Nuclear Development

Nuclear Energy in a Sustainable Development Perspective

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

This publication is intended to assist governments in assessing the extent to which nuclear energy is compatible with the goals of sustainable development and how it can best contribute to them. It provides a review of specific characteristics of nuclear energy from the economic, environmental and social viewpoints of sustainable development, focusing on key issues of relevance for policy makers.

The document does not prejudge the policies of individual Member countries towards nuclear energy. It provides data and analyses on the nuclear option that policy makers may use together with information on alternative options to support their own assessments, trade-offs and choices in the energy field, taking into account national context and priorities.

The publication is a contribution from the Nuclear Energy Agency (NEA) to the OECD project on sustainable development. It was prepared by the NEA Secretariat, with the assistance of experts in the fields of nuclear policy, economics, the environment and sustainable development. The text benefited from comments and suggestions from all relevant NEA Standing Technical Committees as well as experts from other OECD Directorates and the International Energy Agency. It is published under the responsibility of the Secretary-General of the OECD.

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EXECUTIVE SUMMARY

This document is a contribution from the Nuclear Energy Agency (NEA) to the OECD Project on Sustainable Development. It provides information on nuclear energy relevant for policy making within a sustainable development framework. In this context, the specific characteristics of nuclear energy are reviewed from the economic, environmental and social viewpoints of sustainable development. The report deals with nuclear energy, and provides data and analyses on the nuclear option that policy makers may use, together with information on alternative options, to support their assessments taking into account their specific context and priorities.

The intent of the document is not to arrive at judgements as to whether or not nuclear energy can be considered a sustainable technology in particular situations or countries as this will depend on a wide range of factors, many of them specific to local situations. Furthermore, the document does not prejudge the policies of individual Member countries towards nuclear energy.

The intent is to identify the main impacts of nuclear energy in a sustainable development perspective, to outline some of the factors that should be considered in assessing the contribution that nuclear energy can make to sustainable development goals, and to underline the challenges that must be overcome in order to make the contribution of nuclear energy positive. The data and analyses represent the co-operative efforts of the NEA Secretariat supported by the relevant NEA Standing Technical Committees and other experts. In this context, it should be noted that the results from the analysis of nuclear energy characteristics within a sustainable development framework may vary considerably depending on specific value preferences and circumstances. Therefore, some of the information contained in this report may not lead to the same conclusions in all Member countries.

The concept of sustainable development was elaborated in the late 1980s and defined by the Brundtland Report as “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. In a broad sense, sustainable development incorporates equity within and across countries as well as across generations, and integrates economic growth, environmental protection and social welfare. A key challenge of sustainable development policies is to address those three dimensions in a balanced way, taking advantage of their interactions and making relevant trade-offs whenever needed.

A central goal of sustainable development is to maintain or increase the overall assets (natural, man-made and human or social assets) available to future generations. The development of nuclear energy broadens the natural resource base useable for energy production, and increases human and man-made capital. The framework of regulatory, institutional and technical measures already in place in OECD countries aim at ensuring that the use of nuclear energy does not reduce irreplaceable natural assets significantly. Maintaining this framework is essential to address social and environmental concerns. To the extent that these concerns are addressed successfully, the nuclear industry, and the scientific knowledge and institutional infrastructure that support it, can represent an asset for present and future generations.

Technology is critical to support economic development but needs careful control and monitoring to be consistent with the social and environmental goals of sustainable development. In the energy field, services are needed to support economic development and increase social welfare but energy production and use, by any source or technology, has the potential for negative impacts on human health and the environment. Environmental and social burdens have to be minimised in order to achieve sustainable development goals.

Economic competitiveness is a prerequisite for a technology to contribute to sustainable development. Assessments of competitiveness, ideally, should be based upon comparisons of full costs to society including social and environmental costs. Most existing nuclear power plants are competitive by current standards, including those of deregulated electricity markets, since their marginal costs of production are low compared with fossil-fuelled alternatives. This competitive position is robust from a sustainable development perspective since most health and environmental costs of nuclear energy are already internalised. For example, electricity consumers are paying for nuclear safety and insurance against nuclear accidents, decommissioning of nuclear facilities, and radioactive waste disposal.

New nuclear units will have to compete within a broad range of alternatives, including fossil fuels, renewables and demand management, on the basis of full generation costs – i.e. capital, operation, maintenance and fuel costs. The large capital costs of nuclear power plants create financial risks, especially in deregulated markets, and make its competitiveness very sensitive to the discount rate applied when selecting investments. Ongoing R&D efforts to lower capital costs of nuclear power plants should be pursued to achieve significant results. Low discount rates are more favourable to capital intensive projects such as nuclear energy facilities and reflect a preference for the future that may be considered to be in line with the goal of sustainable development. The future competitiveness of nuclear energy will be affected by values placed in each country on environmental resources, such as global climate and local air quality, and social objectives, such as diversity and security of energy supply. However, technology choices in the energy sector will be based largely on market competition and the value of different energy sources for sustainable development will need to be recognised by adequate policy measures.

Nuclear energy has an ample resource base. Current reserves are large enough to support nuclear fuel production for decades. Since the cost of nuclear fuel is a small proportion of the cost of nuclear electricity, higher fuel prices could make much greater resources available without materially affecting the competitive position of nuclear power. Furthermore, the resource base for nuclear energy can be extended through recycling of fissile materials and implementation of advanced fuel cycles that convert fertile uranium and thorium into fissile materials. In broadening the base of natural resource capital, nuclear energy is consistent with the objectives of sustainable development related to the creation and effective use of natural assets and their preservation for future generations.

Finding effective policies to respond to climate change is one of the challenges to sustainable development. Nuclear energy is essentially carbon-free and contributes to reducing anthropogenic emissions of greenhouse gases that induce global warming as well as local atmospheric pollution. Although there are a number of technical options and policy measures available to alleviate or mitigate the risks of global climate change, stabilising carbon dioxide concentration in the atmosphere is likely to require comprehensive policies taking advantage of a range of technologies and economic and regulatory measures. Including the nuclear energy option in the basket of tools aiming at addressing climate change issues is consistent with the precautionary principle and sustainable development objectives.

The record in OECD countries after several decades of commercial use of nuclear energy suggests that, in normal operation under independent and effective regulation, nuclear power plants and fuel cycle facilities have relatively small health and environmental impacts. Radiation protection regimes based upon the "as low as reasonably achievable (ALARA)" principle have been generally effective in limiting the impacts of radiation, to workers in nuclear facilities and to the public, to levels below regulatory limits, which are set conservatively.

Radioactive releases from nuclear facilities are very small in routine operation and a significant threat to worker and public health may occur only under accident conditions. Severe accident is a major concern that is addressed by nuclear safety regulations and measures. Nuclear safety objectives, based upon the precautionary principle, have been strengthened progressively and the lessons learnt from the two severe accidents that have occurred with nuclear reactors – Three Mile Island in 1979 and Chernobyl in 1986 – have led to significant improvements. The potential hazards from nuclear accidents and the probability of such accidents can be further reduced by technological modifications, manpower qualification and training, accident management measures and enhanced regulatory effectiveness.

Radioactive waste from the nuclear energy sector represents small volumes that can be isolated from the biosphere at acceptable costs but raise significant public concern. Repositories for the disposal of short-lived radioactive waste are in operation in many countries. For long-lived radioactive waste, the nuclear industry has always had the goal of containing them safely over the very long periods of time during which they may present a hazard. This ambitious goal, which is consistent with the objective of sustainable development, is seen by experts as technically and economically achievable. For several decades, adequate safe interim storage is in place. For the long term, several options may be considered but geological disposal has been recognised as a strategy responsive to fundamental ethical and environmental considerations in several OECD countries. The implementation of repositories, in ways discussed with and accepted by the public, will be a major step towards meeting sustainable development goals.

The risk of nuclear weapon proliferation is a major concern raised in connection with peaceful applications of nuclear energy although the international non-proliferation and safeguards regime has proven to be highly effective so far. Moreover, since proliferation of nuclear weapons is driven primarily by political incentives and concerns, the goals of non-proliferation must be achieved primarily through political means. It should be noted that most countries who choose to acquire nuclear weapons did so through dedicated, often clandestine, military facilities rather than through diversion from civilian nuclear power programmes, that are mostly under international safeguards. Nonetheless, diversion from civilian programmes is one possible route to the acquisition of fissile material, a crucial technical step towards weapons. Accordingly, the non-proliferation regime must be extended to ensure a very high likelihood of detecting, and hence deterring, any such diversion. This is particularly important as nuclear power programmes spread to new regions and countries.

Nuclear energy is based upon major scientific developments of the 20th century that add to the stock of man-made, human and social capital available to future generations. Because much of the cost of nuclear facilities is embodied in science and technology, rather than resources, nuclear energy is amenable to continuous improvement in performance and safety through R&D and through developments in information, technology and effective training. The scientific and technical knowledge, industrial experience and regulatory framework and institutions that ensure quality in design, operation and regulation of nuclear activities constitute a valuable human and social capital. In countries where nuclear energy is used, it provides opportunities for highly qualified employment and enhances diversity and security of energy supply.

Addressing public concerns is essential to meet the social objectives of sustainable development. For this purpose and in the light of the widespread public concern about nuclear risks, it is necessary to include the public in a democratic decision-making processes through which it gains confidence that its concerns are being heard and addressed. The implementation of nuclear energy projects requires a participation of the public at the national and local level, and the exchange of a broad range of information and perceptions covering scientific, technical, economic and social aspects. It is important to allow the public to put social, ethical and political issues related to nuclear energy into perspective with the issues raised by alternatives, including the different liabilities passed to future generations such as long-lived radioactive waste, climate change or resource exhaustion. It is the responsibility of governments to create the conditions for decision-making processes to be consistent with inter-generation equity and the social objectives and environmental protection goals of sustainable development.

Nuclear energy contributes nearly a quarter of the electricity consumed in OECD countries and with several decades of industrial experience has reached commercial maturity. There are some 350 nuclear units connected to the grid in OECD countries, most of which will stay in operation for more than one decade. In the medium term, energy and electricity demand will grow mainly in non-member countries and nuclear energy development will increasingly occur in those countries. Governments of OECD Countries will have an important role to play with regard to technology transfer, technical assistance and co-operation in the nuclear energy field to ensure that sustainable development goals are taken into account.

Sustainable development policies in the energy sector will rely on comparative assessment of alternative options taking into account their economics, health, environmental and social impacts, at local, regional and global levels. While the NEA may assist Member countries through systematic and in-depth work on indicators applicable to nuclear energy from a sustainable development perspective, broader horizontal work within OECD would be required to establish a comprehensive framework to assess and compare energy alternatives. It would also provide guidance on internalising external costs in a consistent way, so as to allow market mechanisms to be consistent with sustainable development.

National policy decisions result from trade-offs within each dimension of sustainable development and between those dimensions. Trade-offs are based upon factual data but reflect specific socio-economic and political conditions of each country. The overall energy context, environmental sensibility, historical and cultural evolution and political approaches are different from country to country and will affect trade-offs and decisions.

1. INTRODUCTION

This document is a contribution of the OECD Nuclear Energy Agency (NEA) to the OECD three-year project on sustainable development. Its main objectives are: assessing to what extent nuclear energy is compatible with the goals of sustainable development and how it can best contribute to them; and identifying areas where, and means whereby, nuclear energy must overcome challenges in order to contribute more effectively to sustainable development. The document intends to raise relevant issues in order to facilitate discussions of nuclear energy in the overall policy-making framework and should help to establish the linkages between nuclear energy and sustainable development.

The present chapter introduces the report and situates nuclear energy in the context of electricity and energy capacity and growth in the world today. Chapter 2 presents briefly the framework and key concepts of sustainable development that are addressed in more detail in the OECD Analytical Report. Chapter 3 outlines the characteristic features of nuclear energy and their links to sustainable development goals in terms of economic, environmental and social dimensions. Chapter 4 outlines key issues and findings.

The OECD project

The OECD three-year horizontal project on sustainable development was launched by OECD Ministers in April 1998. OECD Ministers called for the elaboration of the Organisation's strategy "in the areas of climate change, technological development, sustainability indicators and the environmental impact of subsidies". They also asked the OECD to "enhance its dialogue with non-member countries and to engage them more actively" [1]. The project offers an integrated framework to address policy issues of interest to governments of OECD countries, including their interactions with the industry and non-member countries. It aims at substantive outputs for the meeting of OECD Ministers in 2001. The project outcomes will include a Policy Report to Ministers, an Analytical Report and a series of Background Reports, such as this one, based on the work of various OECD Directorates and affiliates.

The OECD project aims at making the sustainable development concept operational for public policies and should help Member countries to address fundamental sustainable development issues [2]. The sustainable development framework referred to within the OECD project will integrate economic, social and environmental factors in a way that will meet society's concerns at the lowest cost, and will highlight the linkages and trade-offs between these areas. This framework also reflects the need for equity within and across countries, as well as intergenerational equity.

In this context, the traditional emphasis of the OECD and its Member countries on economic growth will have to be balanced by concerns for environmental and social factors. The OECD project emphasises the need to integrate policies horizontally across a range of sectors and disciplines. It will investigate the key role of energy services in social and economic development and the integration of health and environmental concerns in energy supply strategies contributing to meet sustainable development goals. As noted above, this document is the contribution of the NEA to that effort.

Audience, objectives and scope

The primary audience for this document is policy makers within the OECD and in Member country governments. Governments still have an essential role in setting overall policies, establishing health and environmental regulation, and looking at the long-term implications of current decisions and actions, even though their role may be declining as the world moves to greater reliance on market forces. The document will also be of interest to the nuclear, energy and environment policy communities, as well as to a broader public of interested and affected parties. In order to provide readers, including those who are not experts in nuclear energy matters or not familiar with sustainable development concepts, with a stand-alone document, a broad range of information is given with emphasis on policy issues but covering technical and economic aspects whenever relevant.

The document aims at reviewing nuclear energy in the light of sustainable development goals. It will be relevant primarily for those governments that wish to consider nuclear energy within their portfolio of options for future supply. However, other Member countries may also find the document interesting, as nuclear issues have many international and trans-boundary implications.

The intent of the document is not to arrive at judgements as to whether or not nuclear energy can be considered a sustainable technology in particular situations or countries as this will depend on a wide range of factors, many of them specific to local situations. Furthermore, the document does not prejudge the policies of individual Member countries towards nuclear energy.

The intent is to identify the main impacts of nuclear energy in a sustainable development perspective, to outline some of the factors that should be considered in assessing the contribution that nuclear energy can make to sustainable development goals, and to underline the challenges that must be overcome in order to make the contribution of nuclear energy positive. The data and analyses represent the co-operative efforts of the NEA Secretariat supported by the relevant NEA Standing Technical Committees and other experts. In this context, it should be noted that the results from the analysis of nuclear energy characteristics within a sustainable development framework may vary considerably depending on specific value preferences and circumstances. Therefore, some of the information contained in this report may not lead to the same conclusions in all Member countries.

The concepts of sustainable development that are described in this document are intended to reflect the OECD approach. They are based mainly upon OECD publications, on-going work, and contributions from OECD directorates and affiliates that were provided through discussions and comments on successive drafts of the report. Other authoritative published work and expert views have been used to complement the OECD documentation. The introduction of those concepts serves as a backdrop for assessing the major characteristics of nuclear energy in terms of sustainable development goals and criteria, with respect to economic, environmental and social factors.

All the major aspects of nuclear energy and their links to sustainable development are reviewed, however briefly. The analysis of nuclear energy per se is supported essentially by work carried out within the NEA, but other sources have been used also when relevant. The sources of the information included in the document are quoted either in references or in the bibliography. The analysis is not supported by original research but relies on available information and contributions from Member country experts and policy makers who were consulted throughout the elaboration of the report.

Work on indicators of sustainable development is ongoing and may lead eventually to aggregated indicators applicable to all activities and industrial sectors. Several organisations, including the OECD, are actively involved in the elaboration of harmonised indicators and a framework that could serve as a basis for analyses and assessments in various sectors. The assessment of nuclear energy from a sustainable development perspective eventually will have to be based upon a set of indicators applicable to the nuclear sector agreed upon within an overall harmonised framework. In the meantime, indicators specific to the nuclear sector have been used in this document to illustrate, in so far as feasible, trends towards sustainable development.

Although alternative energy options must be assessed comparatively in a sustainable development context, this document does not embark on comparative assessment in the light of the NEA's limited expertise in broad energy technology and policy. If the OECD and the IEA would undertake such comparative studies of benefits, costs, risks and impacts, the NEA could contribute on relevant nuclear issues and this document could be a preliminary contribution to such an undertaking.

Sustainable development and energy

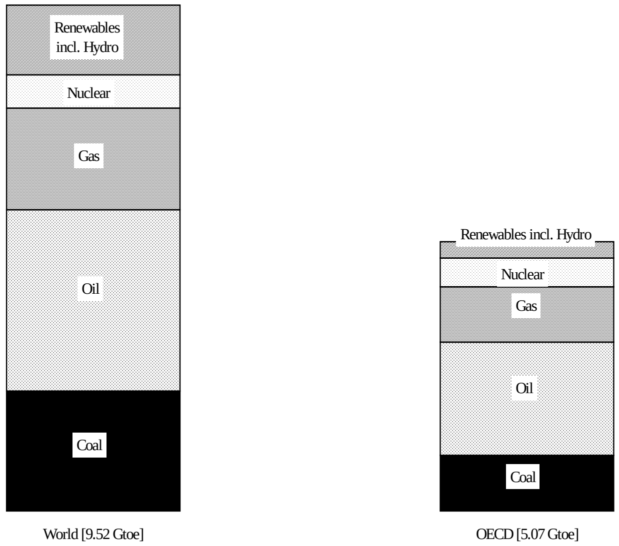
Energy has links with the three dimensions of sustainable development – economic, environmental, and social. Energy services are essential for economic and social development. As energy use will continue to grow, its health and environmental impacts will have to be controlled, alleviated or mitigated in order to achieve sustainable development goals. The main challenge of sustainable development in the energy sector is to extend the benefits of energy services to the world as a whole, and to future generations, without undermining the essential life support systems or the carrying capacity of the environment. Supply technologies, such as nuclear energy, have a role to play in this context.

Energy is the physical driving force, the lifeblood, of modern civilisation. Energy services are essential for human welfare, and contribute to enhanced social stability through improved standards of living. Energy is a critical input to economic development and prosperity. Although the energy intensity of modern economies is decreasing progressively, large amounts of energy will be needed to improve standards in the developing countries. The energy sector itself occupies an important part of the world economy in terms of jobs, income and trade.

Citizens of the OECD countries consume the bulk of the energy – more than half of the primary energy produced in the world, and more than 60% of the electricity generated, are used in OECD countries [3]. On the other side, two billion people from non-member countries have no access to electricity, and two billion others cannot afford amenities such as refrigeration and hot water [4,5].

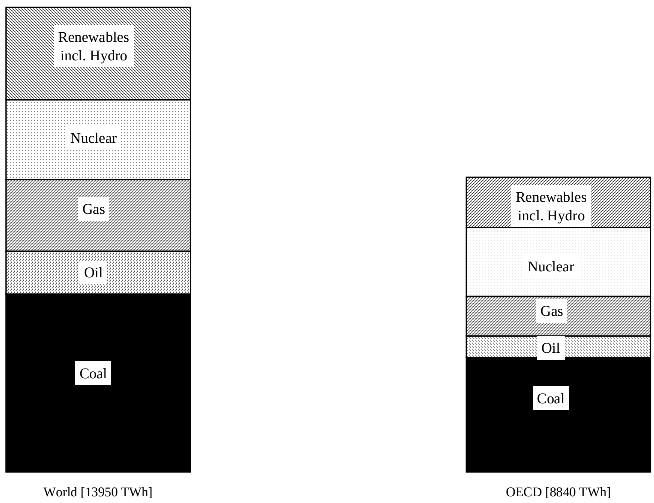
Fossil fuels are by far the most important source, supplying about 80% of the world's primary energy consumption, as shown in Figure 1.1, while nuclear energy provides some 7% of the total. On average, each person on the planet uses about 1.3 tonnes of oil equivalent (toe) of fossil fuels each year, for a total of 7.6 billion toe. In OECD countries, the respective shares of fossil fuels and nuclear energy are 83% and 11%. The share of fossil fuels in primary energy supply is expected to increase even further over the next few decades under business-as-usual scenarios [6].

Figure 1.1 **Primary energy consumption by source in 1997**
Source OECD/IEA Energy Balances of non-OECD countries – 1999 Edition [7]



Electricity generation represents about 37% of total primary energy use in the world and 39% in the OECD countries. The average electricity consumption in OECD countries is around 7 500 kWh per capita but only 2 200 kWh per capita worldwide, and less than 1 200 kWh in non-member countries. As shown in Figure 1.2, in the world, fossil fuels provide about 63% of the electricity (38% from coal, 16% from gas and 9% from oil), nuclear power 17% and hydropower and other renewable sources around 18%. For OECD countries, the shares are not strikingly different, although the contribution of nuclear power is higher and the share of fossil fuels as a whole is lower.

Figure 1.2 **Electricity generation in the world in 1997**
Source OECD/IEA Energy Balances of non-OECD countries – 1999 Edition [7]



A total of around 430 nuclear power plants are in operation worldwide, representing some 350 GWe; they produced 2 400 TWh in 1999 (see Table 1.1). In the OECD, 16 countries have nuclear power plants in operation. The nuclear share in total electricity generation in OECD countries varies from 4% to 75%, and averages nearly one quarter. The nuclear fuel consumption in the world amounts to around 50 000 tonnes of uranium a year in OECD countries and some 10 000 tonnes in non-member countries.

Table 1.1 **Nuclear energy in 1999**

Source: NEA, Nuclear Energy Data 2000 [8] *& IAEA, PRIS 2000* [9]

	World	**OECD**
Number of countries generating nuclear electricity	31	16
Number of nuclear units in operation	434	348
Nuclear capacity (GWe)	349	296
Nuclear electricity generation (TWh)	2 401	2 075
Nuclear share in electricity generation (%)	17	24
Uranium requirements (tonnes)	60 000	50 000
Spent fuel arisings (tonnes)	9 600	8 260
Carbon dioxide emissions avoided* (Mtonnes CO_2)	1 920	1 660
(share of 1990 emissions in the region)	9%	16%

**Estimated assuming that each kWh fossil emits 800 g CO_2.*

In OECD countries, population stability, efficiency gains and the shift to less energy-intensive economies are likely to limit energy demand growth. In the next half-century or so, most of the energy demand growth will occur in non-member countries. Starting from a lower base and driven by population and economic growth, the demand for energy services will increase rapidly in those countries, leading to a continued increase in total world primary energy consumption [10].

Despite gains in the efficiency of electricity use, electricity demand is likely to grow significantly during the next two decades, at rates of about 3% per year worldwide and 5% or more in the developing countries according to business-as-usual projections [6]. By 2020, this will necessitate a doubling of the current world generating capacity of about 3 000 GWe beyond the replacement of about 600 GWe of obsolescent plant capacity. Most of the growth will take place in the developing countries. In the business-as-usual scenario, the OECD share of primary energy, electricity and nuclear energy consumption will decline to 42%, 46% and 72% respectively by the year 2020.

Energy production and use give rise to significant health and environmental impacts. Energy involves large volumes of material flows, and large-scale infrastructures to extract, process, store, transport and use it, and to handle the waste. The flows of many of the world's large rivers are dammed or diverted for hydropower. Besides commercial energy sources, large volumes of non-commercial wood and other biomass are burned for energy supply, especially in non-OECD countries. Acid gas and particulate emissions from fossil fuels degrade local and regional air quality. Some radioactive substances have very long active lives, as do other natural and man-made hazardous materials. On a global scale, the possibility of significant climate change, largely caused by greenhouse gas emissions from fossil fuel burning, especially carbon dioxide, presents a fundamental challenge to the goals of sustainable development, and to the future of human civilisation.

The ways in which energy is supplied largely determine the health and environmental impacts of the sector. The efficiency and quality of energy forms will be important factors in their growth. Electricity production is likely to increase its share of the increasing global primary energy consumption. Its convenience, versatility and cleanliness at the point of use, along with its role in the information economy, ensure its desirability and its future demand growth. The variety of sources from which it can be produced allows for a range of supply options with different implications for sustainable development. For instance, the role of nuclear energy in avoiding carbon dioxide emissions is evident from Table 1.1.

In the interest of bringing basic living standards to the world's people, it seems reasonable that sustainable development goals must accommodate significant growth in global electricity demand. Most of that growth will occur outside the OECD. The energy infrastructure to be built in non-OECD countries over the next two decades of expected rapid growth largely will determine the global sustainability of energy supply and use beyond that period. OECD countries will play a significant role in this regard, as the source of much of the technology and financing. Both sets of countries can benefit from co-operation in areas of institutional development such as policy, regulation and the use of economic instruments, notably with respect to sustainable development.

2. CONCEPTS FOR SUSTAINABLE DEVELOPMENT

Sustainable development was defined by the Brundtland Report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [11]. The report notes that the sustainable development definition relies on two key concepts: one is “needs” – “in particular the essential needs of the world’s poor, to which overriding priority should be given”; the other is “the idea of limitations imposed by the state of technology and social organisation on the environment’s ability to meet present and future needs.”

The definition of needs is dynamic. It will vary with time and with different groups and cultures. Certainly our forebears would have been amazed to see some of the current needs that people have developed with increased incomes, and disappointed to see that for many, basic needs have not been met. However, the present generation still has an obligation to pass on a range of options to help future generations meet their needs, especially the basic ones.

Sustainable development is more like a direction for a journey than a destination. The immediate goal is to take steps in the right direction that enhance the range of available options rather than foreclose any of them. Along the road, further choices and trade-offs will be required.

Capital assets

A useful elaboration of the concept of sustainable development is the idea of non-declining per capita well-being. One can think of passing on capacity to future generations in the form of a stock of capital assets – man-made, natural, human and social. Man-made assets include buildings, machinery and infrastructure in the form of roads, ports and airports, water supplies, pipelines, electrical networks. Natural assets include the environment, which in turn includes both renewable and non-renewable resources. Human and social assets include education, health, knowledge and understanding of science, technology, culture and human behaviour, capacity for creativity and innovation, ability to store and communicate knowledge, institutions and social networks.

One may use up assets of one type but pass on more of another type, as long as they are fully substitutable. This concept of allowing substitution and trade-offs between classes of assets is known as “weak sustainability”. In this concept, some environmental burdens may be passed on, or assets used, as long as this negative inheritance is compensated by passing on adequate wealth and capacity to deal with it. Historically, humans have used or transformed some natural assets, converting forests and grasslands to agriculture, or minerals and energy to man-made assets. In so doing, they have added to the store of knowledge and made advances in science and technology, and in the arts and civic life, which have allowed possibilities for human fulfilment undreamed of even a hundred years ago. On the whole, the OECD countries have increased both their wealth and their populations, with great gains in welfare and in the range of options available to individuals and societies. Most non-member countries have also experienced great gains in welfare in recent decades, and many are undergoing unprecedented growth and social change, but they began later, from a lower base, and are still beset with many challenges.

Can continued increase of population and economic growth be sustained, or are there limits beyond which the loss of environmental assets begins to reduce, perhaps drastically, the total stock of assets passed on? Clean air and water are in short supply in many parts of the world. Increased concentrations of greenhouse gases in the atmosphere could cause irreversible changes in climate. Biodiversity and habitat for many species are threatened. The concept known as “strong sustainability” recognises that some environmental amenities may be essential and irreplaceable, that their loss may be permanent, and that there is no possible substitute or compensation for them. This concept places definite limits on using or degrading environmental resources in order to avoid undermining basic life support systems. It calls for preserving critical ecological systems and respecting air, water and other environmental goods that are essential to human life and cannot be replaced.

Risk and uncertainty

Sustainable development requires decisions and actions across a very broad spectrum of human activities, each with its own risks and uncertainties that increase as we look further into the future. Methods for the assessment and management of risk will be essential tools for policy makers aiming at reducing or mitigating negative impacts, avoiding disasters, ensuring continuity of life support systems, and maintaining or increasing the overall capital stock.

Investments in R&D can reduce uncertainty by improving our understanding of natural and man-made systems. Maintaining a diversity of options, in the energy sector and elsewhere, can help to avoid disruption when one option encounters limits on its use. Innovations in products and processes can represent steps in the direction of sustainable development. To date, innovations have generally served humanity well, but in some cases their impact has become so broad that their overall future benefits are difficult to assess. Some innovations may constitute open-ended experiments with the biosphere. For developments that could have major, irreversible consequences, but whose occurrence is uncertain, it would seem prudent to take some preventive mitigating actions. This is the essence of the precautionary principle – that one should not wait for scientific certainty that a major risk will materialise before taking action to prevent or mitigate it.

Equity and participation

Equity is a key objective of sustainable development. A society that respects the principles of sustainable development requires a greater degree of equity than currently prevails in the world [12]. Worldwide, people aspire to a standard of living that at least meets basic needs. The desire to care for future generations and for the environment that supports humanity implies an equal devotion to the people living now. Equity, within OECD countries as well as between Member and non-member countries, needs to be addressed in order to achieve sustainable development goals.

The OECD Member countries, with a population of about one billion – i.e. less than 20% of the world’s population – own 80% of the wealth. Over the next few decades, almost all the population growth and much of the economic growth will take place in non-member countries, with an increasing impact on the global possibilities for sustainable development. Yet the OECD countries possess some of the key resources needed to address these growth challenges: funds, science and technology, knowledge and skills, and institutions. Thus OECD Member countries will have an increasing interest in decisions taken by non-member countries from the perspectives of both self-interest and global responsibility [13]. This argues for close co-operation between the OECD and the non-member countries, for significant resource transfers to achieve greater equity, and for joint work to meet health and environmental goals. The transfer of institutional expertise, such as effective regulation, will be an important factor.

The concept of sustainable development has a profound resonance because it provides a common vision for people with widely differing views. Sustainable development implies an equal emphasis on quality and on quantity of growth and, thereby, recognises the concerns of advocates for economic development, social welfare and environmental protection all together. The links among these three dimensions of sustainable development can create synergy and may provide some opportunities for win-win measures. However, it will be difficult to meet all the goals of sustainable development at the same time: caring for the present generation, the environment and future generations will require trade-offs between conflicting goals.

The social dimension of sustainable development requires not only social cohesion, but also co-operative actions at all levels of social organisation, from the local to the global scale. Politically, this will not be easy. Although some initiatives may produce net gains for all parties, others will require sacrifices by some for the sake of others. Also, sustainable development issues, which are seen as inherently global and long-term in nature, may not provide strong incentives for urgent local action. Before risking their own immediate welfare, most people will want reassurance that the transfers involved are equitable, that they make a real contribution to the overall goals, and ideally that they bring some benefits back home. In order to make the often difficult choices that will be required, individuals and groups will need a good understanding of the implications of their decisions, not only for the long-term goals of sustainable development, but for the short-term trends in their local communities. Therefore, education and participation will be key to the success of sustainable development policies.

Natural resources

Natural resources are an essential asset for sustainable development. They come in a great variety of forms, from clean air and water to minerals and energy, to agricultural land and soil, to different forms of landscape and wilderness. While the natural world may generate non-use values, natural entities generally become broad economic resources only as a result of demand, which arises from finding uses for the resource. The uses depend in turn on technology and taste. The world’s beaches, wilderness rivers and snowy mountain slopes were not much valued before people began wanting to spend holidays there, and obtained access by planes, trains, and automobiles. Uranium became an energy resource only after the discovery of nuclear fission in 1939. Waste materials that can be recycled are now seen as resources. Thus, resources have to be seen in a dynamic and ever-changing context.

Non-renewable resources

Non-renewable resources, while finite, do not generally seem to have an availability problem at the front end of the product cycles. Although proven economic reserves of many non-renewable commodities represent only a few decades of supply at current rates of consumption, this is only a snapshot of resources discovered as a result of active searching. It is not economic to spend a lot of money looking for resources that will not need to be developed for many decades, so the short-term nature of the reserve picture is not surprising. As more resources are needed, exploration and development will be funded, and more reserves will be defined. Technology is constantly improving the ability to find and develop lower-grade or more remote deposits, and to use resources more effectively. Prices for many commodities are at or near their historic lows, suggesting that scarcity is not imminent, although geographic distribution and politics may affect the price or availability of some commodities, such as oil. The main problem with non-renewable resources in the short and medium term is at the back-end of the cycle, with the capacity of the environment to absorb the waste they create.

While cost and availability may not be a problem today, increasing consumption in a finite world has to take its toll. Extracting lower-grade resources in more remote areas involves higher energy costs and more waste material but also the opening up of new areas to modern development. More extensive conversion of primary fuel resources into increasingly higher-quality products for end-use may lengthen the transportation chain and lower the overall efficiencies of the complete fuel cycle. Decreasing the use of materials and energy by reduced consumption or by greater efficiency, in both production and end-use, can only help the environment. Resource efficiency and productivity thus are key factors in sustainability.

Renewable resources

Sustainability of renewable resources can be defined in different ways. Maintaining the economic output of an ecosystem (e.g. in a commercially exploited forest) is one option and maintaining the integrity of the whole ecosystem (e.g. in an old-growth forest) is another possibility. In addition to the immediate value associated with its economic outputs, the ecosystem that supports the resource flows may have option values for possible future uses, and existence values simply because people value its continued existence. Ecosystems have information value as working models of complex interacting life-sustaining systems, about which we still have much to learn. Option and existence values are less tangible and more difficult to measure than the immediate economic output, but may be of comparable importance, especially in a long-term perspective.

Renewable resources are subject to a variety of stresses, often more powerful than those acting on non-renewables. They are inexhaustible in the sense that they can be continually recycled, but this does not mean they are infinite in amount and does not prevent their degradation. Renewable resources, including air, water and land, are subject to pressures for different uses, which may be incompatible. Air and water are particularly susceptible to pollutants because of the ease with which they can be used as open-access resources for receiving and disseminating waste. Habitat for plant and animal species may be very sensitive to environmental impacts, and easily destroyed. Thus renewable resources should be seen as finite and vulnerable to pressures.

For example, a river system can be dedicated to a variety of purposes: power generation, drinking water, irrigation, industrial use, sport and commercial fishing, recreation in various forms such as rafting and canoeing, swimming, sailing or motor-boating on lakes and reservoirs, scenery for hikers and campers, sites for resorts or cottages, or pure wilderness. Once dedicated, it cannot be used again, without disturbing the constituencies that use its features and whose property values depend on them. Some of these uses may degrade the quality of the water, or spoil it for other uses. In some cases, so much water is withdrawn for various uses that not much reaches the sea or ocean – the Nile and the Colorado are in this condition at times. This in turn can have an impact on coastal currents and water quality, salinity of water in the delta, etc. Policy for renewable resources, including pricing policy, should reflect their scarcity value, multiple uses, and susceptibility to degradation or irreversible loss.

Research, development and innovation

Science and technology are a vital part of the human and social capital that people have developed over the past centuries. Innovation will be essential in moving toward sustainable development. R&D can contribute to both the scientific understanding and the technological innovation that will be needed to meet sustainable development goals. It can extend the existing resource base and create new categories of resources by finding new and more efficient ways of using raw materials. Also, R&D can reduce uncertainty by providing better scientific understanding of technologies and their impacts. Because the issues involved in sustainable development are inherently complex and comprehensive, much of the R&D required will be interdisciplinary in nature and international in scope.

Governments have traditionally embraced the rationale that they should carry out or sponsor fundamental R&D as a public good while leaving applied and commercially oriented R&D to industry. With budget pressures, however, governments have been less inclined to sponsor long-term research that lacks immediate payoff and may leak to other countries, and have tended to invest, often in partnership with industry, in strategic but nearer-term R&D that makes a direct contribution to short-term national policy goals. Sustainable development will require sustained R&D support backed by a long-term vision that may require changes to current policies.

Beyond R&D, governments can also do much to create the framework and the infrastructure for successful innovation. They can provide a range of incentives for innovations that help to protect the environment for example. Designing new products, processes and systems on a life cycle basis from the beginning, with high standards in term of safety and health and environmental protection, is one of the best ways to achieve sustainable development goals. This is particularly the case for energy systems that have large-scale potential impacts and very long lifetimes.

Because of the importance of energy to sustainable development, and the need to meet increasing demand for energy services while reducing overall environmental impacts, R&D will be essential in this field. Innovative developments largely will determine the impact of energy on economic, environmental and social goals over the next decades and indeed well beyond. In a recent report on Climate Change and Nuclear Energy, the Royal Society calls for an international research effort building up to 25 billion USD per year to explore all the different options for meeting the demand for energy, including nuclear energy, while reducing the likelihood and impacts of climate change [14].

Valuation and comparison – The search for indicators

In order to compare the different impacts of human activities, it is useful to assign values to them, similar to giving a monetary value to marketed goods and services. While it is desirable to use a common indicator, or unit of measurement, in order to compare impacts, it is difficult to assign values to entities that have no markets. Those include natural assets like clean air and water, ecosystems such as wetlands, coastal zones, rainforests, mountains, and deserts and also social assets like institutions, participation in democratic debate, and access to information. The task of finding a common indicator for valuing those entities is not an easy one, and economic methods might not capture the real significance for society, in a sustainable development perspective, of goods and services for which there is no market at present.

The search for common indicators is complicated by the variety of economic, social and environmental impacts to be considered. Impacts may be local, regional or global, affect population, ecosystems or macro-economic systems, and have short-term or long-term consequences; they may affect workers or the public. Impacts can occur under routine or accident conditions. Events with low probabilities and high consequences, such as severe nuclear accidents, may require a different treatment from those with high probabilities and low consequences, such as routine releases of pollutants, even though both result in increased mortality and morbidity. Impacts may be valued differently by different groups according to their social and cultural background and sensitivities.

For electricity generation, alternative sources will lead to different health and environmental burdens that are difficult to compare on a level playing field. Fossil fuels generate atmospheric emissions of greenhouse and acid gases, and particulate matter. Nuclear energy produces radiation and radioactive waste. Hydropower results in the dedication of river systems to dams and power production, changes in streamflow and in many cases the flooding of vast areas for use as reservoirs. For other renewable sources, the dedication of large or unique areas to energy gathering systems may be a concern. Units of measurement for such a broad range of impacts vary widely.

Although it is difficult to measure different impacts with a unique unit and express their values with a single indicator, individuals, firms and governments do make decisions implying that they carry out some kind of implicit valuation of these impacts, however simple or intuitive. The goal of explicit valuation is to make the factors going into decision making more transparent. Using a common unit, or a few summary indicators, forces examination of the different impacts within a common framework. Decisions may then be made in a coherent and systematic way, with the hope that they would lead to better overall outcome.

Monetary units are well understood and already functional where markets exist. They have the advantage of reflecting real preferences, which provides a useful basis for extending them to non-market entities. They can take into account time preferences, risks and uncertainties. Valuing impacts is a means to eventually internalise their costs and enhance the efficiency of market mechanisms for supporting sustainable development.

Working with a range of indicators also has its advantages. They can be more precisely matched to the characteristics of impacts and receptors. A recent IEA study shows how looking at disaggregated indicators along the energy chain can inform policy on carbon emissions [15]. For example, indicators adapted to each sector of activity may be tailored to measure progress towards sustainable development and trends in a specific industrial branch, for example.

The OECD and other international bodies are working on an approach that builds a pyramid of indicators [2, Chapter 6]. At the bottom are indicators that describe the impact of developments and policies at the sectoral level – e.g. for energy, agriculture and transport – expressed in physical or monetary terms. Above them are the resources indicators, which describe the accumulation and depletion of the different forms of capital. These may be used to develop green national accounts, where environmental and possibly human and social indicators can be included with the traditional economic ones to produce a broad view of genuine savings. This is a measure of changes in the overall capital stock, and hence of progress towards sustainable development. Although human and social factors are difficult to measure precisely, work to date indicates that they represent the largest share of national wealth in most countries, and are areas in which investment is highly productive [16]. Above these are outcome indicators in the economic, environmental and social dimensions. At the top are summary indicators, which provide a broad picture of the current path towards sustainable development.

The indicators used by the NEA, and more generally by the nuclear community, are mostly specific to energy, electricity and nuclear power. They include some economic indicators expressed in monetary units that can be compared and integrated within a global framework covering all sectors of activity. Other indicators related to health and environmental impacts – e.g. collective doses or volumes and activity of waste – are specific, and work remains to be done to integrate them into an overall assessment of various energy sources. As the efforts to develop more aggregated sets of indicators evolve, the indicators used in the nuclear energy sector will provide a useful basis for further integration. In the meantime, multi-criteria analysis may be relied upon to identify key strategic issues and to allocate resources and take actions appropriately.

Values over time – The discount rate

Sustainable development goals include taking the needs of future generation into account and, thereby, require valuing explicitly future activities and assets within a very long-time perspective. The discount rate that measures how much more we value things right now than in the future [17] is an important policy tool within a sustainable development framework. A zero discount rate implies that the present and the future are valued equally. Sustainable development essentially tells us that all our activities have long-term implications, and they should all be managed with an eye to the future. Giving equal priority to present and future generations may require lower discount rates than those derived from market mechanisms.

Governments and other public agencies with responsibilities for the long-term social and environmental consequences of decisions taken today may use low discount rates to reflect the priority placed on the welfare of future generations. However, specific political issues and level of economic development will have a drastic influence on those choices that will vary from country to country. In order to capture the benefits of investments whose payoff is in the long term, governments may apply a low discount rate to the assessment of such investments, or they can assign a high value to those benefits, so that even after discounting their present value remains significant.

High discount rate implies a strong preference for the present. Decisions taken today based upon a high discount rate are almost not influenced by costs and benefits that will occur beyond a few decades. Poor people struggling for survival will use implicitly a high discount rate since their preference goes to improvements in the very short term. Private investors who look for short pay back periods use explicitly high discount rates.

The introduction of commercial competition into the electricity sector worldwide, along with other sectors, implies increased pressures toward higher discount rates in the assessment of projects. Projects with high capital costs and long development periods, like nuclear power plants, become less attractive under those conditions. Within a sustainable development policy framework, mechanisms and measures should be sought in order to capture the potential future benefits of capital intensive options when they are considered to meet broad public policy goals.

Policy and economic instruments

In its approach to sustainable development, the OECD emphasises policy and economic instruments. Policy instruments include R&D, traditional command-and-control regulation of health, safety, and environmental impacts, as well as broader approaches such as environmental assessments; education, information and participatory processes; and voluntary measures, along with programmes such as product labelling and awards. Economic instruments include taxes, subsidies, and tradeable permit schemes, as well as traditional economic regulation, and measures to internalise the external costs of health and environmental impacts.

Regulation is a core function of governments, both to ensure health and safety, and to ensure fairness and effectiveness of market mechanisms. The challenge is to meet these objectives without burdening the economy or inhibiting the beneficial effects of innovation. In terms of safety and environmental impact, the regulatory challenge is also to balance the risks and benefits across a range of activities. Regulation often tends to be piecemeal, in that there are separate agencies and regulations to deal with different risks such as toxic chemicals, radiation, natural hazards, crime, disease, and so on. Regulators tend to focus on their specific risk responsibilities while integration might enhance the overall effectiveness of regulation. For example, nuclear safety regulation is an essential aspect of energy policy. A coherent approach to risk across society would allocate resources most efficiently, ideally equalising the marginal benefit from any incremental expenditure on health, safety, and the environment.

Education, information and participation are essential components of a sustainable development policy, and often offer opportunities for cost-effective policy measures. A better understanding of sustainable development and a broader participation in key decisions should lead to a greater social willingness to take steps toward it. There would probably be benefit, in many countries, in a more active public discussion of energy issues, covering all available options. Involving all interested and affected parties in decision-making could facilitate reaching agreement on the possible role of alternative options, including nuclear energy, in sustainable development strategies.

Governments employ a range of economic instruments, including taxes, subsidies, and emission trading schemes, that provide incentives to move toward certain goals without necessarily telling the actors how to get there. This leaves the actors free to choose their own paths, which may be more innovative and cost-effective than those imposed by a regulator. Economic instruments help to get prices right, in reflecting the value that society places on the full range of impacts over time. They can help to create markets where none existed before, and hence provide a forum for valuation.

Subsidies often have had negative impacts where they have been used to support inefficient industries or ill-conceived regional development schemes. They have led some resource industries to create capacity exceeding market needs or environmental carrying capacities. Support to traditional activities in some regions has postponed the need to diversify and modernise, hampering the development of the economy. There is general agreement that subsidies need to be reformed in the energy sector, including the nuclear field, as elsewhere. However, transparent subsidies supporting public policy goals and closely targeted to those goals – such as development of cleaner energy sources, more efficient processes, or public transportation – can contribute to sustainable development through facilitating the penetration of technologies that would not enter easily competitive markets otherwise.

Taxes and emission trading can complement subsidies and can be revenue-neutral. The economic penalties on damaging activities, such as pollution, can be used to support environmental or social protection. For instance, green taxes can discourage specific polluting activities, in accordance with the polluter pays principle. Taxes have a direct influence on price, but an indirect effect on the amount of pollutant emitted. By contrast, emission trading can set direct limits on emissions, but its impact on price will be indirect. Both instruments effectively place a value on pollutants, thus helping to internalise their health and environmental impacts. The valuation of these costs, and their internalisation, are important factors in getting prices, and policies, right. As with subsidies, the challenge is to achieve the policy goal at the least overall cost to society.

Climate change

Climate change is one of the most challenging issues to be addressed by sustainable development policies. Anthropogenic emissions of greenhouse gases and their concentration in the atmosphere are increasing. Although there remains some statistical uncertainty in the assessment of the nature and likely extent of the impacts of those emissions, policy makers are increasingly concerned by climate change and have decided to apply the precautionary principle in this instance.

A major international effort is underway to understand the scientific aspects of climate change, and to identify alleviation, mitigation and adaptation measures. The United Nations Framework

Convention on Climate Change (FCCC) is a major step towards controlling and limiting greenhouse gas emissions. Within the FCCC, the Kyoto Protocol of December 1997 imposes binding commitments on the developed countries to reduce their greenhouse gas emissions below 1990 levels by 2008-2012. Although it is recognised that meeting the Kyoto targets will pose a challenge for many countries, further reductions will be required beyond 2012 in order to stabilise atmospheric concentrations of greenhouse gases at acceptable levels.

The main greenhouse gases are carbon dioxide and methane. The burning of fossil fuels resulted in about 6.4 billion tonnes of carbon emissions in the form of carbon dioxide in 1998, or about one tonne per capita for the world population, while the burning of forests caused emissions of an additional billion tonnes or more. Currently more than half of the carbon emissions from fossil fuels originates in OECD countries. In the coming decades, however, most of the growth in energy consumption, and therefore of carbon emissions, will take place in non-member countries. Energy demand growth for electricity and transport will be especially rapid, despite gains in efficiency. Transport will continue to be largely based on oil, but electricity can be generated by a range of options including coal, natural gas, nuclear energy, hydropower, biomass, solar energy and wind.

Clean sources of electricity will be important for large cities, where industry and transport will be driving growth in fossil fuel use and gaseous emissions of all kinds. Electricity should contribute to alleviate the risk of global climate change. Building electricity capacity on the scale required will be a major challenge, not because of the need for fuel resources, but rather for financing, institutions, infrastructure, and technology to meet the economic and environmental requirements.

From a sustainable development perspective, it would seem essential to ensure that impacts that could lead to climate change as well as other environmental impacts are internalised as much as possible in the costs of the activities that produce those impacts. The current situation, where there is no charge, or a very small one for carbon emissions, sends the wrong signals, encourages emissions and discourages non- or low-carbon alternatives. In effect the absence of a value for carbon emissions represents very significant cost savings for fossil fuels. Finding an appropriate way of dealing with carbon emissions is a major part of getting the price right for energy sources, and of meeting commitments for Kyoto and for further reductions beyond.

While some value will undoubtedly be placed on carbon emissions through taxes or permits over time, large values will be resisted by governments eager for rapid development and by producers and consumers of energy. Because of their importance in the economy of every country, it seems unlikely that fossil fuels will be priced out of the electricity market, and likely that fossil fuel technology will continue to improve. Non-carbon sources such as nuclear energy and renewable energy sources can make a vital contribution to reducing emissions, but they will have to compete in markets where fossil fuels are likely to be abundant and relatively low cost. Beyond their advantages in emissions, nuclear energy and renewable energy sources will have to be competitive under prevailing conditions and, in the case of nuclear energy, safe and publicly acceptable.

3. SUSTAINABLE DEVELOPMENT AND NUCLEAR ENERGY[1]

The current situation of nuclear energy is outlined in Chapter 1. There are over 400 nuclear power plants operating in 31 countries, representing about 350 GWe of capacity. The nuclear industry represents a large asset comprising several forms of capital. A measure of the man-made capital may be given by the replacement value of nuclear power plants in operation, which is about 700 billion USD. Technologies for peaceful uses of nuclear energy are proven, and benefit from extensive experience drawn from the design and operation of reactor and fuel cycle facilities as well as the regulation of civil nuclear activities. The cumulative experience relative to nuclear power plant operation amounts to about 9 000 reactor-years.

More than 80% of the nuclear capacity is in the OECD countries. Non-member countries, especially those with large urban and industrial sectors, will experience high electricity demand growth, and the development of nuclear energy over the next few decades is likely to occur primarily in those countries. In order to ensure that nuclear power growth remains compatible with sustainable development goals, the OECD countries have a co-operative role to assume in the areas of technology transfer, training, exchange of experience, and institution building.

Looking at nuclear energy from a sustainable development perspective implies analysing its characteristics in terms of their economic, environmental and social impacts, both positive and negative, in order to assess to what extent and under which conditions nuclear energy may contribute to meeting the goals of sustainable development. The following analysis is intended to cover those aspects and to provide policy makers with elements that could be used to assess how nuclear energy compares with alternatives.

Indicators

Indicators of sustainable development in the energy sector are the subject of ongoing work within the OECD and the IEA. They can take the form of sectoral and resource indicators, and outcome and summary indicators that measure progress toward sustainable development [2, Chapter 6]. Some subjects relevant to the energy sector that may be addressed by indicators include:

- Resource availability and geographical distribution (noting that the definition of a resource is a dynamic one).

1. The term "nuclear energy" encompasses a wide range of activities including reactor design, construction and operation and fuel cycle service supply (see Annex 1). These activities are carried out in many countries with different technologies and institutional infrastructures, and various levels of performance. This term is used throughout this document for the sake of convenience and simplicity, but it is recognised that there is considerable variety within the nuclear energy sector and in the approach to nuclear energy taken by different countries.

- Intensity of energy use and material flows (per capita, per unit GDP, or per unit of end product, e.g. kWh of electricity, passenger-miles of transport), including those to the environment (e.g. carbon emissions).
- Health impacts on different groups (e.g. assessed through dose/response functions).
- Critical environmental load limits for given materials and receptors.
- Land use and impact on natural habitat.
- Potential for causing major and irreversible environmental impacts.

Indicators are often listed for different groups of environmental impacts: biodiversity, climate change, winter and summer smog, biological oxygen demand in lakes and rivers, toxic chemicals, etc. Other less tangible subjects will also be important for sustainability: government policy on education, training, financial support and R&D; marketing and consumer values; valuing of health and the environment and how those values are expressed; quality of health, safety, environmental and economic regulation; effectiveness of institutions.

At the present level of scientific knowledge, it seems relevant to begin with indicators appropriate for each activity and impact, and then work toward aggregating them in appropriate units. A key challenge at this level is to identify the most important elements and focus attention on them.

The task of assessing progress toward sustainable development and comparing it across different energy sources (including efficiency as an equivalent source), is a difficult one. Indicators would be useful in the context of making electricity generation choices once energy and electricity needs are better understood in a sustainable development perspective. This suggests that indicators should be developed for the purpose of eventual comparisons.

Taking the OECD framework of economic, social and environmental dimensions, a number of indicators relevant for nuclear energy may be identified and measured (Table 3.1). The examples given in Table 3.1 are intended to be illustrative and some of them – e.g. doses and waste activity – cannot apply to other energy sources. On the other hand, land use is less relevant for nuclear energy or fossil-fuelled electricity than for hydroelectricity, solar energy and wind power. Health and environmental detriments caused by different pollutants (e.g. SOx, NOx, greenhouse gases and radioactive emissions) are difficult to compare in a quantitative way.

Table 3.1 **Sustainable development indicators**
(Illustrative list applicable to nuclear energy)

Economic indicators	Social indicators	Environmental indicators
Capital cost ($/kWe)	Dose to the public (Sv/kWh)[2]	Volume of solid waste (m^3/kWh)
Marginal cost ($/kWh)	Employment (man/kWh)	Activity of solid waste (Bq/kWh)[3]
	Education (number of university courses)	Fuel use (tU/kWh)
		Activity of liquid & gaseous effluents (Bq/kWh)

2. The Sievert (Sv) is the unit of radiation dose used in radiation protection to measure the biologic effect of ionising radiation.

3. The Becquerel (Bq) is the unit of activity used to measure the number of disintegration per second in radioactive materials; 1 Bq is equal to 1 disintegration per second.

Recognising that progress in the development of generic indicators for energy and more globally may take time, it seems relevant for the nuclear sector to identify key indicators and focus its efforts on measuring those indicators in order to assess trends relevant to sustainable development. This effort has been undertaken already at the national and international level, and data series are collected, harmonised and published on a regular basis.

Economic dimension

Economic efficiency is one component of sustainable development and competitiveness is a relevant indicator insofar as market prices reflect the full costs for society of a given product or activity. The economic aspects of nuclear energy are reviewed and presented below from this perspective, taking into account the criteria applicable to market competition, externalities and subsidies.

The inclusion of nuclear energy into a national supply mix increases technical and fuel diversity and creates potential competition with alternative sources in electricity markets. This has the potential to increase the overall effectiveness and efficiency of energy systems to the benefit of consumers.

Competition

With respect to competition with new fossil plants, existing nuclear plants can be put into three categories, depending on their production costs [18,19]:

- A first group will be able to compete with new fossil plants even when full capital costs of the nuclear plant are included. They will be prime candidates for life extension.
- A second group will be able to compete on the basis of marginal cost (fuel, operating and maintenance costs), but will not recover their full capital costs, which remain as stranded debt. Nonetheless, since their capital costs have already been incurred, it may pay to continue operating those plants, recovering at least some of the investment. Where there is an interest in their continued operation from an energy security or emissions perspective, to maintain nuclear expertise and a nuclear option for the future, supportive measures may be warrented.
- A third group cannot compete on marginal cost, and will likely close if their performance cannot be improved. However, its seems that the current spread in marginal costs for nuclear plants, for example in the United States [20], is due mainly to individual plant management, implying opportunities for the more expensive plants to lower their marginal costs.

Most existing nuclear plants are expected to continue functioning to the end of their design lives. Life extension likely will be cost-effective for many nuclear power plants. Refurbishment to extend plant life will improve performance, help to meet increasingly stringent safety standards, and offer opportunities for plant upgrade. It will provide additional electricity generation capacity at lower investment costs than most alternatives.

The bulk of existing plants came into service in the 1970s and 80s. Assuming a 40-year design life, they would nominally be replaced by 2030. Although many lifetime extensions of 10 years or more are expected, new reactor designs, whether evolutionary or more innovative, will be needed eventually. They will have to compete with other sources of electricity on a full-cost basis with no compromise in safety standards. They must be cheaper and quicker to build, and easier to maintain, than existing nuclear power plants. While this will be a major challenge, it is a necessary precondition for the long-term viability of nuclear power.

New nuclear plants to replace those reaching the end of their useful lives, and to meet electricity demand growth, will compete with a range of generation options. Natural gas plants (combined cycle gas turbines) now look like the technology of choice that will set the standard for competition for new generating capacity for the next few decades in areas where gas is readily available. In many non-member countries coal likely will be the strongest competitor for nuclear power.

The total levelised cost of generating electricity with new nuclear units to be ordered in the coming years would range between 2.5 and 6 cents per kWh at a 5% discount rate and between 4 and 8 cents per kWh at 10% discount rate [21].

Cost estimates that serve as a basis for decision-making depend strongly on the discount rate adopted. Low discount rates, which reflect a relatively high value for the future, as may be called for by sustainable development goals, enhance the competitiveness of capital-intensive technologies such as coal and nuclear energy. With a 5% discount rate, nuclear power plant of current generation would compete favourably with alternatives in a number of OECD and non-member countries, but in a competitive and deregulated market a 10% discount rate is more likely to prevail.

Nuclear energy is characterised by high capital costs and low marginal costs of generating electricity. Nuclear power plants are generally large in scale and they come in billion-dollar packages. According to Table 3.2, drawn from an IEA/NEA study on projected costs of generating electricity [21], at 5% discount rate, the share of capital investments, including interest during construction, in total nuclear electricity generation cost is around 60% while O&M take some 25% and fuel around 15%.

Table 3.2 **Nuclear electricity generating costs**

Country	**Discount rate**	**Investment (%)**	**O&M (%)**	**Fuel (%)**	**Total cost (cent/kWh)**
Canada	5%	67	24	9	2.5
	10%	79	15	6	4.0
Finland	5%	59	21	20	3.7
	10%	73	14	13	5.6
France	5%	54	21	25	3.2
	10%	70	14	16	4.9
Japan	5%	43	29	27	5.7
	10%	60	21	19	8.0
Korea (Republic of)	5%	55	31	14	3.1
	10%	71	20	9	4.8
Spain	5%	54	20	26	4.1
	10%	70	13	17	6.4
Turkey	5%	61	26	14	3.3
	10%	75	17	9	5.2
United States	5%	55	27	19	3.3
	10%	68	19	13	4.6

Capital costs of nuclear power plants vary with design, component suppliers, construction methods, labour and management skills and relations, quality assurance, and regulatory and approval processes. Total investment costs, including provision for decommissioning and interest during construction, for nuclear plants using currently available designs, range between 2 000 USD and 2 500 USD per kWe. For a 1 GWe plant, this means an investment exceeding 2 billion USD. Designers and manufacturers of new reactors are aiming at significant capital cost reductions of 25% or more for the next generation of nuclear plants [22].

Safety and decommissioning costs are included in the capital costs of nuclear power plants and amortised by the plant owner over the lifetime of the unit. The prices paid by electricity consumers include decommissioning costs and there is little or no financial liability left behind to future generations. The electricity generators set aside liability funds to cover expenses in due course [23]. Decommissioning cost estimates are based mainly on experience acquired with research facilities or small reactors but with increasing feedback experience, the uncertainties on those costs are progressively reduced. The undiscounted costs span a range between 10 and 20% of initial capital costs but when discounted contribute only a few per cent to the total investment cost since major expenses will be incurred several decades after the closing down of the plant [24].

The share of capital cost in the overall cost of generating electricity varies considerably from plant to plant and with the discount rate, capital weighing more at higher discount rates. To date, it has always been higher for nuclear than for fossil fuel alternatives. For coal-fired power plants, capital costs generally range between 1 000 USD and 2 000 USD per kWe; for gas-fired power plants, capital costs are even lower in the range 500 USD to 900 per kWe. Also, construction times are shorter for gas-fired plant, 2 to 3 years, and for coal-fired plants, around 5 years, than for nuclear units, 5 to 7 years. For coal-fired power plants, the breakdown is about 35% for capital investments, 20% for O&M and 45% for fuel. For gas-fired power plants, capital costs represent around 20%, O&M 10% and fuel 70% (see Table 3.2 and [21]).

Once operating, a nuclear plant offers stability of production costs. The cost of uranium ore itself constitutes only a few percent of the overall cost of electricity from nuclear energy and, therefore, even a significant price increase for uranium would not have much impact on the cost of generating nuclear electricity. On the other hand, the cost of fuel accounts for a large proportion of total generating costs for fossil-fired electricity plants, in particular for gas-fired power plants (around 70% or more). Thus the prices of fossil fuels, which have been highly volatile in the past, will have an important influence on the competitive situation.

Nuclear power may be competitive with alternatives in deregulated electricity markets in countries where large programmes based on standardised units have been implemented and where plants are operated and managed efficiently. If a nuclear plant runs at a higher-than-planned capacity factor, or for a longer period then planned without major refurbishment, it can earn a significant return. In countries, such as the United Kingdom, where the electricity market has been deregulated nuclear units have been performing rather well in general and have contributed to low and stable electricity prices.

Subsidies

The removal of inappropriate subsidies is essential to achieve sustainable development goals in a deregulated market. Subsidies to be considered in the nuclear field include support to R&D beyond basic and fundamental research, export financing and governmental guarantees covering financial liabilities and third party liabilities in case of severe accident. As the nuclear industry progressively reached commercial maturity, export financing and government financial guarantees for liabilities have been reduced significantly. Support to R&D for a given technology has to be assessed in the light of the overall national policy goals, including security of energy supply and environmental protection.

Financial support from governmental export development agencies, which often was provided in connection with nuclear power projects undertaken in non-member countries, is not unique to nuclear projects. OECD countries engaged in nuclear exports have agreed on rules that have evolved to the point where any government financing is now almost entirely at commercial rates, although there is some flexibility in training, technology transfer, warranties and other areas. To the extent that government-backed financing, even at commercial rates, is seen to represent a subsidy, it would have to be looked at in terms of public policy goals such as reducing global emissions, and in terms of trade promotion practices for other products and services.

A central goal of sustainable development is to avoid the transfer of large burdens through time to future generations. Future financial liabilities associated with facility decommissioning and radioactive waste disposal could require subsidies if adequate provisions were not set aside by the nuclear industry. Since decommissioning and waste disposal occur long after nuclear electricity is generated, the economic actor responsible for the facility and its waste may not exist when the funds will be needed. In OECD countries, the cost of decommissioning nuclear power plants and disposing of radioactive waste is largely included in the generation costs [21, Annex 7] and passed on to current electricity customers. Schemes in place in OECD countries for covering future financial liabilities from nuclear activities ensure that funds will be available to finance decommissioning expenses costs when they will occur [23].

Nuclear liability insurance regimes provide many guarantees to both the industry and potential victims of accidents, and the coverage of damages is increasingly taken on by nuclear operators. Nuclear energy has been a pioneering field in setting up liability regimes and in looking at long-term liabilities. Pressures are increasing on other industries to cover their external costs and future liabilities, as is done by the nuclear industry. To the extent that limited liability of the companies operating nuclear facilities can be seen as a subsidy to the nuclear industry, it should be compared with liability regimes in other areas.

Government-funded R&D, including the building and operation of equipment such as research reactors, will likely constitute the main subsidy to nuclear energy, as it has in the past. A vigorous R&D effort is required to conceive and develop designs that will meet more stringent safety standards, have enhanced technical performance and compete successfully with alternatives. Governmental support to R&D should be justified by the expected contribution of the outcomes to public policy goals, such as social welfare, environmental protection and sustainable development. It should be allocated to a range of options according to their respective potential contributions to the shared goals of the country, and the rationale for the approach adopted should be fully transparent. In this connection, the share of nuclear R&D in the overall technology and energy R&D budget should be adapted to the role foreseen for nuclear energy in the national policy.

External costs and benefits

The costs of health and environmental impacts from residual emissions and burdens represent negative externalities. Norms, standards and regulation are reducing the impacts from electricity generation chains and *de facto* internalising the costs corresponding to environmental and health protection. Remaining external costs are supported by society as a whole through taxes, health or environmental degradation, and burdens passed on to future generations. The non-internalised costs may be considered as a benefit to producers and users of the technologies that cause the impacts. In so far as those costs are not reflected in market prices, they prevent market mechanisms from supporting sustainable development.

The nuclear industry is operating under regulations that impose stringent limits to atmospheric emissions and liquid effluents, and is committed to contain its waste and isolate it from the biosphere as long as it may be harmful for human health and the environment. Thus the industry has accepted the full long-term responsibility for its emissions, effluents and waste and has internalised the corresponding costs, which are borne by the consumers of electricity. This internalisation extends fully to waste management, waste disposal and plant decommissioning. It also applies to the liability in the event of a major accident although the total liability assumed by the industry is capped and governments carry the residual risk.

A number of studies have examined the impact of different fuel cycles on human health and the environment, and provide some information on progress towards recognition, valuation and internalisation of external costs. The most ambitious studies are those that have tried to aggregate the indicators for different kinds of impacts in a single unit, usually monetary. These studies use preferences revealed by market values where they are available. Where market values do not exist, researchers try to obtain equivalent values through other ways of discovering preferences.

Valuation is a controversial area and there is no consensus on the feasibility and relevance of assigning a monetary value to every good, commodity and service, let alone to human life. It is difficult to reduce the variety of environmental impacts to a single unit, and to agree on the monetary value of some assets. However, the approach has some merits in making preferences as transparent as possible and subjecting them to a systematic assessment, where the higher priority impacts can be identified and compared.

A thorough study of the health and environmental impacts of several fuel cycles for electricity generation, using specific technologies and sites, was carried out by the European Commission [25]. The methodology and results have been further refined but the 1995 conclusions remain essentially valid. Other studies differ in some of the specific numbers, but many of their conclusions are similar.

Under routine operation, nuclear energy has low impacts, comparable to natural gas and renewable energy sources. These are valued within the ExternE study, assuming a zero discount rate, at less than 1 mECU per kWh, except for a longer-term global impact from reprocessing of 2 mECU. The latter valuation is based upon multiplying very small exposures by very large number of people that could be exposed over the next 100 000 years. Such broad extrapolations of low-level impacts are controversial. They are most useful when applied to specific populations over shorter time periods.

The external cost of a severe nuclear accident, calculated with a probability of 5×10^{-5} per year for core damage, was estimated by the ExternE study at about 0.1 mECU. Other estimates of external costs of severe accidents show fairly large discrepancies and are considered controversial. The results obtained for nuclear power plants with good safety standards in operation in OECD countries show low quantifiable contributions of severe accidents to external costs of nuclear power [26]. However, while economic estimates are of interest in this context, they cannot reflect adequately the strong public aversion to accidents involving large numbers of people, even if their probability is very low. Valuing the impact of low-probability/high-consequence events raises the issue of the additional weight that individuals tend to assign to those events. The full assessment will involve the probability, consequences, and emotional weight that each person assigns to these events, and their beliefs in the possibility of avoiding or mitigating the negative effects while still enjoying the benefits. This aversion is reflected in the special approach of governments to large accidents as opposed to small ones, for instance in setting up emergency preparedness organisations or special regimes like those for nuclear liability.

The biggest impacts from routine operation of the fossil fuel cycles are climate change and the public health effects of the coal and oil cycles, mainly due to respiratory diseases caused by particulate and other contaminants. According to the ExternE study, these are of the order of 10 mECU per kWh. The public health impacts of the natural gas cycles are an order of magnitude smaller. Occupational health impacts from the coal fuel cycles are also significant, mainly from pollution (dust and radon) in underground mines, but they are largely internalised through wages and would be much reduced for open pit mines.

A further important dimension of external costs is that of energy security, including the value of diversity within an electricity supply system. Nuclear energy creates a new and abundant energy source that would not exist otherwise, extending the world's energy resource base and providing greater security and diversity through its unique characteristics. Although security of supply is not perceived as a major issue for most countries, the reserves of conventional oil, the most essential fossil energy resource, are concentrated in the Middle East, which could cause problems in the event of political instabilities there, even if the market is seen today as functioning well. Some countries depend on imports from distant sources for their natural gas supply. Diversity and security of supply are designated as a policy priority in the shared goals of IEA Member countries.

Environmental dimension

The core indicators for the environmental dimension of sustainable development include criteria related to natural resource management, climate change, air and water quality, and biodiversity and landscapes. Environmental hazards arising from nuclear energy mainly result from radioactive emissions and waste. The nuclear industry in OECD Member countries has undertaken great efforts to ensure that the environmental risks from nuclear energy are kept within socially acceptable levels established by independent regulatory agencies.

The nuclear electricity generation chain does not release gases or particles that acidify rains, contribute to urban smog or deplete of the ozone layer. Carbon dioxide emissions from the entire nuclear fuel cycle are negligible. A single large nuclear power plant of 1 GWe capacity offsets the emission of about 1.75 million tonnes of carbon each year if it displaces coal, about 1.2 million tonnes if it displaces oil, and 0.7 million tonnes if it displaces natural gas. The actual figures will vary with capacity factors, thermal efficiencies of fossil-fuelled plants, fuel properties, etc. A nuclear plant will also offset the emission of SOx, NOx and particulate matter, thereby contributing significantly to local air quality.

Natural resource management

Efficiency of resource use is a key indicator of sustainable development in the energy sector. Nuclear power plants of the present generation operated once-through extract more than 10 000 times more energy per unit mass from uranium than other technologies do from fossil or renewable fuels. This very high energy density is a measure of resource efficiency. A much smaller amount of material is extracted, processed, stored, and transported for each kilowatt-hour of electricity produced than for other sources, and the waste volumes are also proportionately smaller.

Uranium has no significant use other than nuclear energy production. Producing electricity with uranium extends the overall resource base available for human use, provides greater diversity of choice and allows the use of other resources, such as hydrocarbons, where they are most effective e.g. transportation or petrochemicals.

The world's nuclear power plants consume the equivalent of about 60 000 tonnes of natural uranium per year. Known uranium resources represent more than 70 years of present consumption [27]. Uranium reserves, proven and economically exploitable, represent nearly 40 years of current consumption. The ratio of reserves to consumption is similar for uranium and oil [28]. As for any mineral resource, current reserves represent only what has been found because it has been looked for, with a fairly short-term economic return in mind. There is not much incentive to explore for uranium now if it will not be brought to market for many decades. It is known, however, that uranium is abundant in the earth crust and conventional resources are estimated to represent some 250 years of current consumption. In addition, unconventional resources contained in marine phosphates and sea water are two order of magnitude larger.

Uranium resources and reserves are distributed among many countries in different regions of the world, providing diversity and security of fuel supply. They occur in rock formations that are generally different from those yielding fossil reserves, so there is a geological diversity as well. The high energy content of the fuel, the stability of its ceramic form and the low share of fuel in total nuclear electricity generation cost make it feasible and cost-effective to maintain strategic inventories at reactor sites that provide a high level of security, allowing ample time for any interruptions in supply to be resolved.

Furthermore, nuclear fuel supply may continue to be sought from various sources other than newly mined uranium, including recycled materials and thorium. The capacity for recycling of nuclear fuel is a unique feature that distinguishes it from fossil fuels which, once burned, are largely dispersed into the environment in gaseous or particulate forms. The used fuel from the once-through nuclear fuel cycle contains fertile material that can be converted to fissile plutonium in adequately designed reactors. The current once-through nuclear fuel cycle uses mainly the fissile ^{235}U that constitutes less than one per cent of natural uranium. The resource base can be extended by a factor of about 30% by reprocessing the fuel and recycling the fissile material as mixed oxide fuel (MOX) in light water reactors. This technology has been developed and utilised to a significant extent in Europe and is being deployed in Japan.

By converting the bulk of the uranium resource to fissile material in fast neutron breeders or other types of advanced reactors it is possible to multiply the energy produced from a given amount of uranium by 60 times and more, as compared with present reactors using the once-through fuel cycle. A decision to move to those types of reactors and fuel cycles could transform the used fuel repository or storage facility into a veritable mine of nuclear fuel. That is part of the interest in maintaining a capacity for retrieving the spent fuel, seeing it as a potential resource rather than waste. Because such fuel cycles would permit so much value to be extracted per unit mass of natural uranium or thorium, much lower-grade ores of both elements could become economic. This would make nuclear energy a long-term energy source that could supply a large part of an increasing world energy demand. This recycle capacity contributes to an even higher level of overall resource efficiency and productivity, and to sustainable development goals.

Radiological protection

Radiological protection is essential to ensure that nuclear energy is compatible with sustainable development. Though the risks associated with radiation are among the most extensively studied hazards known to man, several factors increase public anxiety about radiation. It is invisible, unfamiliar, difficult to understand, and probabilistic in its effects, which to the public means uncertain. Radiation from nuclear fuel cycle facilities is produced by complex technologies, controlled and regulated by institutions that may appear remote from local experience. However, nuclear energy is not unique in this regard.

Since the beginning of the nuclear industry, OECD countries have established infrastructures for radiation protection including legislation, expertise, regulation and an awareness of radiation safety issues [29]. The principles that support the radiation protection approach and system are consistent with the goals of sustainable development. The effectiveness of these systems may be measured by the status and trends in radioactive emissions from nuclear facilities and the exposure of the public and workers to radiation.

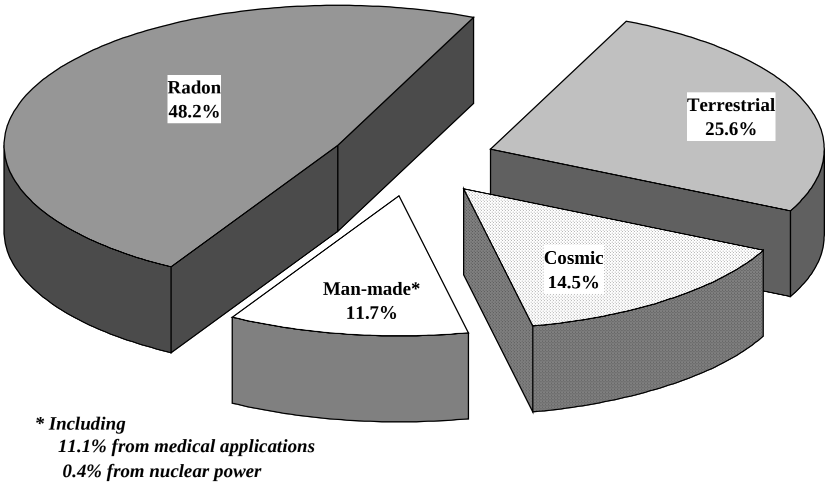
The International Commission on Radiological Protection (ICRP), a non-governmental body of experts, makes recommendations for the protection of people from the harmful effects of ionising radiation that are reflected in national regulations. The latest recommendations of the Commission for a system of radiological protection were published as ICRP Publication 60 in 1991 [30].

The primary aim of radiological protection, as stated by the ICRP, is to provide an appropriate standard of protection for mankind without unduly limiting the beneficial practices giving rise to the radiation exposure. Standards and recommendations are based on limiting by all reasonable means the risk of health effects, adopting a precautionary approach, but not on eliminating that risk entirely. Three principles form the framework for protection concerning practices that involve exposure: justification of the activity; limitation (i.e. keeping individual doses within regulatory limits); and optimisation (i.e. keeping doses as low as reasonably achievable – ALARA – economic and social factors being taken into account).

Regulatory standards for radiation apply to those human activities which cause public or worker exposure. The dose limits recommended for these activities are 1 mSv per year[4] for exposure of the public, and 20 mSv per year for exposure of workers. These limits can be compared with the average dose from natural background radiation of about 3 mSv per year, noting that actual figures vary widely with location. The natural variation in background radiation results in some regional populations being exposed to as much as about 10 mSv per year, with small populations being exposed to even higher natural doses. No effects have been identified in these cases. Figure 3.1 illustrates sources of exposures from radiation.

4. Since the Sievert is a large unit, doses are reported usually in milli (mSv) or micro (μSv).

Figure 3.1 **Average shares of annual exposures to radiation from natural and artificial sources**
Source UNSCEAR, Ionising radiation sources and biological effects, 1994 [31]



The driving force in operational radiation protection being the ALARA principle, the public and most workers generally receive only a small fraction of the regulatory limits as a result of activities undertaken within the nuclear energy sector. Typically, for populations living around nuclear power plants, the annual doses from the plant to the most highly exposed members of the public range from 1 to 20 μSv [31, §146], that is, between 50 and 1 000 times less than the annual limit. Conservative estimates for the most highly exposed individuals living near fuel reprocessing plants can range from 200 to 500 μSv [31, §146], or less than half the annual limit for the public. The average annual dose to workers in all nuclear fuel cycle activities is around 3 mSv [31, Table 3], which is comparable to the natural background or to the 2 to 3 mSv [31, §163] of occupational exposures received annually by air crews due mostly to cosmic radiation at high altitudes.

Occupational exposures at nuclear power plants, and within the fuel cycle in general, have been dropping for the last ten years or so, such that current levels of annual collective dose per reactor in 1999 are less than half what they were in 1987 [32]. At present, the dose commitment from the entire nuclear power industry is around 300 times lower than the natural background, and there is a trend of decreasing radioactive emissions per kWh [31]. Further progress is expected with improvements in operating procedures, plant design changes and fuel-cycle developments.

Radiation protection is a dynamic field. It benefits from continuing R&D. Research into biological susceptibility to radiation may help to target protection standards. Other promising areas include: continuing epidemiological studies and research on the effects of different kinds of radiation, doses and dose rates; the synergy of radiation with other health impacts; and the role of radiation in the multi-step process of cancer inducement [33]. Radiation protection will also improve further with new developments in instrumentation and in the management of radiation in the workplace.

In the case of radiation protection, public concerns seem to be more associated with the institutions and processes, and less with the actual risks and hazards, than for other energy sources or industrial activities. Thus the social aspect of these concerns must be addressed. The factors affecting public concern include the perceived benefits associated with the activities leading to the additional dose received, the need for those activities, their advantages over alternatives and the degree of control over the decision [34]. Policies and processes are key factors in this regard, although education and information about the hazards of radiation, the radiation protection regime, and risks in general, have an important role to play. Processes will be required, depending on the specific situations, that give equal importance to two sets of criteria without sacrificing the importance of either: the scientific nature of the risks involved; and the democratic right of citizens to participate in decisions that affect them, and to have their legitimate concerns taken fully into account.

Safety

If nuclear energy is to play a role in sustainable development policies, the health and environmental impacts of nuclear facilities and transport of nuclear materials – which are very small in routine operation – should remain below socially acceptable limits even in accidental cases. It means that the probability of a severe accident leading to off-site releases must be kept very small and that the consequences of such releases, should they occur, must be limited. In the OECD countries, nuclear power plants and fuel cycle facilities, operating under independent and competent regulatory regimes supported by a robust infrastructure of legislation, regulation, and standards, have achieved a good safety record.

The amount of fuel to be transported for generating nuclear electricity is small, owing to the high energy density of nuclear fuel. However, transport of nuclear fuel to and from nuclear power plants requires adequate packaging and regulatory measures to protect humans and the environment from being exposed to hazards from radiation. Physical security of sensitive materials should also be ensured. Regulations for the safe transport of radioactive material were published for the first time by the IAEA in 1961 and are revised and updated on a continuing basis. This regulatory regime has proven its effectiveness by the record established in the last 30 years in which there has been no known case of significant injury due to radioactivity in the transport of civil radioactive material.

Since nuclear facilities, and in particular reactors, are complex systems with a large inventory of radioactive materials, they have the potential to cause significant damage and require comprehensive safety systems. The basic technical approach to reactor safety is the defence in-depth concept representing five successive barriers. Careful implementation of this concept in nuclear power plant designs has resulted in a number of control, limiting and protection systems including multi-redundant stand-by, active and passive engineered safety features. Also, at various stages early in an accident sequence, a reactor protection system will intervene to stop the chain reaction and human actions will complement the prevention of an accident.

The risk of an accident leading to core damage has been estimated to be below 10^{-4} per plant operating year for reactors in operation in OECD countries. Taking into account the containment measures along with severe accident management and mitigating measures, the probability of a major external radioactive release should be further reduced by a factor of at least ten. This implies that for the individual member of the public living close to existing plants the risk of exposure to a significant radiation release would be less than 10^{-5} per year. Since the mid-1980s, improvements to design and operating procedures which have lowered significantly the risk of accident and indicators for reactor safety, as well as for radiation protection, show continuing progress.

The target for new designs is to lower the risk by a factor of ten as compared with current designs [35]. Both accident prevention and accident mitigation will be improved. Accident prevention will be enhanced by reducing the frequency of equipment failures and of human errors through improved man-machine interfaces, additional use of information technology, and self-testing protection systems. Accident mitigation will be enhanced by introducing specific design features for severe accidents which will practically eliminate large early radioactive releases and thereby limit off-site consequences so that off-site emergency plans, including evacuation of the public, will not be necessary, even in the case of an accident with severe core damage.

The reactor design and quality of construction, along with sound operating practices, are not the only means of ensuring safety. The analyses of causes and consequences of the two accidents that occurred with nuclear power reactors – Three Mile Island in the United States in 1979 and Chernobyl in Ukraine in 1986 – have led to significant improvements in reactor safety. In particular, they highlighted the need for more attention to human factors, including training and procedures at the operator level and stressed the importance of a safety culture.

Safety culture means an overriding priority to safety issues, extending from national legislation at the top, through the regulatory processes, to the senior management of the operating organisation and further to each individual having the potential to affect safety. It also includes ensuring feedback from the bottom to the top, learning from the experience of the global nuclear industry, and understanding the root causes of events that could lead to accidents. The independence of regulatory bodies is of high importance in this regard. Regulators are developing methods to assess the safety culture at operating organisations and tools for early intervention to correct deficiencies [36].

Regulatory oversight focuses on ensuring that the reactor does not reach a condition where any threat to the integrity of safety barriers occurs. If the regulator has any cause to believe otherwise, the reactor will not be allowed to operate. Governments have the responsibility to ensure that effective legislation exists and that the regulatory agency is independent and competent, and has all the resources needed to fulfil its responsibilities. While the prime responsibility for safety rests with the operator of the facility, a regulator is essential to monitor the operator's performance against accepted standards. It must have the authority and means to implement safety measures, including the ultimate authority to shut plants down. Regulators, operators and governments should be on guard against complacent attitudes that could reduce the priority for safety, especially in an era of ageing reactors and increased competitive pressures.

Another challenge is to engage people in a process of comparative assessment of risks and benefits from various human activities, so as to achieve an optimal allocation of resources in support of sustainable development. People tend to be more concerned about low-probability/high-consequence events than about more probable events with smaller consequences, even though the total impact of the latter may be greater [37]. For example, plane crashes get more attention than car accidents, although the latter claim more lives in total. Perceptions of the acceptability of risks also varies greatly with factors such as the degree of participation and control, the benefits, uncertainty about the likelihood or consequences of events, trust in the institutions that are involved, familiarity with the risks, fear of the consequences [38]. A comprehensive and consistent approach to risk management would contribute to enhance the effectiveness of control and mitigation systems and measures including nuclear safety.

With increased competition and privatisation, governments are withdrawing from their traditional role of supporting nuclear R&D. To the extent that safety research can be seen as a public good, like safety research in other regulatory areas such as food, medicine, and air quality, governments could consider some level of support for nuclear safety R&D. International co-operation on operations, regulation and safety research is an efficient way to share costs and facilities. International co-operation on safety matters is vital to ensure high safety standards throughout the world, especially if nuclear energy is to be used in a growing number of countries.

Third party liability

The third party liability regime is unique to nuclear energy and addresses a number of relevant issues in the context of sustainable development. While traditional insurance deals with high-probability/low-consequence events, the regime established for nuclear energy deals with low-probability/high-consequence events. There are increasing pressures for insurance regimes to deal with events of comparable scale arising from real natural and environmental disasters, which have become very costly in recent years.

Although the high safety standards of the nuclear industry mean that the risk of an accident is low, the magnitude of damage that could result to third parties from such an accident is potentially considerable. It was thus recognised from the very inception of the nuclear power industry that a special legal regime would need to be established to provide for the compensation of victims of a nuclear accident; the ordinary rules of tort and contract law were simply not suited to addressing such a situation in an efficient and effective manner.

If the ordinary law applied, victims would likely have a great deal of difficulty determining which one of the many entities potentially involved in the nuclear accident was actually liable for the damage caused. Also, without a limit on the amount of liability imposed upon the liable entity, that entity would not be able to obtain financial security, such as insurance, against that risk. In addition, accounting principles dictated that the operators of nuclear installations and the suppliers of nuclear goods and services simply could not carry such potentially large liabilities on their books, regardless of how unlikely a severe accident might be.

The nuclear liability regimes result from a reconciliation of several goals: providing adequate protection to the public from possible damage; ensuring that the growth of the nuclear industry, from which this same public benefits, would be protected from excessively burdensome liabilities; marshalling international insurance market resources to ensure that sufficient financial security is available to satisfy potentially large claims; and ensuring that liability and compensation mechanisms address the trans-boundary nature of nuclear damage. This led to a system, reflected in both national and international regimes, that is based upon the following principles: a nuclear operator’s strict and exclusive liability; limitations upon the time and amount of a nuclear operator’s liability; and the nuclear operator’s obligation to financially secure its liability.

National regimes are implemented through legislation in most OECD Member countries, and progressively in non-member countries. The current international regimes are reflected in the following Conventions: the 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy established under the auspices of the OECD and to which 14 OECD Member countries from Western Europe are Contracting Parties; and the 1963 Vienna Convention on Civil Liability for Nuclear Damage established under the auspices of the International Atomic Energy Agency, which is worldwide in character and to which four OECD Member Countries[5] are Contracting Parties. These two Conventions are themselves linked by a Joint Protocol.

Since the Chernobyl accident, the international nuclear community has recognised the need for extensive revision of the international regimes to enhance their provisions for protecting victims and to promote a global regime attractive to all countries. Those efforts resulted in a Diplomatic Conference in 1997 that led to the Convention on Supplementary Compensation for Nuclear Damage, as well as the Protocol to the Vienna Convention. In addition, efforts to revise the Paris Convention are expected

5. The Czech Republic, Hungary, Mexico and Poland each acceded to the Vienna Convention prior to becoming Member countries of the OECD.

to be completed in 2001. Widespread adherence to these instruments will go a considerable way towards internalising fully the costs of nuclear accidents and reflecting sustainable development goals.

The liability limit imposed upon nuclear operators under national legislation varies considerably between OECD Member countries. These variations result from the differing limits imposed under the two international Conventions, from the extent to which countries utilise nuclear power for energy production and from other political and economic factors. It should be noted as well that several OECD Member countries have adopted national legislation providing for the unlimited liability of their nuclear operators for nuclear damage, albeit with corresponding financial security amounts that are, of necessity, limited.

The argument against limiting the liability of the operator is that the operator is subsidised by not having to face the full value of an accident, and will have less incentive to ensure safety, thus making an accident more likely. On the safety issue, governments have argued that the operator and the operating staff have a strong self-interest in plant safety, and that the operator is strictly regulated by a competent independent organisation.

Radioactive waste management

From a sustainable development perspective, waste management practices are intended to ensure the confinement and disposal of waste materials in a way that minimises harmful impacts on humans and the environment at any time. Radioactive waste can be short- or long-lived depending on its intrinsic rate of decay. The main challenge for nuclear energy is long-lived waste that remains hazardous in the very long term. However, this characteristic is not unique to radioactive waste. Other types of toxic waste, such as heavy metals, remains in the biosphere indefinitely, or cause enough impact in the near term to permanently influence the longer term. Waste arising from the use of nuclear energy represents small volumes, typically less than 1% of the overall toxic waste in countries with a nuclear energy industry, and they can be isolated from the biosphere at affordable costs using available technologies.

The estimated cost of waste management and disposal represents a few per cent of the overall cost of nuclear generated electricity [21]. This cost is accounted for by nuclear electricity generators and reflected in the prices paid by consumers – i.e. internalised. In most OECD countries, funding for the repository is obtained from a charge to the consumer on the electricity whose production results in the waste. The funds accumulated and set aside will then be used when needed to cover waste disposal expenses. While the overall cost of waste management and disposal is rather high in absolute value, it does not add significantly to nuclear electricity costs once spread over the large amount of electricity generated.

Lightly contaminated materials, or materials whose radioactive contamination is relatively short-lived, which constitute the bulk of the volume of radioactive waste, present relatively low hazards. All OECD countries treat, transport and store such waste routinely, and methods for its management and disposal are well established. Its radioactivity decays to background levels in a few hundred years and does not create any major health or environmental problem. It can be disposed of in shallow or ground-level repositories that are in operation already in many OECD and non-member countries. There is a trend to reduce the volumes of this type of waste per unit of electricity generated, in order to reduce costs and to lower environmental burdens [39].

Uranium mining and milling activities generate tailings, which are radioactive at a relatively low level for very long periods and occupy surface areas of many hectares. The tailings have the same kind of volumes, depending on the ore grade, as tailings from other mining activities. Assessments of current tailings practices for licensed facilities in OECD countries have shown that the tailings can be effectively managed over long periods with minimal long-term health and environmental impacts. Future uranium mining developments in OECD countries will undergo close environmental scrutiny before being allowed to operate [40].

Long-lived waste, mostly solidified high-level waste conditioned through reprocessing or – for countries which have decided not to recycle – spent fuel, represents only a small fraction of the overall waste volume. The amount of spent fuel produced annually in the world is about 10 000 tonnes. The high-level waste may remain hazardous over many thousands of years and needs to be isolated from the environment over commensurably long time scales. However, the most intense part of the radioactivity and heat output is actually short-lived. It initially decays rapidly, making handling, further processing and disposal easier as time goes by. In OECD countries with nuclear power programmes, spent nuclear fuel and long-lived waste produced under licence are stored in safe and reliable pools or in dry storage canisters. The interim storage may be carried on safely and economically for many decades.

Although there is no environmental, technical or economic incentive for early disposal, interim storage is not a permanent solution and the concerns of sustainable development for burdens passed on to future generations are calling for progress toward final disposal. It is generally agreed that the best way to achieve long-term isolation is deep underground disposal in stable geological formations, a concept that is over 40 years old. Repository designs are based on a multiple-barrier approach ensuring isolation of harmful waste from the biosphere.

Assumptions used to assess the safety of repositories have been tested in nature. Over a billion years ago in Gabon, a natural nuclear reactor functioned on and off for several million years, moderated by natural water flow through a uranium ore deposit. The fission products from the nuclear reactions that took place did not move more than a few centimetres from their location of origin [41]. Also, other phenomena important for geologic disposal, as diverse as metallic corrosion, evolution of clay properties, solute migration in different media, chemical sorption and long-term climate change, have been studied in natural analogues, thus allowing a check of the understanding of processes that are too slow, or too large in scale, to be directly measured in the laboratory or the field.

Scientists and experts consider that nuclear waste can be handled safely and isolated from the environment for thousands of years and more until they become harmless. Technology for constructing and operating repositories is now mature enough for deployment, based upon experience gained worldwide that covers underground research laboratories and, in several countries, underground facilities for disposal of radioactive waste, including waste containing longer-lived radioactive components. The first purpose-built geologic repository of long-lived waste, which started operation in March 1999 in the United States, will provide additional industrial experience.

The nuclear industry has accepted its long term responsibilities with regard to containing its waste over its active lifetime. It set up standards for waste management in the long term at a time it was less common to do so in other sectors involving hazardous materials. However, radioactive waste has given rise to more public concern than most other types of toxic waste that also require adequate management and disposal policies [42]. The public does not necessarily share the high level of confidence of the scientific and technical community in the long-term safety of nuclear waste management. The inevitable uncertainties that arise in dealing with projections over thousands of years lead to reservations about committing to a course of action whose consequences cannot be fully assessed.

The process of finding a site for high-level waste disposal, developing a repository, putting waste in it, and closing it will take the better part of a century. The repositories now being planned are not expected to begin receiving waste until 2020 or later, and will remain open for many decades. The waste will remain retrievable, at least during the initial phases of the repository, and even beyond at an increasing cost. Monitoring and surveillance can be continued beyond the closing period. There will be many steps, and at each step the opportunity for regulatory action and for public participation in decisions. In particular, there is time to engage in comprehensive processes to decide on future steps, including the siting process. There will be opportunities to alter direction, or to benefit from new technologies. This approach guarantees that future generations will be given opportunities to make their own choices.

There is a need for coherent policy and a strict regulatory framework, with identified decision points that allow for public dialogue and participation. As for other controversial projects, universal support is not a realistic aim. On the other hand, society must be assured that every decision taken is a well-considered one. The process of step-wise decision-making should allow opportunities for input from all affected groups, on topics of their choice, and should include rigorous technical reviews as well. The technical information will be an essential input to the discussion but not the only one. Politically, the public concerns are as important in the process of decisions about long-term waste management as the confidence of the scientific community. Ultimately, governments are responsible for making decisions that achieve both an appropriate level of public support and an acceptable level of safety. If the challenges to radioactive waste management are social and political, the solution, while based on good science and technology, must be social and political as well. Sustainable development is about equity and participation as much as it about science and technology.

Social dimension

The human and social dimension of sustainable development comprises human capital in the form of knowledge, education and employment opportunities, human welfare, equity and participation, and social capital in the form of effective institutions and voluntary associations, the rule of law, and social cohesion. From these viewpoints, nuclear energy, like a number of other advanced technologies, is characterised by a net contribution to human and social capital and a challenge in terms of public acceptability and widely varying perceptions of the risks and benefits.

Human capital

Nuclear energy is one of the great scientific discoveries of the 20th century, and represents a valuable component of intellectual capital to be passed to future generations. It has a strong foundation in science and technology. It is an energy source based more on knowledge, and less on materials, than most others, and so should be amenable to greater improvement through gains in the gathering, processing and communication of information. It provides high-tech jobs and outlets for creativity at the highest levels. Nuclear science and technology interact productively with other fields such as medicine, robotics, sensors and control systems, materials sciences, and information technology.

The human capital for nuclear energy includes the highly qualified manpower that is essential for the design, construction and operation of complex facilities within the fuel cycle chain, including uranium mining and radioactive waste management, and for regulatory activities and R&D. These skills are an important part of a modern society’s overall range of scientific and technological resources. Renewal of this human capital, and of nuclear R&D capacity, will ensure that nuclear energy continues to contribute to scientific knowledge and technological opportunities in and beyond the nuclear fuel cycle.

To create a competitive electricity source from a breakthrough in fundamental science, extensive R&D programmes were necessary. According to the statistics published by the IEA, total government budgets for nuclear fission R&D in IEA Member countries during the period 1974-1995 ranged between 4 and 9 billion USD per year [43]. Now, nuclear energy has reached industrial maturity and R&D in commercial support of existing reactors may be taken up by industry, or even reduced to some extent. However, in order for nuclear energy to contribute effectively to sustainable development goals, R&D oriented to the longer term may be required. Governments can contribute particularly to R&D that supports public policy goals in areas such as safety, regulation, and environmental impact including waste management. International co-operation in these areas helps to make efficient use of human resources, funds and facilities.

Institutional framework

The institutional framework established around peaceful nuclear activities is unique in many ways. Nuclear fission was discovered in 1939 and its first major application was the development of nuclear weapons. Given national security implications, governments of countries that developed peaceful applications of nuclear energy did so at the highest political levels, through institutions dedicated to that end. In the nuclear weapons states, these institutions were often dual-purpose, with both military and civilian goals. National nuclear institutions usually preceded the establishment of broader energy institutions. The same is true internationally – the formation of the IAEA and the NEA predated by many years the creation of the IEA and other bodies looking at energy in a broader context. Today, nuclear energy remains an issue generally considered at the highest levels of government in most countries.

The existence of nuclear-specific institutions, with separate funding and in many cases dedicated national laboratories, was initially beneficial to a development of nuclear energy consistent with governmental policy objectives. However, in retrospect this isolation of the nuclear institutions might have been detrimental to its integration in the basket of options considered within the broader energy policy debate. Also, the sheltered situation of the nuclear industry did not facilitate its timely adaptation to market competition. Moreover, the public perception of nuclear energy has been negatively influenced by the impression of secrecy associated with the separation of nuclear institutions from other governmental bodies.

The original nuclear institutions generally were not independently regulated, as national security was the priority at that time, rather than safety and environmental protection. Activities that were not independently and adequately regulated have been the sources of many of the more serious safety and environmental problems that have occurred in the nuclear industry. While the responsibility for safety rests with the operator, effective and independent regulation, backed by strong legislation, makes an essential contribution to nuclear safety and to a safety culture. It also builds confidence in nuclear energy.

Independent regulatory bodies now in place play a key role in ensuring that nuclear energy activities are carried out in compliance with high safety and radiation protection norms. In OECD countries, nuclear regulatory bodies have established high standards of expertise and independence, and have helped to ensure a track record on reactor safety, waste management and radiation protection that has generally been very good. The key attributes of an effective regulator may be easier to achieve in democratic systems, where publicly acceptable standards of safety are achieved through legislation enacted by an elected parliament, and where institutions are more likely to be both trustworthy and trusted. Continued support for effective, independent regulatory bodies is essential for nuclear energy to contribute to sustainable development policies, as is the encouragement of effective regulation in countries outside the OECD.

In most countries with nuclear energy activities, there are strict legislative requirements in place to ensure the health, safety and security of workers and the public, and the protection of the environment. However, not all countries have comprehensive nuclear legislation in place and, even where the legislative requirements extend explicitly to the goals of sustainable development, there can be gaps in how those requirements are administered. Nuclear regulatory authorities need sufficient resources, legal authority and incentives for compliance to be able to administer the regulations under their jurisdiction. Institutions for the long-term management of nuclear wastes will require careful attention in their design, regulation and funding.

Non-proliferation

In order to contribute to sustainable development goals, nuclear energy should not contribute to the proliferation of nuclear weapons. It is a major concern for policy makers and the public that sensitive nuclear materials, in particular highly enriched uranium and plutonium, as well as technology and equipment developed and used for civilian activities, could be diverted to military or terrorist purposes. However, the potential proliferation of nuclear weapons is not a danger stemming only from the peaceful uses of nuclear energy: renouncing nuclear energy would not eliminate the risk of nuclear weapon proliferation.

The proliferation threat must be seen in the political context of international security and the overall strategic role of nuclear weapons. The basic political challenge is to improve international relations, and the understanding of the consequences of nuclear war, to the point where countries do not see nuclear weapons as legitimate instruments of defence or diplomacy. The threat of a nuclear exchange between the superpowers has receded with the end of the Cold War. Isolated countries confronted by powerful adversaries and countries in regions with great tensions are the most likely candidates to perceive nuclear weapons as attractive. Finding other solutions to their security problems may reduce their incentives to acquire such weapons.

The most important instrument for discouraging the production or diversion of weapon-grade materials is the permanent Treaty on the Non-Proliferation of Nuclear Weapons (NPT) of 1970 that commits 187 countries and carries an explicit commitment by the non-nuclear-weapon States to receive the benefits of peaceful nuclear technology in return for agreeing to forego nuclear weapons. The compliance with the latter commitment is being verified by an international safeguards regime, administered by the International Atomic Energy Agency (IAEA). Through its safeguards system the IAEA can verify that nuclear activities in non-nuclear-weapon States party to the NPT are being used exclusively for peaceful purposes. Most countries are parties to the NPT and accept international safeguards on their nuclear programmes. The effectiveness of safeguards controls has been strengthened recently in order to enable the IAEA to provide credible assurances about the non-diversion of declared nuclear material and the absence of undeclared nuclear material and activities.

Basic knowledge of nuclear weapons technology is fairly widespread, although many aspects related to fissile material and weapons production remain closely guarded. With the political will and the commitment of adequate funds, a country with a sufficient level of scientific and industrial know-how will be able to develop weapons. If a political decision is taken, nuclear weapons can be acquired independently of any civilian nuclear power programme. In fact, historically, most countries possessing nuclear weapons acquired them before they developed peaceful applications of nuclear energy. They have used dedicated facilities and staff for military activities, including the production of weapons-suitable fissile material, rather than civilian power programmes.

A number of technical difficulties must be overcome in order to use a nuclear power programme as a source of materials for weapons. In particular, plutonium from reactor-grade fuel produced under normal operation for power generation is much less suitable for weapons than that from dedicated facilities with low fuel burn-up. Moreover, in countries having signed comprehensive safeguards agreements, all nuclear facilities are subject to peaceful use commitments verified by international controls. Civilian nuclear power programmes under international safeguards are not very attractive for use in a clandestine nuclear weapon programme, since a misuse of material under safeguards would have a high probability of being detected. A country that takes the political decision to embark in a military programme would likely use dedicated, and probably clandestine, facilities under separate military control.

Controls also encompass research facilities and facilities handling highly enriched uranium or separated plutonium since such fissile materials may be used for developing nuclear weapons. Technologies that enrich uranium or separate plutonium are considered sensitive as they could contribute to a weapons programme. They are used by a limited number of countries. The enrichment of uranium requires a complex physical process to separate the different isotopes of the same chemical species. Plutonium, which is created in nuclear reactors, can be separated chemically from the used fuel, an easier process, though one still fraught with technical problems and hazards. Generally, "dual-use" technologies that can have critical applications for both civilian and military goals must also be carefully monitored. Dual-use aspects should be and are an important focus of the international non-proliferation regime. Monitoring dual-use and other proliferation-sensitive activities also takes place through national technical means.

Just as nuclear power programmes everywhere in the world must be safe, they must also be secure against the threat of proliferation. In spite of significant improvements, concerns remain about inadequate controls over nuclear weapon materials in some countries, illicit trafficking in fissile materials, the possibility of clandestine activities by some countries in violation of their NPT commitments, and the activities of countries that remain outside the NPT. Continued international efforts are necessary to deter and prevent the diversion of sensitive materials. This is a key objective from a sustainable development perspective and has to be ensured through policy measures and technology progress – e.g. reactor designs and fuel cycle processes that integrate non-proliferation criteria, including safeguards requirements. The Convention on the Physical Protection of Nuclear Materials and the IAEA programme aimed at preventing illicit trafficking are already serving as effective tools to address the issue.

Public participation and political aspects

Public participation in policy making and public acceptance of processes and decisions are central to meeting the social goals of sustainable development in terms of equity and transparency. In democracies, public concerns and political aspects of projects and policy measures have to be addressed by decision makers. For nuclear energy, as for a number of other technologies, most concerns arise from the public perceptions of the risks involved. Achieving acceptability will require an understanding of risk perception and communication, and the development of processes and institutions that involve greater participation by the public. While such participation might limit momentarily the use of nuclear energy, it is a key to the social acceptance required for any technology to contribute effectively to sustainable development.

Risk assessment, communication and management is a discipline still in a period of evolution. Initially, it was believed that frequent differences between expert and public perceptions of risk arose because the experts were right and the public was wrong, due to lack of education or information about the risks. The challenge was to educate the public so that it would understand the risks and, by implication, come to agree with the experts. More recently, it has been argued that the public is not wrong, and that its concerns must be addressed on its own terms [44]. What is needed is not just a one-way flow of information to the public, but rather more dialogue and participation.

The dissemination of accurate information is essential, but it does not seem to be enough by itself. Communication is a two-way street, and trust in the communication process often seems to be more important than specific information on technical matters. Authoritative information can be offensive if the implication is that the audience must take the information on faith, and that its fears are due to its own ignorance. Also, while comparisons of options are essential in making good policy decisions, pointing to other activities that cause greater harm does not of itself inspire confidence. Risk comparisons in a controversial context may be perceived as a means to trivialise anxieties and hide problems. The context and criteria for comparisons have to be accepted before the results are given credibility. The role of governments is essential on those very sensitive issues.

Many factors affect the way risks are perceived. A major factor is whether risks are seen as voluntary or imposed. Voluntary risks, such as those taken by driving a car, are far more readily accepted than those which are perceived as imposed, such as those associated with nuclear energy [45]. Another important factor is the perceived benefits that balance the risk. In the case of nuclear energy, the benefits are largely diffuse and perceived as obtainable by other means. Nuclear energy is not a consumer product or activity that builds brand loyalty like a car, or which gives people a sense of participation, like energy-efficient windows. Often, nuclear energy is an unseen part of the electricity supply mix, therefore, its risks seem to be perceived as more immediate and dramatic than its benefits. Where the need and the benefits are clear, or where nuclear facilities are familiar and seen to be properly managed, the risks tend to be more accepted.

Nuclear risks are also seen as more acute than other energy-related risks such as climate change or even local air pollution. A potential accident at a local nuclear plant may not affect the long-term future of the earth, but will be seen as having a very direct negative impact on the lives of nearby people. If a project is seen primarily as bringing a risk to a community, its messages are not likely to be well received. The proposed siting of a nuclear facility may not be the most propitious occasion for educating the local public about nuclear issues. It is important that the information be provided on an ongoing basis, and that the process of decision allow the time and opportunity for a thorough discussion to be carried out. Credibility takes time to establish. Once lost, it is hard to restore.

Other factors affecting risk perception include: the degree of control, the familiarity of the technology, the degree of uncertainty or controversy surrounding an issue, the fear of consequences, the perceived interests and power of the participants, the degree of trust in institutions, the process of consultation or decision-making, and the ideas and values of the immediate community in which people live. The impact of previous experience and the treatment of this and similar events in the media, as well as broader social and political phenomena involving the participants, can all condition people's perceptions and determine their positions on issues and their response to specific messages. Plans for communications and processes must keep in mind the mindset and the attitudes of those involved.

The acceptability of nuclear energy will depend partly on a better understanding of nuclear matters, nuclear safety in particular, at the level of the public. This forms part of the broader issue of public attitude towards new technologies and technical development. In many cases, as noted above, there is a large gap between the understanding of risk issues by scientists and experts, on the one hand, and the lay public, on the other. This gap is often filled by the media or by special interest groups. If the authorities are not seen as providing full and accurate information, or responding to people's concerns, they will lose credibility and other sources will fill the gap. Thus it is important for the authorities to provide accurate and timely information and to respond to the public's concerns as they arise. Public education on nuclear energy issues will have to be addressed to all social categories and all ages.

Governments wishing to consider maintaining the nuclear energy option as a contribution to sustainable development may want to devise processes that give people a better sense of participation in nuclear decisions. Public hearings and debates can enhance confidence in the relevance of a decision about continuing with nuclear energy. Even though some of the players may use the occasion to rehearse well-entrenched arguments, it is important for the public to see that its concerns are thoroughly debated in the specific context of the decision at issue. Building trust seems to be one of the keys to acceptability. Trust requires listening carefully to people's views and acting on them. This is not to say that decisions should be based on perceptions rather than science. One has to have both the science and the trust. Once trust is established the process becomes easier.

Societies have to develop a consistent and broadly acceptable approach to risk management across the whole range of human activities and to implement processes for doing so. Sustainable development demands a comprehensive long-term global approach. It will also depend on many near-term actions and decisions at the local level. Nuclear energy must demonstrate its effectiveness on both sets of scales. Dealing with public concerns and negotiating acceptable solutions will be a challenge. The role of governments will be crucial in setting out the processes and acting as a source of objective information, and as the ultimate decision maker. Governments will have to dedicate adequate resources for this purpose.

International co-operation

Nuclear activities in any country have an impact on programmes in other countries. As with other contaminants, radioactive releases can have transboundary impacts. There is already a well-established international co-operation framework in the nuclear energy field covering R&D, regulations and legal aspects, exchange of information, technology transfer and material trade. The implementation of nuclear energy policies consistent with sustainable development goals may be achieved more efficiently with an increasing degree of international co-operation.

While most of the world's nuclear electricity is currently generated within the OECD area, most of the growth in the next few decades will most likely occur outside it, in developing and transitional countries. They will need co-operation and assistance on training, institution building, legislation and regulation, as well as a full exchange of information on operating experience, to ensure safety and good performance. Nuclear energy has a strong institutional base in OECD Member countries, which can share their information and experience with other countries.

The International Convention on Nuclear Safety is a relevant example of trends towards more effective international co-operation in developing institutional frameworks. It has been ratified by about 50 countries and has entered into force recently. This and other conventions – the Convention on Early Notification of Nuclear Accident and the Convention on Mutual Assistance in Case of a

Radiological Accident – are basic elements of the current international nuclear safety regime. States Parties to the Nuclear Safety Convention have agreed to submit on a regular basis their National Reports for mutual peer review. In these reports they are supposed to report on the status of implementation of all obligations specified in the Convention. The first review meeting took place in April 1999. This practice will be one more instrument to encourage countries to develop and strengthen the relevant institutions and the required safety culture.

Considerable progress in nuclear safety has been made in Eastern Europe and the Former Soviet Union, but there are still some concerns among safety experts about some of the Russian-designed reactors, such as the Chernobyl-type RBMK reactors and the older Soviet-designed pressurised water reactors. Design changes and system improvements have been made. Reactor operations, along with in-service inspections and maintenance, have also improved, but more needs to be done to encourage a pervasive safety culture. Legislation is largely in place in those countries and regulatory agencies are acquiring the necessary independence and authority, but they still lack resources in many cases. Western organisations, including the OECD/NEA, are co-operating with the authorities in the Former Soviet Union and Eastern Europe to improve safety standards, and to promote modern legislative and regulatory regimes. Satisfactory responses to those issues are essential from a sustainable development perspective.

International co-operation in nuclear R&D is especially relevant to enhance the overall efficiency of national efforts and facilitate technology development. Governments and industries could benefit from pooling resources and carrying out studies jointly instead of separately. As national nuclear R&D budgets are shrinking, co-ordinated strategies on investments in capital-intensive R&D equipment would facilitate technology progress and safety enhancement. Given their experience in co-operation and joint projects, international organisations like the NEA can play an important role in this regard. One of the challenges of international co-operation in a competitive environment, for nuclear energy as for other advanced technologies, will be to integrate the work of companies and business associations into governmental efforts.

4. KEY ISSUES AND ROLE OF GOVERNMENTS

The data and analyses included in Chapter 3, based on the experience accumulated on in the peaceful uses of nuclear energy, give insights on the relevance and potential contribution of nuclear energy to sustainable development goals and policy. Nuclear energy is one of several supply options. Its benefits, costs and risks should be analysed and compared with those of other options, including demand management. Since the information given in this report covers nuclear energy, it should be complemented by similar data and analyses on alternatives in order to provide a robust basis for policy making. Furthermore, as for any technology, the use of nuclear energy within national energy policies will be decided on the basis of criteria and trade-offs that will vary from country to country, depending on specific domestic situations and priorities.

While economic deregulation will place emphasis on market mechanisms, governments will maintain a central role in ensuring the framework conditions for technology development. Governments will assess nuclear energy in the context of their overall policy on energy supply, environment and sustainable development. The outcomes will differ depending on domestic energy resources, present and past reliance on nuclear energy as well as public acceptance and political aspects. In the light of the transboundary issues raised by nuclear facilities, all governments will have interest and responsibilities in the field of radiation protection, safety, third party liability and non-proliferation. The role of government includes ensuring transparency across boarders in the field of nuclear safety.

The analysis of nuclear energy characteristics within a sustainable development framework shows that the approach adopted within the nuclear energy sector is fairly consistent with sustainable development goals of passing a range of assets to future generations while minimising environmental impacts and burdens. In this connection, the statistical data series compiled by the nuclear sector on a regular basis provide a sound preliminary approach to the establishment of indicators on sustainable development trends. Governments and governmental organisations should pursue their efforts in maintaining a consistent framework to measure progress in this regard.

Other characteristics of nuclear energy create challenges for its future contribution to sustainable development policies. The economic competitiveness for new nuclear power plants will remain an issue, even if a more level playing field is established, and public concerns about nuclear risks and their management may limit the use of nuclear energy. The role of governments is important in this regard since they are responsible for getting the prices right (to get the right technologies in place) and for providing the regulatory framework that may enhance public confidence in the ability to control and manage technological risks.

Existing nuclear power plants are economically competitive in most cases and perform well in deregulated electricity markets. Those plants represent an asset for utilities and for governments, in connection with policies to address global climate change in particular. New nuclear units, however, are seldom the cheapest option in present markets and require high investments, which will need more than two decades to be amortised. A significant reduction in capital costs of nuclear power plants will be necessary and research and development efforts in that direction, such as the Generation IV initiative in the United States, need to be continued.

From a sustainable development viewpoint, however, the competitiveness of different supply options should be assessed on the basis of the full costs to society, taking external costs into account and removing inappropriate subsidies, as well as integrating their contributions to alleviating the risk of global climate change and to the security and diversity of supply in a world energy system largely based on fossil fuels. Comprehensive studies on the comparative health and environmental impacts of alternative options, at the national and international level, would be helpful in this regard. International bodies such as the OECD, the IEA and the NEA may assist governments in this field. Eventually, governments will be responsible for designing and implementing policy measures that aim at getting the prices right while meeting other public policy goals.

Governmental support to nuclear energy R&D and infrastructure should be assessed in the light of public policy objectives that nuclear energy can help to meet and in conjunction with support to other options that offer similar opportunities. Government funded R&D should not substitute for industry supported R&D but complement it in the fields that are under the main responsibility of the government such as basic sciences, safety and environmental protection as well as innovative concepts for long-term development. Enhanced international co-operation in those R&D fields could improve the efficiency of national efforts through synergy and joint projects.

In OECD countries, nuclear energy in routine operation has low impacts on health and the environment. Its high standards of radiation protection and reactor safety ensure a low probability of accidents or releases that could lead to significant health and environmental impacts. Most indicators of radiation protection, reactor safety, and environmental impact show improving trends. In order to make a continuing contribution to sustainable development goals, nuclear energy will have to maintain its high standards for safety in spite of increasing competition in the electricity sector, ageing reactors, and the expansion of the industry to new countries and regions. The effectiveness of international regimes will need to be ensured through improvements in international agreements and controls whenever necessary.

Radioactive waste management policies in place aim at containing all hazardous substances throughout their active life. Safe interim storage is the current practice for long-lived radioactive waste that will eventually be disposed of in repositories. Geological disposal has been identified as a technically safe solution that can be implemented without affecting the competitive position of nuclear energy. While there is no technical urgency to implement long-lived waste repositories, it is important to construct and commission such facilities to fulfil the goals of sustainable development, including social acceptance of nuclear energy.

The role of governments is essential in formulating regulatory frameworks and policies that will allow a coherent step-by-step approach towards decommissioning of nuclear facilities and final disposal of all types of radioactive waste. They are responsible for decisions on long-lived waste disposal strategies and measures to ensure that adequate funds, collected from the users at the time they benefit from nuclear energy, will be set aside and guaranteed to cover in due course expenses associated with decommissioning of facilities and disposal of waste.

Effective regulation and high safety standards should be maintained in the nuclear energy field but those standards and norms should be put into perspective. It is important that governments support a consistent approach to risk management and regulation across society's activities, taking into account available resources, possibilities for improvement, and perceptions of risk. Societies should allocate their scarce resources for dealing with risks in ways that produce the best results.

The potential links between peaceful uses of nuclear energy and the proliferation of nuclear weapons merit special attention. Diversion from peaceful nuclear energy programmes is one possible route, although not the most likely one, to the acquisition of essential technology, equipment, or fissile material for weapons by countries or groups who seek them. Since proliferation is essentially a political problem, governments should seek political solutions, including confidence building between countries and enhancing regional security.

An international non-proliferation and safeguards regime has been put in place to address this risk. This regime is regularly reviewed and adapted to keep pace with a wider access to nuclear technologies throughout the world. National export controls should be consistent with the aims of international agreements in this area. Non-proliferation concerns should be integrated into the development of new nuclear facilities and processes.

The national and international institutional frameworks that support nuclear energy are well established, especially in OECD countries that operate nuclear energy facilities. Nuclear energy has a tradition of exchange of information and experience and of international co-operation, through governmental agencies such as the IAEA and the NEA, that is worth pursuing. Nuclear laws, safety regulation, safeguards systems and liability regimes form a comprehensive institutional infrastructure that governments should maintain in OECD countries and contribute to establish in non-member countries that embark on nuclear energy programmes.

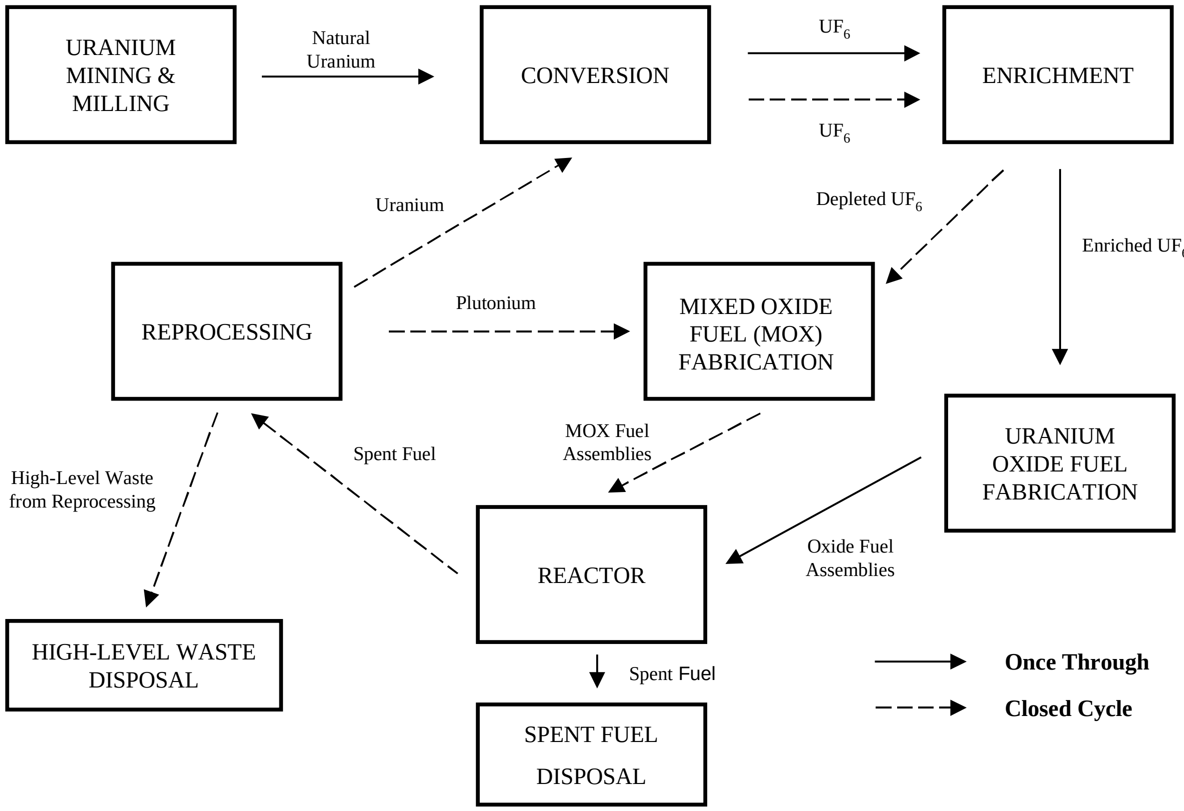
In order to meet sustainable development goals in the areas of equity and participation, nuclear energy will have to achieve a higher level of public acceptability than it enjoys in many countries today. New processes should be developed for public participation in nuclear issues generally, based on the best scientific information available but keeping in mind that communication must be a two-way street and that the public's perceptions and concerns must be heard and addressed. Governments have a key role in designing such processes, and allocating the required resources to their implementation. Education based on accurate information and good science will continue to be essential, but equity and participation will have their own importance. Ethical issues such as those raised by geological disposal of radioactive waste must be debated and put in perspective with other burdens passed to future generations such as the impacts of greenhouse gas emissions and other pollutants, and the exhaustion of natural resources. Other social and political issues have to be addressed in the process in an integrated way that allows for the identification of the full range of costs, benefits and possible trade-offs.

Technology transfer, technical assistance and co-operation with non-member countries will be especially important in the light of the growing demand for energy in those countries. Most of the new nuclear energy capacity is likely to be built in non-member countries in the medium term. Governments from OECD countries will have an important role in providing those countries with information and resources to address key issues in the field of legal frameworks, health and environmental protection, safety and waste management.

Annex 1

SCHEMATIC DIAGRAM OF THE NUCLEAR FUEL CYCLE FOR A LIGHT WATER REACTOR

The following diagram summarises the main steps of the fuel cycle for a light water reactor. It illustrates the number of activities that constitute the nuclear energy sector. The details of fuel cycle steps and levels vary from reactor type to reactor type but the main elements remain similar for current nuclear power plants. The fuel cycle of a nuclear power plant can be divided into three main stages: the so-called front-end, from mining of uranium ore to the delivery of fabricated fuel assemblies to the reactor; the fuel use in the reactor; and the so-called back-end, from the unloading of fuel assemblies from the reactor to final disposal of spent fuel or radioactive waste from reprocessing.



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