in a sustainable manner, to meeting the energy needs of the 21st century or require R&D follow-up actions to achieve a sustainable nuclear contribution. It is a tool to assess nuclear energy systems and innovative technologies, encompassing all nuclear fuel cycle facilities during their lifetime in the assessment areas discussed below.

How to conduct a NESA using the INPRO methodology is described in detail in IAEA TECDOC 1575 Rev.1, *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems: INPRO Manual – Overview of the Methodology*, which is available at ***www.iaea.org/INPRO/Publications*** or can be ordered from the IAEA.



Users of NESAs

In general terms, these assessments are of benefit for both countries with established nuclear programmes, wishing to assess existing or future nuclear energy systems; and countries wishing to embark on new nuclear programmes who want to assess if possible future nuclear systems will contribute to meeting the sustainable development criteria of a country.

Given its comprehensive nature, a NESA with the INPRO methodology is targeted at:

- *Nuclear technology developers, to identify possible gaps in research and development, and associated actions to fill those gaps;*
- *Experienced nuclear technology users, to assist with strategic planning and decision making concerning the development of or expansion of a nuclear energy system;*
- *Prospective first time nuclear technology users to identify issues that need to be considered when deciding on the step by step development of a nuclear energy system (building a first nuclear power plant and developing the necessary infrastructure with support from the IAEA infrastructure team) for long term energy supply, and to assist such users in their planning and decision making.*

How the INPRO Methodology Works

The INPRO methodology is organized in a three tier hierarchy of

- *Basic principles*
- *User requirements*
- *Criteria, consisting of indicators and acceptance limits.*

At the highest level is a **basic principle**. This is a statement of a general goal to be achieved in a nuclear energy system and provides broad guidance for further research and development. An example in the area of nuclear safety is that *"a nuclear energy system shall incorporate enhanced defence-in-depth as part of its fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations"*.

At the second level is a **user requirement**, which sets out measures to be taken by the main stakeholders, i.e. designers/developers, owners/operators, government institutions, and industry, in order to meet the general goal of the corresponding basic principle. A user is an entity that has a stake or interest in potential applications of nuclear technologies and therefore an interest in applying the methodology or reviewing the results of an assessment. Users thus include:

- *Representatives of investors, R&D organizations, designers, power generators and utilities;*
- *Decision makers such as national governments, legislative and regulatory bodies, local organizations and authorities and NGOs;*
- *End users of energy (industry, public, etc.);*
- *Interested media;*
- *International organizations (e.g. IAEA, OECD-IEA, OECD-NEA).*

An example of a user requirement in the area of nuclear safety is the functional requirement that *"a major release of radioactivity from an installation of an nuclear energy system should be prevented for all practical purposes so that nuclear installations would not need relocation or evacuation measures outside the plant site, apart from those generic energy measures developed for any industrial facility used for similar purposes".*

The INPRO Methodology includes seven areas to assess a nuclear energy system for sustainability.

At the third and lowest level, an **INPRO criterion** (or several criteria) verify whether the main stakeholder, i.e. designer/developer, owner/operator or government institution, has met the user requirement. A criterion consists of an indicator specific for the assessed nuclear energy system and a corresponding acceptance limit. It is fulfilled if the indicator of the assessed nuclear energy system meets the corresponding acceptance limit.

Assessment Areas

Seven areas were identified by the methodology developers, which together encompass the dimensions of sustainable development: economics, infrastructure (institutional arrangements), waste management, proliferation resistance, physical protection, environment (impact of stressors and resource depletion) and safety of reactors and of nuclear fuel cycle facilities. For each of these assessment areas, one or several basic principles, user requirements and criteria with indicators and acceptance limits were defined.

Economics: The basic principle identified in the area of economics is that in order to contribute to sustainable development, energy and related products and services from a nuclear energy system must be affordable and available.

The corresponding user requirements demand that in order to be sustainable in a country or region,

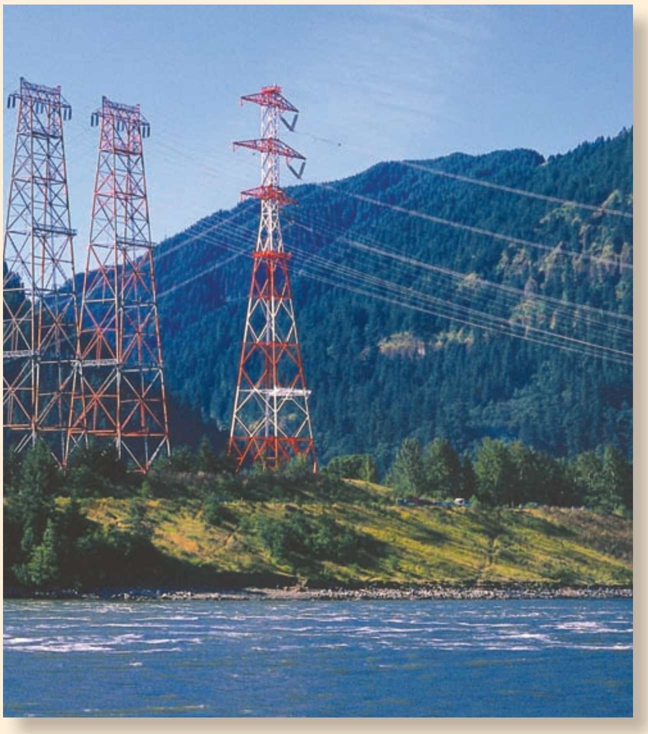
(1) Products of nuclear energy, i.e. electricity or heat, should be cost competitive with the cost of locally available alternative energy sources such as renewables, i.e. hydro, solar, wind or fossil plants;

(2) The total investment required to design, construct and commission a nuclear energy system can be raised, and the risk of investment is acceptable compared to investments in other energy projects;

(3) Innovative nuclear energy systems have the flexibility to meet requirements of different markets.

Both existing and new nuclear energy systems to be installed in the future can be assessed with these user requirements.

Infrastructure: The basic principle defined calls for a limited effort only that would be needed to establish and maintain an adequate infrastructure (institutional arrangements) in a country that intends to install or maintain a nuclear energy system. These efforts could be limited by future regional and international arrangements to be made available to such countries.



Electricity produced by nuclear power plants should be cost competitive with other local energy sources.

The corresponding user requirements recognize the need to establish and maintain a national legal framework including international obligations, to define the necessary industrial and economic infrastructure for a nuclear power programme, to determine appropriate measures to secure public acceptance, and to address the availability of adequate human resources.

In the area of infrastructure, the INPRO requirements are directed primarily at the government, the operator of a nuclear facility, and national industry involved in a nuclear power programme. The requirements are suitable to assess both an existing nuclear energy system and a new one.

Waste management: Four basic principles for waste management were derived from the nine IAEA Fundamental Principles of Radioactive Waste Management:

(1) Generation of waste shall be kept to a practicable minimum;

(2) Waste shall be managed so as to secure an acceptable level of protection of human health and the environment regardless of the time or place at which impacts may occur;

(3) Waste shall be managed in such a way that undue burdens are not imposed on future generations; and

(4) Interdependencies among all waste generation and waste management shall be taken into account.

Radioactive waste storage facility at Rokkasho-mura, Japan

These principles, in turn, lead to user requirements to minimize the generation of waste, in particular waste containing long-lived toxic components that would be mobile in a repository environment; to limit exposures to radiation and chemicals from waste; to specify a permanently safe end state for all wastes and to move wastes to this end state as early as practical; to classify wastes and to ensure that intermediate steps do not inhibit or complicate the achievement of the end state; and to accumulate assets for managing all wastes in the life cycle so that the accumulated liability at any stage of the life cycle is covered. These requirements can be used to assess existing and new, future nuclear energy systems.

Proliferation resistance: The basic principle for proliferation resistance requires that technical design characteristics (intrinsic features), such as easiness of inspection, and commitments of countries (extrinsic measures), such as safeguard agreements, always be implemented together in a nuclear energy system throughout the full life cycle.

The corresponding user requirements ask a country to establish and maintain an appropriate legal framework, and the designer to keep the attractiveness of nuclear material low, make diversion of nuclear material difficult and easily detectable, incorporate multiple barriers against diversion, and enable the implementation of cost effective safeguard measures by optimizing the design and engineering of nuclear systems.

Inspectors conducting a first survey of a nuclear facility

The requirements in the area of proliferation resistance are suitable to assess new nuclear facilities to be installed in the future. The legal framework of an existing nuclear energy system can also be evaluated.

Physical Protection: The basic principle requires the implementation of an adequate physical protection regime throughout the lifetime of an innovative nuclear energy system.

The corresponding user requirements are based on the fundamental principles of the amended convention on the physical protection of nuclear materials and facilities. They cover the four general areas of the physical protection regime: (1) legislative and regulatory framework; (2) siting, layout and design of nuclear facilities taking into account physical protection; (3) design of a physical protection system against malicious actions; and (4) planning of contingencies and mitigation of consequences of malicious actions.

The requirements for physical protection are primarily intended for assessments of new nuclear facilities to be installed in the future. Existing nuclear facilities can also be assessed, with the exception of siting, layout and design.

Environment: The basic principles related to the environment are:

(1) Acceptability of environmental effects, i.e. stressors caused by nuclear energy, and

(2) Capability of an innovative nuclear energy system to deliver energy while making efficient use of non-renewable resources.

Uranium mill at Key Lake, Saskatchewan, Canada

The two user requirements corresponding to the first environmental basic principle demand that environmental stressors, e.g., release and impact of radioactive substances from a new nuclear facility, be within national regulatory limits; also, the ALARP concept (as low as reasonable practicable, economic and social factors taken into account) should be applied.

The first user requirement demands that fissile and fertile materials, such as uranium, needed for the fabrication of nuclear fuel is available. Also, other materials needed for the construction and operation of a nuclear energy system, such as zirconium, must be available for a period of at least one hundred years. Such materials should be used more efficiently in nuclear facilities built after 2004, which is the reference point in time chosen by INPRO.

The second user requirement primarily calls for an adequate energy output in comparison to the energy needed to construct and operate a nuclear energy system.

Nuclear Safety: INPRO has developed four basic principles in the area of safety of nuclear installations based on the IAEA Fundamental Safety Principles, utility requirements such as EPRI Advanced Light Water Reactor Utility Requirements, and an extrapolation of current trends assuming a large increase of nuclear power in the 21st century.

The first basic principle, for a new facility, calls for an enhanced application of the concept of defence-in-depth (DID) in which different levels of protection are more independent of each other in comparison to a nuclear facility operating at the end of 2004 (reference design). The corresponding user requirements provide recommendations on how the designer/developer can achieve a higher safety level compared to the reference design, by intensified use of the DID concept in each of its five levels.

The second basic principle and the corresponding user requirement ask the designer to consider the increased use of passive systems and inherent safety features to eliminate or minimize hazards.

The third basic principle sets a high level goal by requesting the designer to reduce the level of risk from nuclear facilities due to radiation exposure of workers and the public, so that this nuclear risk is comparable to the level of risks arising from similar facilities of non-nuclear industries.

The fourth basic principle and its user requirements demand that a sufficient level of R&D be performed for new nuclear designs. This would bring the knowledge of plant characteristics and the capability of analytical tools to at least the same confidence level as in the reference design (a facility operating at the end of 2004). A NESA in the area of nuclear safety is primarily suitable for assessing new designs of nuclear facilities installed after 2004.

If the assessment points to a gap, follow-up actions such as additional R&D are defined and further studies should be undertaken to close such gaps. It is important to note that failure to meet all principles, requirements and criteria does not necessarily mean that a nuclear energy system should not be deployed in the interim. It may well be that the system as defined can make a significant contribution to meeting the energy needs of a country or region on an interim basis; however, in due course some facilities may need to be supplemented with additional components or phased out in favour of other ones.

Experience Gained and Lessons Learned

To date, six countries have performed national nuclear energy assessments: Argentina, Armenia, Brazil, India, the Republic of Korea and Ukraine. Eight countries participated in a joint international study: Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and Ukraine. The studies included both technology users and developers and different levels of assessments. Gaps in R&D, identified by the assessments are being closed through INPRO Collaborative Projects, which are currently undertaken with the participation of 22 INPRO members and seven additional IAEA Member States.

China's first experimental fast breeder

In 2008, the assessment studies were evaluated regarding their main technical results, recommended follow-up actions, benefits of performing a NESA, and improvements and ease of use of the INPRO methodology. In addition to an IAEA in-house evaluation, an IAEA technical cooperation workshop, held in February 2009, discussed the results of these studies and reached consensus on further actions to be performed within the INPRO project.

Assessment teams from both technology holder and technology user countries conducted NESAs to identify gaps in planned nuclear power development and installation programmes, and listed follow-up actions to close these gaps.

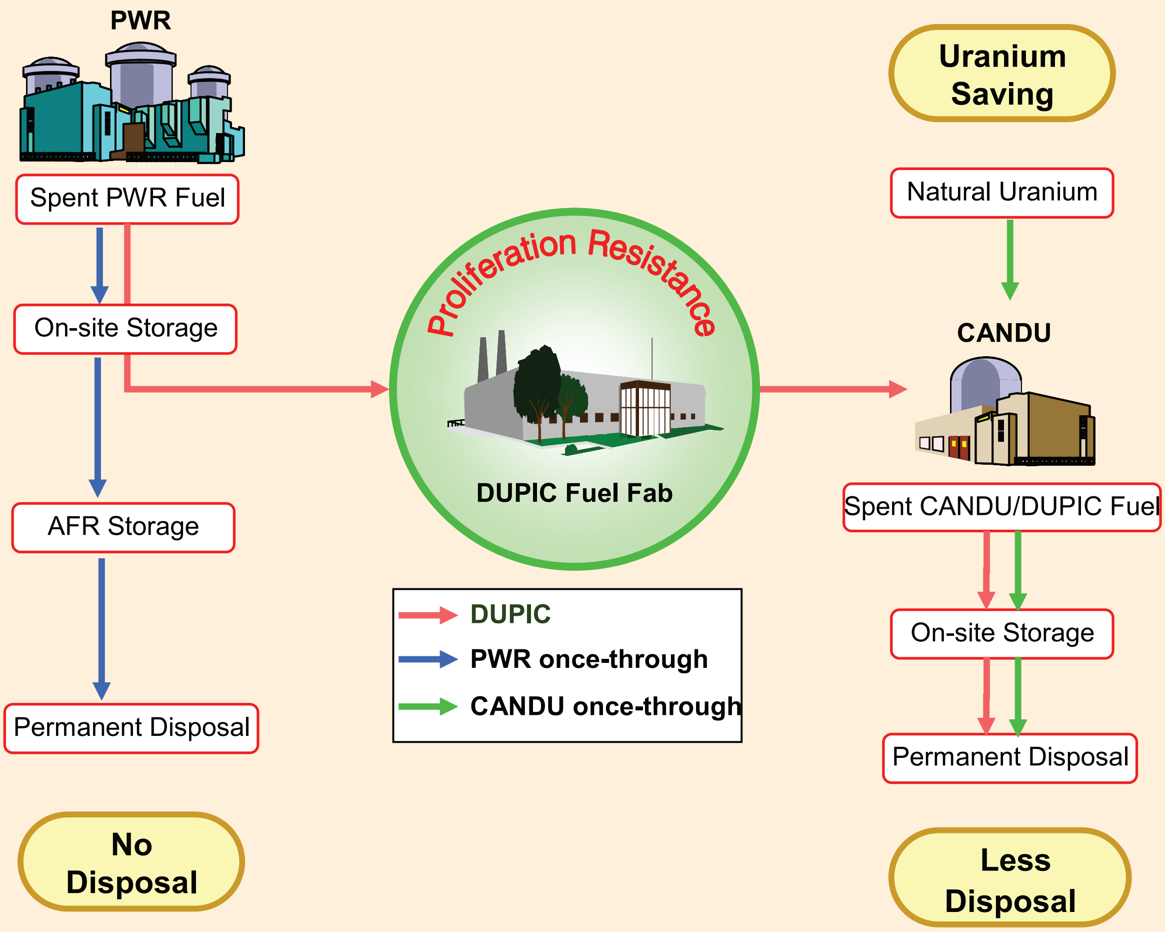
NESAs in technology developing countries confirmed that the ongoing national nuclear energy development programme is sustainable. Also, knowledge gained about similar development programmes in other countries highlighted some key global issues, such as availability of plutonium for fast reactors. The application of the INPRO methodology identified gaps in the development programme that required Member States to reprioritize R&D work.

Technology user countries with existing nuclear power programmes compared different reactor options to expand their nuclear power programme in the future, and considered the advantages and disadvantages of these options in all INPRO assessment areas.

Technology user countries with limited nuclear experience found that conducting a NESA helped them to better understand all issues associated with the establishment of a nuclear power programme that meets sustainable development criteria. Also the assessment increased the knowledge base of key decision makers and stakeholders in examining all aspects of the decision to deploy nuclear energy.

National Assessment Studies

Argentina and Ukraine (see description below) evaluated the sustainability of their planned national nuclear energy systems by assessing all facilities of the nuclear fuel cycle and performing comprehensive NESAs in all assessment areas.



The NESA by the Republic of Korea assessed the proliferation resistance of the DUPIC fuel cycle.

Brazil, India and the Republic of Korea assessed specific reactor designs and associated fuel cycles in selected areas of the INPRO methodology. The Brazil team (see box on p.age 26) chose the IRIS reactor design and assess it in the areas of safety and economics; the Fixed Bed Nuclear Reactor (FBNR) design was assessed for sustainability in the areas of safety and proliferation resistance. The Indian study investigated the replacement of fossil fuel by hydrogen in the transportation sector. The prime objective of the study by the Republic of Korea was to develop a qualitative analysis to determine the level of proliferation resistance of the DUPIC fuel cycle, where spent PWR fuel is transformed into new fuel for CANDU reactors.

Armenia performed a NESA primarily to familiarize national decision makers with all issues of the planned nuclear power programme of replacing the existing reactor by a larger unit around 2025.

Examples of National Nuclear Energy System Assessments

Brazil

The national energy policy, based on an evaluation of current energy supply and future growth in energy demand, predicts that nuclear power supply may quadruple to 5300 MW(e) by 2030. Using data from this national energy evaluation, the Brazilian assessment team evaluated specific reactor designs and associated fuel cycles in the INPRO assessment areas of economics, proliferation resistance and safety. Due to ongoing R&D work in Brazil, the national assessment team chose two reactor designs for the NESA: the IRIS reactor design was assessed in the areas of safety and economics, while the Fixed Bed Nuclear Reactor (FBNR) design was evaluated in the areas of safety and proliferation resistance. The safety assessment confirmed that the IRIS design achieves a high level of safety; a similar safety level is predicted for the FBNR design, which is at an early design stage. For the economic assessment of IRIS, a new modular design was compared with ANGRA-3, a large nuclear power plant in Brazil. The assessment indicated that three modules of IRIS are economically more viable than installing a single large unit. The proliferation resistance of the FBNR design was also found to be high. The assessment team defined further R&D work for both designs, to be undertaken before commercial application can be envisaged.

ANGRA-3 nuclear power plant, Brazil (Photo: Eletronuclear, Brazil)

Ukraine

In a comprehensive energy planning study, Ukraine defined the role of nuclear power until the year 2030. Nuclear power is expected to increase its capacity to 30 000 MW(e) until 2030, which is more than double the 2005 capacity (13 100 MW(e)). Ukraine assembled an assessment team including experts in each of the INPRO assessment areas. The team investigated 14 options of a future nuclear energy system. The evaluation focused on different types of new reactors (WWER1000, EPR, AP1000, AES2006) and the national fuel cycle, i.e. the use of national production facilities, such as producing fuel elements in a national facility with imported enriched UF6, or leasing fuel elements from a foreign supplier. The results of the NESA were numerically aggregated, and the 14 options were compared taking into account the level of maturity of individual nuclear facilities. The study identified the strengths and weaknesses of each option; leasing fuel elements from a foreign supplier was identified as the optimal solution for the country.

Zaporizhzhe nuclear power plant, Ukraine, (Photo: Energoatom, Ukraine)

Joint Assessment Study

In a joint international study, Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation, and Ukraine assessed a nuclear energy system consisting of sodium cooled fast reactors with a closed fuel cycle (CNFC). The study concluded that a comprehensive programme of R&D is essential in several areas, especially economics and safety. It should include an interdisciplinary approach and international collaboration to make an energy system consisting of fast reactors with a closed fuel cycle a viable alternative to conventional sources of power. Based on the joint study, several INPRO Collaborative Projects related to fast reactors are now under way.

Related IAEA Publications

Lessons learned from Nuclear Energy System Assessments (NESAs) using the INPRO Methodology, IAEA-TECDOC (2009).

Status and Trends of Nuclear Technologies – Report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1622 (2009).

Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy Systems: Report of Stage 1, IAEA Nuclear Energy Series No. NP-T-2.1, STI/PUB/1380 (2009).

INPRO Joint Assessment Study on the Innovative Nuclear System based on Closed Fuel Cycles with Fast Reactors (2009).

International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO): 2008 Progress Report.

Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Overview of the Methodology (Volume 1–9), Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1575 Rev1 (2008).

Proceedings of International Conference on Innovative Technologies for Nuclear Fuel Cycles and Nuclear Power Vienna, 2003, (IAEA-CN-108).

Methodology for the Assessment of Innovative Nuclear Reactors and Fuel Cycles: Report of Phase-1B of INPRO, IAEA-TECDOC-1434 (2004).

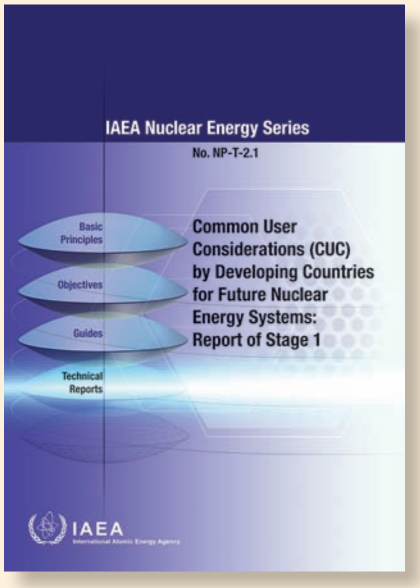
Guidance for the Evaluation of Innovative Nuclear Rectors and Fuel Cycles: Report of Phase 1A of INPRO, IAEA-TECDOC-1362 (2003).

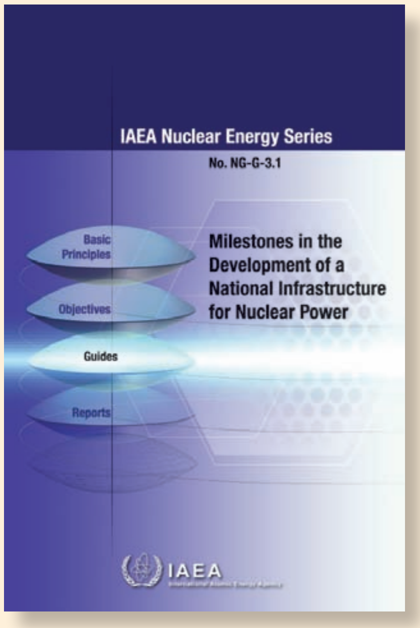
INIR — Integrated Nuclear Infrastructure Review Missions: Guidance on Preparing and Conducting INIR Missions (Booklet, 2009).

Evaluation of the Status of National Nuclear Infrastructure Development, IAEA Nuclear Energy Series No. NG-T-3.2, STI/PUB/1358 (2008).

Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series No. NG-G-3.1 (2007).

Considerations to Launch a Nuclear Power Programme (Booklet, 2007).





IAEA Assistance and Support

Energy Systems Planning

The IAEA provides technical assistance to its Member States, in particular to developing countries, to improve their capabilities for performing integrated energy assessments. These studies assist in formulating long term strategies for sustainable energy development and assessing the possible role of nuclear power in meeting future energy needs. Assistance from the IAEA comprises:

- *Transferring energy assessment methods and analytical tools*
- *Training for energy model set-up and application*
- *Interpreting, synthesizing and applying model outputs to policy formulation.*

Assistance is provided through a range of programmes that aim at specific aspects of capacity building in energy analysis and planning:

Technical cooperation (TC) projects: Each TC project in the area of sustainable energy development is tailored to a country's specific needs. A typical project includes assessment of future energy and electricity needs, technical, economic and environmental evaluations of all energy supply options, and the formulation of medium to long term energy strategies. Projects build local capabilities by transferring IAEA analytical tools and providing training and guidance in the use of the tools for national energy planning studies.

Regional and national workshops and training courses: The IAEA organizes regional and national workshops and training courses on the use of its energy models, including topical and specialized lectures, group discussions and work sessions. Each workshop or training course focuses on one model and is designed to provide an understanding of the methodology and train participants in collecting and compiling input data, operating the model, interpreting results and synthesizing policy recommendations. In addition, the IAEA organizes training for trainers to expand the pool of experts who contribute to regional and national workshops on energy and also assist in the application of IAEA energy models for national energy studies.

Recently, the IAEA has initiated distance learning programmes for capacity building.

Coordinated research projects (CRPs): These projects promote research to acquire new knowledge, experience, data and information related to approved technical programmes of the IAEA. The CRPs in the field of energy focus on new or improved methods for (1) analysing nuclear power's economic and environmental effectiveness compared to other technologies, (2) analysing sustainable energy development and climate change, and (3) updating and expanding key databases and tools necessary for such specific needs.

Nuclear Energy System Assessments Using the INPRO Methodology

The IAEA offers support to Member States in conducting NESAs using the INPRO methodology and has developed a NESA Support Package for Member State use.

The NESA Support Package includes a wide range of possible assistance including a kick-off meeting to start a NESA which addresses:

- *Required technical expertise to perform a NESA;*
- *Benefits for and contributions from a nuclear 'newcomer' country;*
- *Benefits for and contributions from a technology user country;*
- *Benefits for and contributions from a technology developing country;*
- *Full documentation of the INPRO methodology;*
- *Relevant examples and experience gained to date in performing nuclear energy system assessments.*

Also, the IAEA provides training material and courses in using the INPRO methodology and organizes assistance missions to Member States for data collection and evaluation. In addition, the IAEA offers assistance in establishing a technical database for input data (e.g. design information) and provides expert support in performing a NESA and evaluating the final results.

Angra-2, Brazil (Photo: Eletronuclear, Brazil)

Kudankulam nuclear power plant, India

APPENDIX: About INPRO

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established in 2001 as a commitment of IAEA Member States to help ensure that nuclear energy is available to contribute, in a sustainable manner, to meeting the energy needs of the 21st century.

It plays an important role in understanding the future development of nuclear energy systems from a national, regional and global perspective, and the role of innovations in technologies and institutional arrangements in support of this development.

INPRO provides a forum for discussion and cooperation between experts and policy makers from industrialized and developing countries on all aspects of sustainable nuclear energy planning, development and deployment. INPRO promotes a mutually beneficial dialogue between countries with nuclear technology and countries considering these technologies to develop new nuclear energy capacity. It also provides support to national strategic planning and decision making and an awareness of technology innovation options for the future.

Working in partnerships

Over the years, membership in INPRO has grown to 31 members and today includes: Algeria, Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, the Czech Republic, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Kazakhstan, Morocco, the Netherlands, Pakistan, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, the USA and the European Commission.

Ten other countries are participating on a working level or have observer status as they consider membership. In addition, INPRO is working in synergy with other international initiatives including the Generation IV International Forum (GIF) and the Sustainable Nuclear Energy Technology Platform (SNETP).

INPRO Members (in grey)

More information on INPRO is available at ***www.iaea.org/INPRO***.

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