IAEA
International Atomic Energy Agency

IAEA NUCLEAR ENERGY SERIES

No. NG-T-4.8

Approaches to Cost-Benefit Analysis of New Nuclear Power Projects

TECHNICAL REPORTS

IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

STRUCTURE OF THE IAEA NUCLEAR ENERGY SERIES

Under the terms of Articles III.A.3 and VIII.C of its Statute, the IAEA is authorized to "foster the exchange of scientific and technical information on the peaceful uses of atomic energy". The publications in the **IAEA Nuclear Energy Series** present good practices and advances in technology, as well as practical examples and experience in the areas of nuclear reactors, the nuclear fuel cycle, radioactive waste management and decommissioning, and on general issues relevant to nuclear energy. The **IAEA Nuclear Energy Series** is structured into four levels:

(1) The **Nuclear Energy Basic Principles** publication describes the rationale and vision for the peaceful uses of nuclear energy.
(2) **Nuclear Energy Series Objectives** publications describe what needs to be considered and the specific goals to be achieved in the subject areas at different stages of implementation.
(3) **Nuclear Energy Series Guides and Methodologies** provide high level guidance or methods on how to achieve the objectives related to the various topics and areas involving the peaceful uses of nuclear energy.
(4) **Nuclear Energy Series Technical Reports** provide additional, more detailed information on activities relating to topics explored in the **IAEA Nuclear Energy Series**.

Each publication undergoes internal peer review and is made available to Member States for comment prior to publication.

The IAEA Nuclear Energy Series publications are coded as follows: **NG** – nuclear energy general; **NR** – nuclear reactors (formerly **NP–** nuclear power); **NF** – nuclear fuel cycle; **NW** – radioactive waste management and decommissioning. In addition, the publications are available in English on the IAEA web site:

www.iaea.org/publications

For further information, please contact the IAEA at Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of the IAEA Nuclear Energy Series publications are invited to inform the IAEA of their experience for the purpose of ensuring that they continue to meet user needs. Information may be provided via the IAEA web site, by post, or by email to Official.Mail@iaea.org.

APPROACHES TO
COST–BENEFIT ANALYSIS OF
NEW NUCLEAR POWER PROJECTS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CABO VERDE
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GAMBIA
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUINEA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS, KINGDOM OF THE
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT KITTS AND NEVIS
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAMOA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TONGA
TRINIDAD AND TOBAGO
TUNISIA
TÜRKİYE
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NG-T-4.8

APPROACHES TO COST–BENEFIT ANALYSIS OF NEW NUCLEAR POWER PROJECTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2024

COPYRIGHT NOTICE

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/publications

Printed by the IAEA in Austria
April 2024
STI/PUB/2079
10.61092/iaea.5t26-8tpd

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Approaches to cost-benefit analysis of new nuclear power projects / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2024. | Series: IAEA nuclear energy series, ISSN 1995-7807 ; no. NG-T-4.8 | Includes bibliographical references.
Identifiers: IAEAL 24-01669 | ISBN 978-92-0-105324-4 (paperback : alk. paper) | ISBN 978-92-0-105224-7 (pdf) | ISBN 978-92-0-105424-1 (epub)
Subjects: LCSH: Nuclear power plants — Cost effectiveness. | Nuclear power plants — Economic aspects. | Nuclear power plants — Management.
Classification: UDC 621.311.25 | STI/PUB/2079

FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology. While the guidance provided in IAEA Nuclear Energy Series publications does not constitute Member States' consensus, it has undergone internal peer review and been made available to Member States for comment prior to publication.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

The IAEA offers a wide range of services to support the introduction or expansion of nuclear power. To assist Member States, in 2015 the IAEA published IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), Milestones in the Development of a National Infrastructure for Nuclear Power, which provides an overview of the 19 issues to be addressed in the three phases of infrastructure development. One of the key activities carried out during phase 2 is a feasibility study for the first nuclear power plant. The feasibility study provides stakeholders with the information needed to justify and implement the nuclear new build project. The scope of a typical feasibility study is described in IAEA Nuclear Energy Series No. NG-T-3.3, Preparation of a Feasibility Study for New Nuclear Power Projects. The publication suggests conducting multiple studies to justify the implementation of a nuclear new build project, including an economic cost–benefit analysis.

This publication suggests the use of a canvas and framework when conducting a cost–benefit analysis for a nuclear new build project as part of a feasibility study. Cost–benefit analysis is a microeconomic evaluation approach enabling the assessment of a project's long term impact on society by quantifying the relevant costs and benefits in monetary terms. The methodology allows for the acknowledgement of the social, environmental and economic costs and benefits associated with investments in power generation systems. The publication also includes an example illustrating the application of the cost–benefit analysis methodology to a fictitious nuclear new build project.

The IAEA officers responsible for this publication were S. Dardour and D. Subbotnitskiy of the Division of Planning, Information and Knowledge Management.

EDITORIAL NOTE

This publication has been edited by the editorial staff of the IAEA to the extent considered necessary for the reader's assistance.

It does not address questions of responsibility, legal or otherwise, for acts or omissions on the part of any person.

Although great care has been taken to maintain the accuracy of information contained in this publication, neither the IAEA nor its Member States assume any responsibility for consequences which may arise from its use.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The IAEA has no responsibility for the persistence or accuracy of URLs for external or third party Internet web sites referred to in this book and does not guarantee that any content on such web sites is, or will remain, accurate or appropriate.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Nuclear power generation matches three of the main objectives of modern energy policy: reduction of carbon emissions, increase in security of supply and predictable generation costs [1, 2]. This is why some countries intend to introduce nuclear power or expand existing nuclear programmes in the coming decades [3]. However, a commitment to nuclear energy also entails a number of inherent challenges, including a long, complex and costly regulatory process and exposure to political risks [3, 4], which cannot be neglected.

Similar to other large infrastructure projects, new build nuclear power plants (NPPs) are large, complex and capital intensive investments with extended economic lives, and are often preceded by long design, development and construction periods. These lengthy phases typically lead to large funding requirements and, ultimately, to extended financing costs.

In the context of limited financial resources, governments promoting the development of nuclear new build projects will seek efficient allocation of their resources and to ensure that the benefits of nuclear power exceed its costs, including the external costs. By taking the perspective of society as a whole, a cost–benefit analysis (CBA) measures and compares the socioeconomic costs of an investment with its socioeconomic benefits, thereby determining whether it is an efficient use of resources or not.

1.2. OBJECTIVE

The objective of this publication is to provide IAEA Member States with a common framework for ex ante CBA of nuclear new builds.

Although there is a wealth of literature on CBA, no guidelines have been prepared specifically for nuclear new build projects to date. This is the primary driver behind the IAEA's effort to develop this detailed guidance publication, building upon existing efforts, in order to address the specifics of nuclear CBA.

This publication aims to respond to Member States' requests, in particular those from newcomers, for approaches to conducting CBAs for nuclear new build projects as part of a feasibility study. Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.3. SCOPE

The scope of the publication is that of the economic analysis section of the IAEA's publication, Preparation of a Feasibility Study for New Nuclear Power Projects (IAEA Nuclear Energy Series No. NG-T-3.3) [5]. It develops the content of this section, providing a conceptual framework for CBA of nuclear new build projects, covering areas such as demand and supply analysis; options analysis; financial analysis[1]; and economic analysis.

The multistep procedure suggested in this publication (Fig. 1) reflects state of the art approaches in CBA and expert judgment. It does not constitute recommendations made based on a consensus of Member States.

---

[1] In the context of this publication, 'financial analysis' refers to a preparatory step for the 'economic analysis'. Therefore, it is different from a 'standard financial analysis', conducted by investors, for example, to evaluate the project's ability to generate value for its shareholders.

FIG. 1. Proposed CBA procedure.

1.4. STRUCTURE

This publication comprises five sections, including this introduction (Section 1).

Section 2 provides a general introduction to CBA and provides an overview of the key principles and steps of a CBA.

Section 3 focuses on the specifics of nuclear power projects and presents the application of CBA for nuclear new build projects.

Section 4 presents an illustrative case study for a CBA applied to a nuclear new build project. The case study is solely intended to be a worked example of the general methodology described in Section 3. The selected project, its counterfactual and the assumptions made do not reflect the variety of reasons that can possibly justify the implementation of an NPP project. The example provided is not meant to be seen as representative or standard for nuclear new build projects in any country.

Building upon previous sections, Section 5 summarizes the prior sections and presents concluding remarks.

Finally, the appendices provide complementary information. They contain an overview of approaches for estimating the discount rates, an overview of methods to estimate willingness to pay (WTP), a review of external costs studies in the energy field, illustrative tables for the calculation of the financial and economic performance indicators and a description of the IAEA Nuclear Power Cost–Benefit Analysis Toolkit.

1.5. USERS

This publication is intended for economic analysts and energy planners exploring ways to inform energy policies and strategies at the governmental level as well as at ministries leading or contributing to energy planning studies. The suggested approach to CBA is aimed, in particular, at evaluators and managers of organizations conducting feasibility studies (FSs) for new NPP projects and considering developing an economic assessment study as part of the FS. In addition to the evaluation methodology, this publication also provides a few insights into the costs and benefits associated with investments in nuclear new builds, which might be of interest to different stakeholders potentially affected by the project.

2. AN INTRODUCTION TO COST–BENEFIT ANALYSIS

2.1. GENERAL DEFINITION OF COST–BENEFIT ANALYSIS[2]

The process of determining whether an investment proposal (e.g. a project) can be accepted or not is called project evaluation. It provides a basis for identifying and confirming investments with a positive net impact.

CBA is an analytical tool used by public sector decision makers [6][3] to assess an investment decision comprehensively over the long term — particularly for large capital intensive investments in infrastructure. To do so, a CBA identifies, quantifies and values (in monetary terms) the costs and the benefits for a given society that are attributable to an investment, and determines its net benefits relative to a reference scenario — that is, the status quo or an alternative investment proposal.

For convenience of computation, money is used as an accounting unit, but any other good could play the role of numeraire; however, CBA is different from standard financial analysis of a project. A key difference between financial evaluations (mostly used in the private sector) and CBA (as used in the public sector) is the consideration of a project from a social perspective. CBA tries to consider all costs and benefits to society as a whole; that is, the social costs and the social benefits. For this reason, CBA is often referred to as social CBA.

A key objective of CBA is to support public sector decision making and improve social welfare. More specifically, CBA attempts to optimize project selection within a scarce resource environment. CBA is not simply about choosing between different project options; rather, it is a tool for determining, from a socioeconomic standpoint, whether the project is worth implementing. In line with this, and from a public sector perspective, the ultimate aim of CBA is to maximize social return rather than financial return. In principle, if the benefits (B) exceed costs (C), it would be a good idea for the Government to enable (if not necessarily directly support) the nuclear new build project. Conversely, if the costs exceed the benefits, such an investment would not be justified.

If $B>C$ ➜ positive net benefits ➜ the society is better off with the project
If $B<C$ ➜ negative net benefits ➜ the society is worse off with the project

Finally, CBA is a normative analysis — that is, it illustrates resource allocation under a certain set of assumptions about social behaviours and values, but not how resource allocation decisions are made in the real world. CBA is just one of many inputs to the political decision making process.

2.2. KEY PRINCIPLES OF COST

Economic or social CBA is based on a few key principles:

(a) It employs an incremental approach against a counterfactual scenario;
(b) It takes a long term perspective;
(c) It monetizes social costs and benefits;
(d) It discounts costs and benefits to determine present value;
(e) It adopts a microeconomic approach.

---

[2] The term ‘economic’ is often omitted from ‘economic cost–benefit analysis’ for convenience, but it is implicit.

[3] For a nuclear project, CBA is typically (and not systematically) developed by the project sponsor as part of a comprehensive feasibility study, a key activity usually undertaken during Phase 2 (reference is made here to the Milestone’s approach [6]) to provide justification for the nuclear power project.

These key principles are briefly explained in Sections 2.2.1–2.2.5. Section 2.2.6 briefly elaborates on some common mistakes in CBA.

2.2.1. Incremental approach

CBA compares one or more potential projects with a counterfactual scenario that describes what would happen in the absence of the project (Fig. 2). Using an incremental approach, the net benefits of the project are assessed against a viable counterfactual, or 'without the project', scenario.[4] This implies that the analyst needs to make an assumption about what would happen in the absence of the project. There are three basic types of counterfactual scenario against which to compare the project, namely:

(a) *Business as usual/do nothing*. This scenario assumes that in the absence of the project, no investment takes place at all. In cases where a project consists of a completely new asset — for example, there is no pre-existing service or infrastructure — the status quo scenario is typically a scenario with no operations.

(b) *Do something else*. This scenario presents an alternative option to meet the objectives pursued by the project. This may consist of a different technology, project scale, or project location. It is an appropriate counterfactual for analysing a project against the next best option (see Section 3.2.3), once it is established that 'something' needs to be done.

(c) *Do the minimum*. In some cases, the 'do something else' scenario may consist of carrying out the minimum necessary investments to keep the installed capacity operational for the full life of the project. It is a suitable counterfactual for upgrading projects rather than for new build plants.

2.2.2. Long term perspective

Investment result in costs and benefits over time. CBA attempts to quantify those costs and benefits each year along the economic life of the project. More specifically, it develops an estimate of the incremental costs and benefits relative to the counterfactual scenario.

The number of years for which forecasts are provided corresponds to the project's reference period or time horizon. It can be challenging to define an appropriate time horizon for an analysis because there is

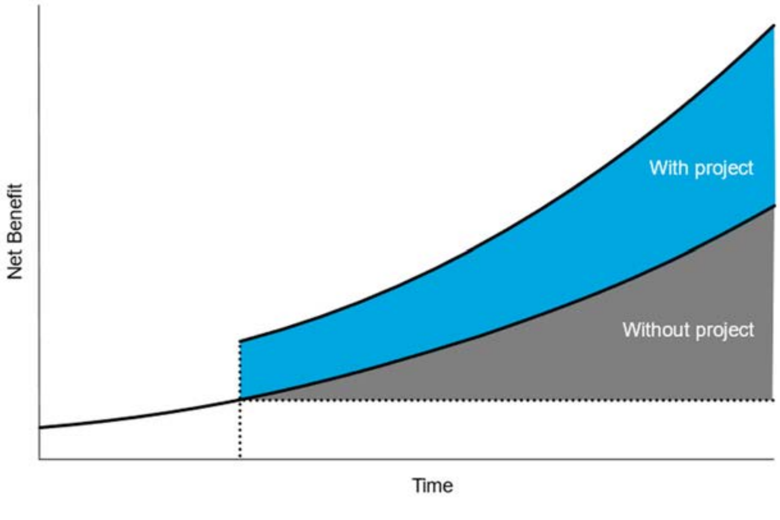


FIG. 2. Incremental approach.

---

[4] The term 'incremental' is often omitted for convenience, but it is implicit.

a trade-off between capturing long term effects and increasing the uncertainty of the estimates. Therefore, an appropriate time frame for the analysis will cover the preparation, construction and operation phases until the assessment is still meaningful, which typically coincides with the end of the project's economic lifetime. The economic lifetime is the period of time for which the asset remains in operation.

2.2.3. Monetizing social costs and benefits

CBA attempts to monetize — that is, to assign a value in monetary terms — a project's full range of costs and benefits (Fig. 3). The costs included in a CBA are social costs, comprising both private costs[5] and external costs[6] (these are also referred to as negative externalities). Similarly, social benefits include direct private benefits and positive externalities.

The concept of 'opportunity cost' is used in CBA to assign a monetary value to the inputs required to implement the project. In other words, opportunity cost is the value of what society would forgo using the input in the project rather than in its best alternative use. This implies that even resources, such as land, that are already owned by the Government or by another investor — for example, a public contractor, a power supplier, etc. — need to be considered in the analysis and valued at their opportunity cost.

Typically, the value of the most intuitively important benefits is measured in terms of WTP — that is, the amount that a person is willing to pay to obtain access to a good or service. Where markets exist and work well, marginal WTP can be derived from market prices. At competitive market equilibrium, marginal costs equal marginal WTP, thereby setting the market price. Where markets do not exist or are affected by market failures or distortions, WTP can be proxied using different techniques (see Appendix II).

2.2.4. Discounting to obtain net present value

To aggregate costs and benefits that occur in different years, CBA discounts future benefits and costs relative to present ones. In other words, CBA calculates the difference between the present value of incremental benefits (PV(B)) and the present value of incremental costs (PV(C)) to determine the net present value (NPV) as illustrated by Eq. (1). Future costs (C_t, incurred at time t) and benefits (B_t) are

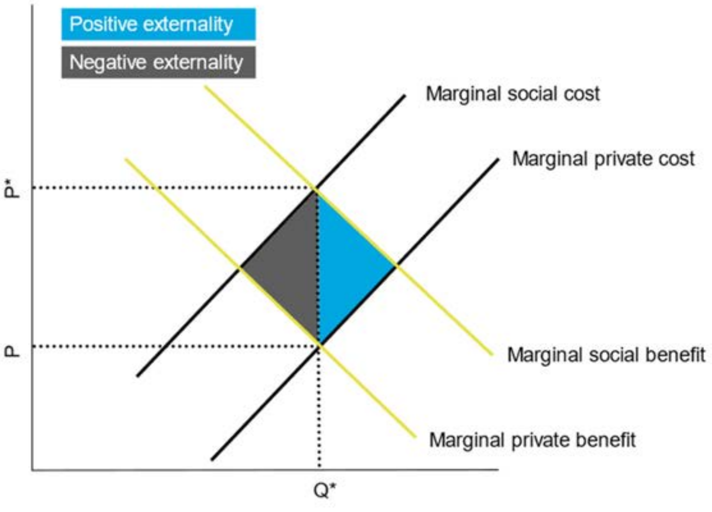


FIG. 3. Social costs and benefits. Note: Q refers to quantity and P refers to price.

---

[5] Costs that show up in the profit and loss statement (of the plant) at the end of each year.

[6] These are costs that arise when the activities of someone have an impact on someone else and when that impact is not fully compensated for by the party or parties responsible for incurring the cost.

converted to their present value using a social discount rate[7] (i), which reflects the social view of how future benefits and costs are valued against present ones, as illustrated by Eq. (2).

$$\mathrm{NPV} = \mathrm{PV}(B) - \mathrm{PV}(C) \tag{1}$$

$$\mathrm{NPV} = \sum_t \frac{B_t}{(1+i)^t} - \frac{C_t}{(1+i)^t} \tag{2}$$

There are two reasons for discounting in CBA. First, there is an opportunity cost to the resources used in a project; this means that they could earn a positive return if employed elsewhere. Second, the time value of money concept means that money is more valuable in the present than in the future; most people prefer to consume now rather than later.

The choice of an appropriate discount rate plays a critical role in CBA, and it is not trivial. The higher the rate, the lower the value attached to future costs and benefits, and vice versa. If there is not a prescriptive social discount rate to be applied consistently to investment in the country (e.g. one required by government guidelines), the parameter needs to be estimated and its value tested through sensitivity analysis. For projects that do not have impacts beyond 50 years, social discount rates typically range from 3–5% if estimated with the social time preference (STP) approach. Higher rates derive from the application of the social opportunity cost of capital (SOC) approach (see Appendix I). Developed countries typically apply lower rates (3–7%) than developing countries [7]. If the project is inter-generational — that is, it has impacts that occur far into the future (typically beyond 50 years) — time declining discount rates may be adopted. For a more detailed discussion see Appendix I.

2.2.5. Microeconomic perspective

CBA is a microeconomic tool enabling assessment of a project's direct effect on society as a whole.[8] Therefore, while direct effects are reflected in the analysis, indirect effects on secondary markets and wider effects — that is, on public funds, country economic growth, etc. — are usually excluded [8, 9]. The main reason for not including indirect effects is that, if the secondary markets are undistorted[9], they are already captured by the shadow prices[10]. Therefore, adding indirect effects to the costs and benefits already measured in primary markets would result in double counting. Instead, if secondary markets are distorted, indirect effects are to be valued separately, although their calculation is usually very difficult. In practice, however, even when secondary markets are distorted, indirect effects are ignored, and usually assumed to be small. Wider effects arise when the impact of a policy intervention is transmitted into the wider economy — for example, a policy intervention may reduce the cost of production in some industries, ultimately lowering the prices at which the goods are sold. Wider effects are typically left out because in competitive markets they cancel out, resulting in a net effect that is nil — that is, because of falling prices in the economy, consumer surpluses increase. Otherwise, wider effects can be assessed separately through other appraisal techniques, such as computable general equilibrium models.

It is worth noting that CBA is different from economic impact analysis, which measures the impact of a project on the economy, typically proxied by gross domestic product (GDP) instead of social well-being. The impact of projects on GDP growth is a separate metric from well-being, because GDP is an imperfect well-being yardstick for several reasons [10].

---

[7] The social discount rate is distinct from the discount rate used in 'financial analysis', see Appendix I.

[8] Direct effects are related to the initial spending. Indirect effects are the results of economic activities indirectly caused by the direct effects. Induced effects are due to increased income caused by both direct and indirect effects.

[9] Market distortion refers to a situation in which prices do not reflect supply, demand and market equilibrium under conditions of perfect competition.

[10] Shadow price refers to the price of a good or service that is not normally priced.

Nevertheless, for megaprojects such as nuclear power projects, it is recommended to provide a qualitative description of secondary and wider effects or even to complement CBA with a macroeconomic analysis to assess the contribution of the project to the country's economy.[11]

2.2.6. Common mistakes in cost–benefit analysis

Below is a list of examples of common mistakes made when conducting CBA:

- *Scope of CBA is too narrow*. Local or regional governments (i.e. within the country) often only want to consider costs and benefits to their residents, which can overlook costs and benefits borne by countrywide residents.
- *Misinterpretation of financial costs and revenue as a proxy for economic cost and benefits*. Equating benefits and cost with, respectively, revenue inflows and outflows to an organization, firm or government, can lead to misinterpretation of the results. Regarding CBA as a budget impact analysis, or a cash flow analysis, will ultimately neglect the opportunity cost of resources and impacts valued by people, such as time and lives saved.
- *Misinterpretation of expenditures and benefits*. Regarding government expenditures on constituents as benefits rather than costs ultimately does not recognize that project resources are being diverted from other potentially productive uses. As a result, expenditures on labour (employment) are considered to be a benefit rather than a cost.
- *Incorrect discount rate*. Adopting financial discount rates (FDRs), instead of social discount rates, can provide an incorrect calculation of the net present value.

2.3. LIMITATIONS AND ALTERNATIVE METHODS

The most common criticism of CBA is that it provides a unidimensional view on a project, and it attempts to place a price on everything. Although a thorough discussion of these criticisms goes beyond the scope of this guide, this section focuses on the limitations of CBA.

First, technical limitations — for example, lack of data or analytical resources — may make it impossible to quantify and monetize all relevant costs and benefits. In these circumstances, if at least a quantification of costs and one major benefit is possible, it is appropriate to switch from CBA to cost effectiveness analysis (CEA). However, it is worth noting that the non-monetary valuation of benefits in CEA is based on the strong assumption that all options considered deliver the same major benefit and no relevant externalities.

Second, in some cases, goals other than efficiency are relevant for politicians, the general public and economists to evaluate the proposed project's potential to solve social problems — for example, equality, political feasibility, national security, etc. In such cases, CBA usually remains a useful metric for comparing projects in terms of their efficiency, alongside other goals. However, CBA may be complemented by multicriteria or multigoal analysis (for a detailed description see Ref. [11]). Distributionally weighted CBA can be considered in situations where both efficiency and equity[12] are relevant. Comparisons of these different assessment techniques are presented in Table 1.

---

[11] Multibillion dollar investments in large infrastructure projects are a synonym for economic growth and job creation over many decades, provided that they do not create excess capacity. Macroeconomic impacts — direct, indirect and induced — can be described by an input–output model, such as the Extended Input–Output Model for Sustainable Power Generation (EMPOWER) model developed and maintained by the IAEA, or a general equilibrium model.

[12] Equity refers here to the distribution of the project costs and benefits across stakeholders.

TABLE 1. ALTERNATIVE ASSESSMENT TECHNIQUES FOR PROJECT APPRAISAL [9, 12–15]

	Description	Limitations
CEA	CEA aims to select the project that, for a given output level, minimizes the net present value of costs, or, alternatively, for a given cost, maximizes the output level. Accordingly, it can identify the least cost alternative or the most cost effective one	CEA is only practicable when the output or service is homogeneous and easily measurable (e.g. provision of electricity)
Multicriteria analysis	A multicriteria analysis does not try to express all effects in one dimension (in monetary terms); rather, several dimensions are used at the same time. The overall assessment of a project or the ranking of different projects uses criterion weights applied to all criteria, and ultimately forms an expression of political priorities	Generally, experts choose scores and weights, but it is unclear how this method deals with issues of discounting and changing relative valuations over time
EIA[a]	EIA seeks to identify and quantify the environmental implications of a particular project (or programme), both desirable and undesirable. EIA content is regulated by national regulations. In some cases, EIA is similar to CBA, as it seeks to apply monetary values to environmental impacts	Similar to CBA, EIA faces problems of quantification and in applying monetary values to environmental impacts
Risk–benefit analysis	Risk–benefit analysis involves calculating and comparing the risk associated with a particular project, and comparing this to the potential benefits received from the project	There may be missing data, or a lack of data on the risk associated with certain projects or activities
Economic impact assessment	Economic impact assessment comprises macro level analysis. It seeks to quantify how an economy is likely to change (e.g. in terms of GDP) because of a project. Hence, it calculates direct, indirect and induced benefits from projects. Standard economic impact assessment is based on multiplier analysis using input–output models	Major criticisms of standard economic impact assessment based on an input–output model relate to the use of inappropriate and overinflated multipliers and/or negative effects being ignored

[a] EIA: environmental impact assessment.

2.4. SEVEN STEP PROCESS

CBA is intended to be embedded in the preparation of the feasibility study [5], and its preparation requires various inputs from different kinds of preliminary analyses — for example, analysis of needs, demand, costs, options and plant design.[13] Although these analyses are not formally part of the CBA, their results need to be reported concisely and used as one of the main data sources within the CBA (Fig. 4).

Therefore, it not unusual to affirm that a fully fledged CBA of a project is based on seven levels of analysis or formed by seven steps (Fig. 5) [8]. Obviously, the core of a CBA is the economic analysis (step 6). Steps 1–5 are preparatory and the risk assessment (step 7) is complementary. These steps are illustrated with reference to the nuclear power sector in the next section.

---

[13] Most NPP vendors already have a preliminary design — and a reference plant — when they engage with nuclear newcomer countries. Design adaptations are usually related to site conditions and regulations. For regulations, it is assumed that the newcomer will rely on the IAEA safety standards and security guidance, in addition to those of the vendor.

FIG. 4. Interphases between feasibility studies and CBA.

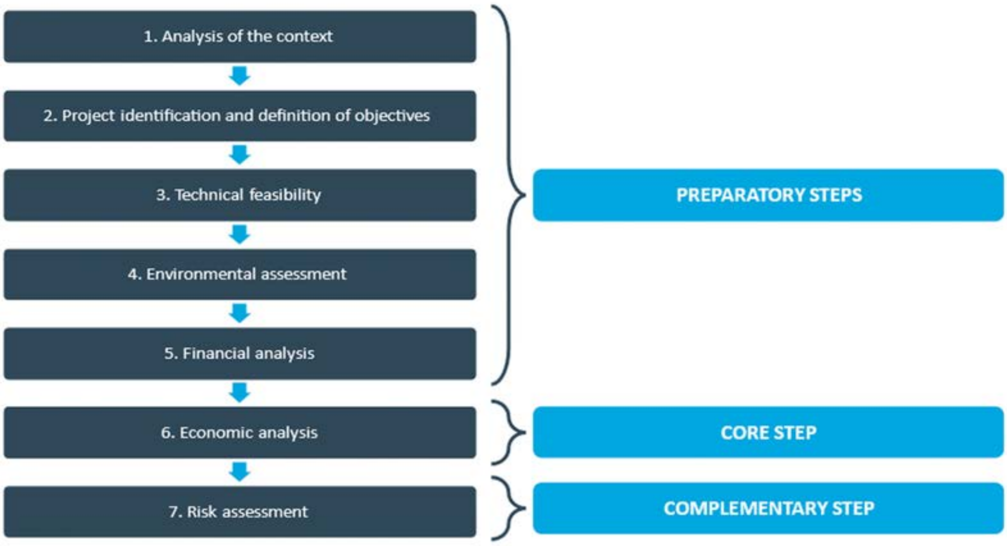


FIG. 5. Seven steps of a CBA [8]. Note: a technical feasibility study has to be undertaken in all instances, whether a fully fledged CBA is performed or not.

3. APPLICATION OF COST–BENEFIT ANALYSIS IN THE CASE OF NUCLEAR PROJECTS

Nuclear power projects fall under the broader category of power generation projects. They interact physically — and economically — with a variety of electricity producing units within a country’s power grid (Fig. 6). As a result, nuclear new build projects share the same CBA rules that are valid for other power generation projects. NPPs exhibit specific features and risk profiles, however, requiring greater attention.

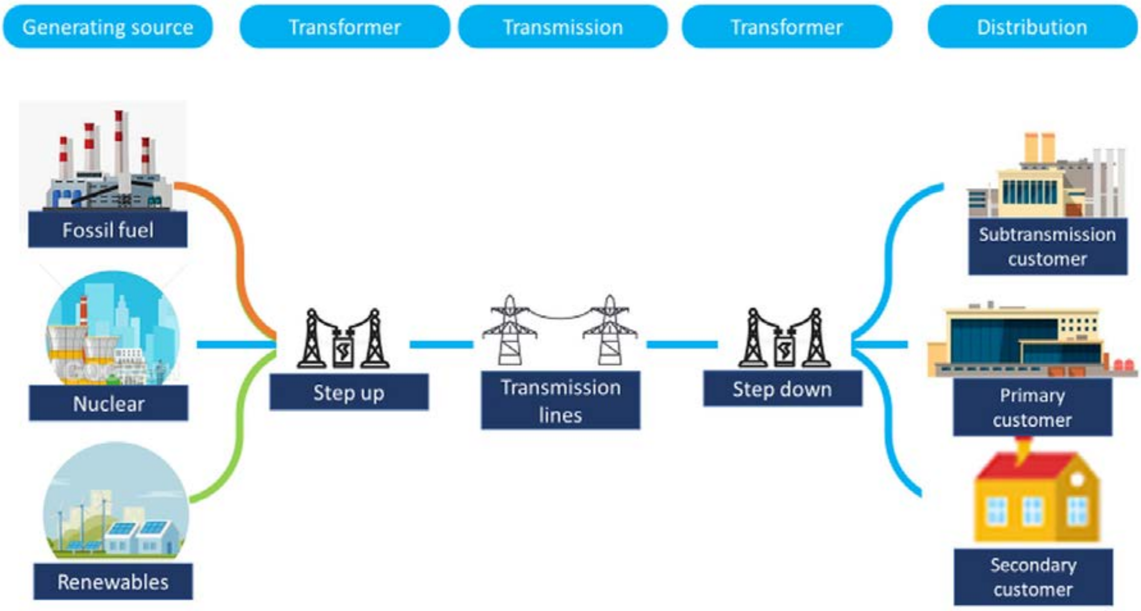


FIG. 6. Power generation plants within the energy chain.

3.1. SELECTED REMARKS ON SPECIFICITIES OF NUCLEAR NEW BUILD PROJECTS

There are several nuclear specific considerations that various key stakeholders need to account for carefully when deciding to develop and finance a nuclear new build. A list of high level features to consider is detailed below:

(a) *Commitment to a long time horizon*. This includes project development, construction operations, decommissioning and long term management of waste, with extended liabilities and a long lasting legacy (intergenerational effects).
(b) *Strong underlying political choices*. This requires lasting national (and local) political support across parties.
(c) *Strong stakeholder engagement, especially with the general public*. Public trust can be built by sharing clear information on the benefits and risks of nuclear plants; it can also be built by thoroughly addressing any concerns that are raised.
(d) *Fully fledged international and national legal and regulatory frameworks in place.*
(e) *Robust and independent safety and licensing authorities*. These should be provided with appropriately funded budgets and skilled staff with high technical and scientific competence.
(f) *An effective emergency response strategy and organization*. This results from the mutually supportive planning and preparedness of several parties, including the companies that operate the plants, local and national agencies, and emergency response services.
(g) *A comprehensive EIA and licensing process*. This begins prior to construction and continues through ‘never ending’ monitoring throughout the project’s life cycle — that is, from development until decommissioning.
(h) *Large, upfront capital costs, leading to challenging funding requirements*. As with other capital intensive technologies, the cost of an NPP depends on the cost of capital and is very sensitive to construction lead times.
(i) *Extensive and complex contractual environment*. This applies for both the construction and operations frameworks that are put in place. Typically, NPPs require contracting and management of complex

contracts with the reactor technology vendor and other key suppliers of the nuclear steam supply system (NSSS).[14]

(j) *Dealing with a combination of low probability risk and potential high impact*. This could include low frequency but major accidents that require specific and complex insurance regimes.

To clarify the object of the appraisal, it is worth noting that NPP construction,[15] are embedded in but distinct from the nuclear power programme. The latter includes infrastructure development[16] (prior to NPP construction), one or more NPPs, possible related projects (such as, uranium exploration and fuel fabrication), treatment plants and medium and/or long term storage facilities for spent nuclear fuel and other radioactive waste and the supporting infrastructure. Although the CBA approach would be appropriate even to assess the merits of a nuclear power programme, the present guide focuses on the application of CBA to nuclear power projects, specifically new build plants, typically during phase 2 of the Milestone Approach (Fig. 7).

As a final remark, the assessment of NPP externalities requires a life cycle approach. Therefore, it is worth describing the nuclear cycle that is formed by the so called front end and back end of the nuclear fuel cycle (Fig. 8). The front end starts with the preparation of uranium for use in a nuclear reactor, including mining and milling, conversion, enrichment and fuel fabrication. The back end starts after the uranium has been used in an NPP. The spent fuel undergoes further steps, including interim storage, reprocessing and recycling, before final disposal as waste. Figure 8 shows an overview of the entire fuel cycle.

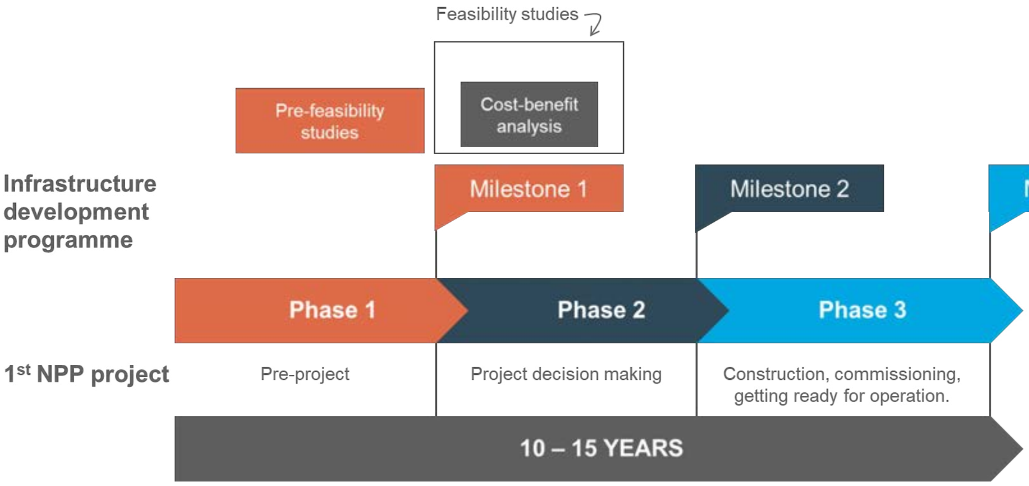


FIG. 7. CBA within the nuclear power programme process. Adapted from Ref. [6].

---

[14] As documented in IAEA Integrated Nuclear Infrastructure Review (INIR) peer review mission reports, nuclear newcomer countries usually opt for one contract with the engineering–procurement–construction (EPC) contractor.

[15] An NPP comprises the construction of one or more nuclear generating plants.

[16] In the process to develop the infrastructure for a national nuclear power programme the country carries out the work required to prepare for the contracting, financing and construction of the first NPP during phase two of the IAEA's Milestone approach [11].

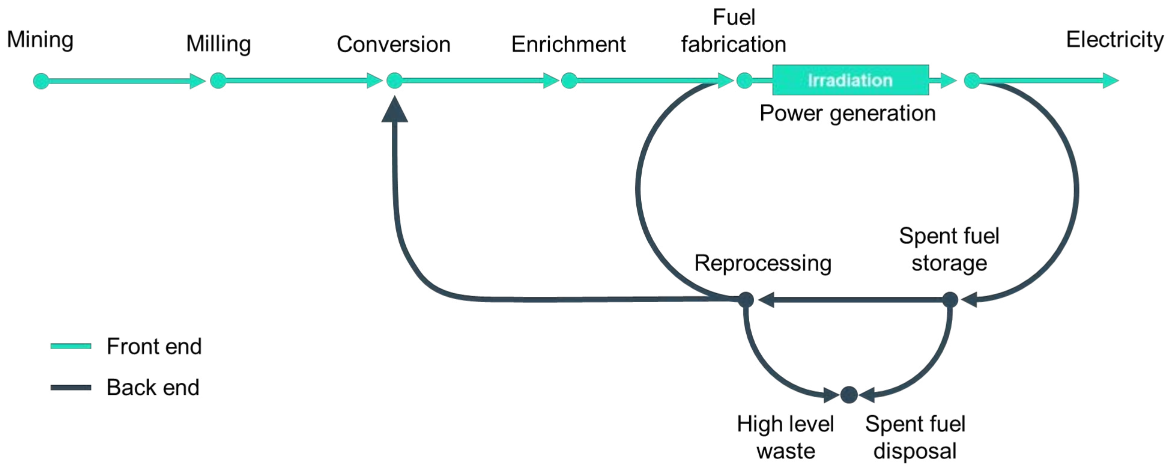


FIG. 8. Nuclear fuel cycle. Adapted from Ref. [16].

3.2. STEPS 1–4: PREPARATORY STEPS

For nuclear power projects, the first four preparatory steps to CBA are carried out at the programme or NPP level, and they are a preliminary activity in the development of a specific nuclear plant. The analyses and studies carried out at this upstream stage provide key information and data to prepare the CBA for a new build plant.

3.2.1. Step 1: Analysis of the context

The first step consists of investigating and presenting the project's overall context — in particular, the socioeconomic and political trends, the institutional and regulatory framework, etc. in the country where the project is located. This investigation is instrumental in verifying that the project is appropriate to the local context, identifying the project necessity (see next step) and forecasting future trends, especially for demand analysis.

It is recommended that the following baseline contextual elements are described as part of step 1 [17]:

(a) Economic/demographic trends and the energy intensity of the economy;
(b) Relevant energy policy/strategy documents;
(c) Relevant legal and regulatory frameworks, with reference to the energy sector and nuclear plants, in particular;
(d) Physical and functional structure of the electricity transmission and distribution grid;
(e) Structure of the energy market and regulatory issues, including energy utilities, wholesalers and retailers, the competitiveness of the market, and the types and number of final consumers;
(f) Tariff and/or energy price system, nuclear fuel price trends;
(g) Energy production and consumption balances, intermediate and final consumption, import and export by type of energy (oil, coal, natural gas, electricity, etc.), local resources, import dependence rate;
(h) Amount of interconnection and integration with other countries;
(i) Decarbonization policy;
(j) Weather and climate conditions.

3.2.2. Step 2: Definition of the objectives, project identification and choice of the counterfactual

3.2.2.1. Definition of the objectives

After the contextual analysis, the project promoter outlines the needs that the project satisfies and the key objectives of the project. The needs assessment would demonstrate that, in the context specified in step 1, the project is expected to solve or contribute to solving a clearly defined and present problem or problems. The intended objectives are expected, then, to be logically linked with the stated need(s). Ideally, a target is set for each objective to ensure accountability and monitoring of achievements. Defining the objectives is instrumental for identifying the effects of the project, which will be further evaluated during the economic analysis (step 6).

Nuclear new build projects generally aim to:

- Expand supply to meet growing energy demand.
- Reduce the price of electricity and/or electricity price volatility (e.g. by displacing old facilities), thereby improving the long term affordability of electricity.[17]
- Diversify energy sources and supply markets.
- Improve the reliability and security of energy supply (e.g. by reducing dependence on energy supplies from abroad or by strengthening grid security to improve overarching system reliability and resilience).
- Reduce greenhouse gas (GHG) and pollutant emissions from energy production.

3.2.2.2. Project identification

Once the objectives of the investment are defined, the next step is to present the proposed project to be implemented, which is the result of several analyses carried out at the pre-feasibility study and feasibility study stages (see step 3). The basic information to characterize a new build plant includes:

- Type of plant and technology;
- Number of power units that comprise the power plant;
- Connection of the facilities to the power grid;
- Installed capacity (MWe) in total and for each power unit;
- Load factor;
- Full investment costs, including relevant investment needed, in connecting the electricity grid;
- Physical components of the projects and their main functions and locations and the services provided;
- Management of the project in the various phases of its lifespan (design, construction, operation, service supply, project closure, decommissioning);
- Impact area and stakeholders of the project.

The implementation of the project needs to be justified against a set of feasible alternative options that would allow the achievement of the defined objectives (see next section).

3.2.2.3. Choice of the counterfactual

Establishing the counterfactual scenario, which is the without the project scenario over time, is a challenging task. In addition to identifying what the current situation (status quo) is, the counterfactual also needs to consider what will happen in the future, including any relevant predicted trends. Energy

---

[17] Affordability is closely related to the cost of generation and so called ‘system costs’, which include the costs of delivering electricity and maintaining a reliable grid. While costs are important, the ultimate price and affordability of electricity also depends on market structure and competition, the regulatory environment, subsidies and taxes [18].

planning studies (electrical system expansion planning) could be used as a reference and starting point for establishing the counterfactual scenario.

Depending on the main objective of the NPP, the counterfactual scenarios below can be used as an illustrative guide:

(a) If the project aims to change the electricity mix while keeping the total supply constant, the typical counterfactual scenarios are:
   (i) The business as usual scenario, assuming the status quo is a sustainable situation;
   (ii) The do something else scenario if the status quo is not a sustainable situation — this can include the adoption of a different electricity source, the substitution of self-production with import or of import with self-production, or the change of the electricity import country.

(b) If the project aims to expand the supply to meet increasing demand, the typical counterfactual is the do something else scenario, which may imply the adoption of a different electricity source or the import of additional electricity.

The counterfactual scenario is different from the project options. In principle, all the options would be assessed against the same counterfactual (see Fig. 9).

3.2.3. Step 3: Technical feasibility

A feasibility study is a prerequisite for CBA, which usually includes a broad range of detailed input data and information (e.g. demand and options analysis).

3.2.3.1. Demand analysis

The demand analysis identifies the need for an investment by assessing the current and future demand for the project. The accuracy of demand projections is key to conducting a rigorous CBA. Therefore, the information about the demand projection models used and the working hypotheses that support the analysis are fundamental elements of transparency. Assumptions concerning the policy and regulatory framework evolutions need to be clearly expressed. Any uncertainty in the prediction of future demand needs to be clearly stated so that it is appropriately treated in the risk analysis (see step 7). It is worth noting that demand projections apply to both the scenarios with and without the project to implement a CBA. In many cases, the two coincide.

In line with the IAEA technical guidelines, the feasibility study of a specific NPP contains, among other things, an updated electrical system analysis and the confirmation of the selected option [5].

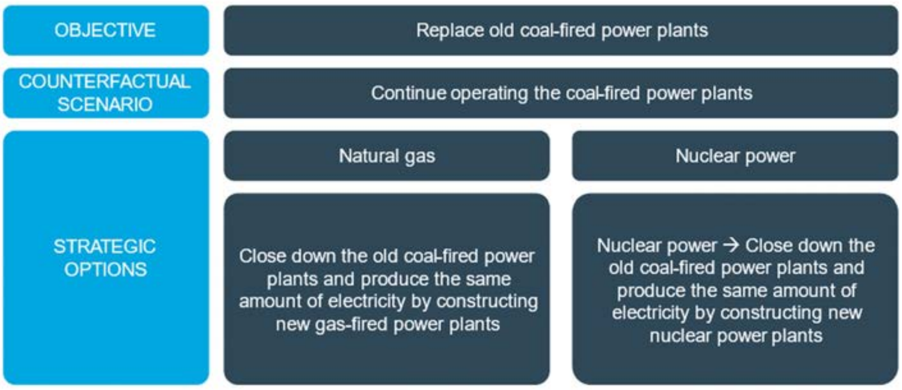


FIG. 9. Illustrative example: Counterfactual scenario and options analysis.

An electrical system analysis encompasses a broad range of analyses (analysis of electricity demand, generation capacity and capacity expansion options available, transmission and distribution models) aimed at characterizing the existing network and projecting its future expansion. According to Preparation of a Feasibility Study for New Nuclear Power Projects (IAEA Nuclear Energy Series No. NG-T-3.3) [5], the electrical system analysis includes:

“— Electricity demand and electricity demand projections (base scenario);
— Electricity supply system characteristics (current and future system expansions);
— Electricity market structure and organization;
— Electrical system expansion plans, including generation, transmission and distribution (base scenario);
— Nuclear power project impact evaluation on the grid.”

In a CBA perspective, the results of all the listed analyses are important; however, the electricity demand projections and the electrical system expansion planning, specifying how the demand is to be met with different generating technologies, are key.[18] Indeed, the demand projections — expressed in megawatt-hours (MW·h) — represent the quantity to be used in both the financial and the economic analyses. The comparison of different generating options provides useful information for the identification of the counterfactual scenario (see Section 3.2.2).

3.2.3.2. Options analysis

The options analysis aims to explore a set of feasible alternatives and provide evidence that the proposed project choice can actually be implemented, ideally as the best option among all feasible alternatives. The alternative options needs be realistic and not constructed as an ad hoc justification for the selected option. They are also expected to be feasible and not affected by an overly pessimistic or optimistic bias.

The options analysis for nuclear new build projects is usually implemented in two stages. The first stage of the options analysis demonstrates whether nuclear power is the best choice in comparison to other alternatives (oil, coal and gas fired plants, renewable energy sources) in relation to different criteria. The comparative criteria could include the levelized cost of energy (LCOE[19]), the need to limit environmental emissions, the desire to limit import, the availability of fuel, the security of supply, etc. This is the so called ‘strategic analysis’ that is carried out within the electrical system expansion planning at the pre-feasibility study stage (and updated at the feasibility study stage).

It is worth noting that any comparison of nuclear electricity with other technologies needs to consider that nuclear power may have a competitive or complementary position in relation to fossil fuel power plants and renewable energy sources.

The second stage of the options analysis demonstrates whether the new build NPP is sited in the best available location and adopts the best available size and technological solutions among those that the market offers. This is called ‘project options analysis’. The candidate reactor technology, size and

---

[18] The IAEA provides a suite of energy planning tools and related capacity building to support its Member States with such analysis. The suite includes the IAEA Model for Analysis of Energy Demand (MAED), which evaluates future energy demands based on medium to long term socioeconomic, technological and demographic development scenarios [19]. The suite also includes tools such as Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE), which can help design long term strategies by analysing aspects such as cost optimal energy mixes, investment requirements, energy supply security, energy resource utilization and environmental impacts.

[19] LCOE might not be a relevant indicator for power system operating in cogeneration mode, typically integrated power and desalination plants.

siting options are usually proposed at the pre-feasibility study stage, but they need to be confirmed at the feasibility study stage. The different options are typically compared in terms of:

- Available technological alternatives (considering applicable regulations that may limit technological options);
- Nuclear unit size and station capacity;
- Location of plants (including considerations of land availability, water cooling possibilities, geological structure and stability, population density, distribution of surrounding plants, access to transportation routes, weather conditions, environmental constraints).

If there are large numbers of feasible options — for example, because there are different possible technologies — then a scoring system is used to select the project option(s) to be further analysed. Such a system is normally underpinned by a clear set of criteria — for example, investment cost, net present value, adherence to national strategic objectives, maturity of the technology, riskiness — or at least by the comprehensive LCOE indicator. The latter is typically a good indicator for the life cycle and cost effectiveness when comparing alternative technologies. To calculate the LCOE, all expenditures incurred over the lifetime of a given plant are divided by the total amount of electricity generated during the same time period, with both figures discounted to the base year by using an FDR reflecting the risks associated with the project. However, the LCOE does not include grid level or system costs and externalities beyond those included in environmental taxes and charges accounted for in the operating expenditures. A further limitation of the LCOE is that a constant capacity factor and thus generation is assumed in its calculation. The metric, therefore, does not take changes in the energy system's composition into account. Given the increasingly ambitious decarbonization targets in many countries, these changes may have a considerable impact on the future power plant dispatch and generation.

Figure 10 shows how nuclear compares to other utility scale power generation technologies on an LCOE basis. The cost ranges reflect regional and national differences related primarily to market structure and resource endowments.

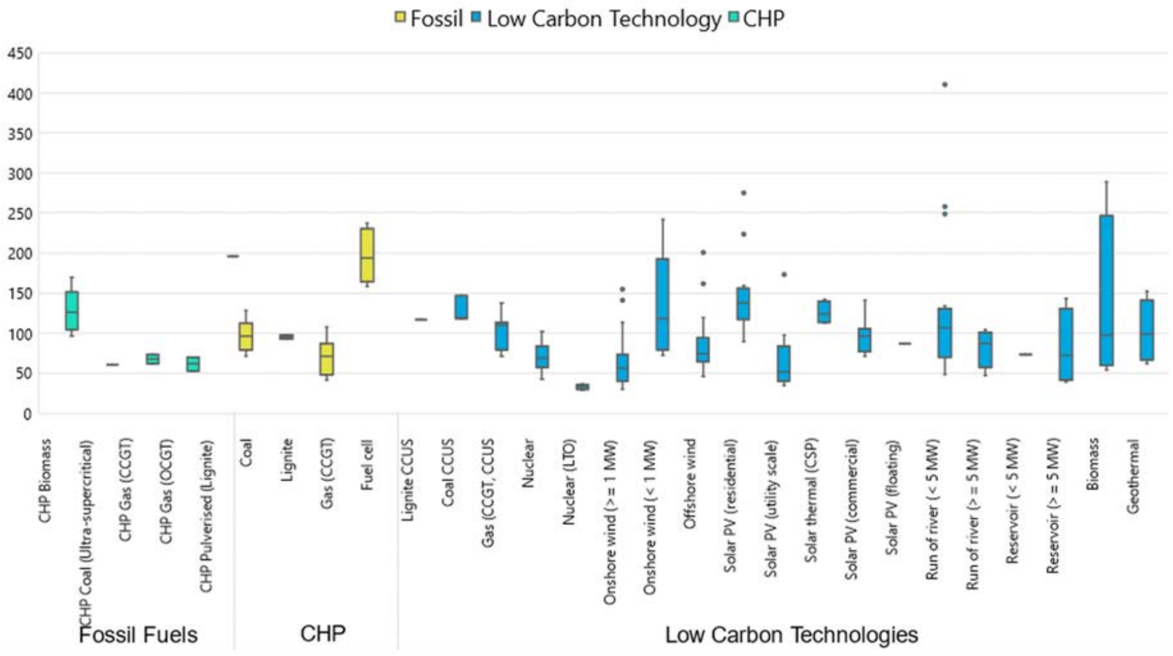


FIG. 10. LCOE comparison [20, 21].

TABLE 2. FINANCIAL VS SOCIOECONOMIC LCOE

Financial LCOE	Socioeconomic LCOE
Capital expenditure	Capital expenditure
O&M[a] costs	O&M costs
Fuel costs (if relevant)	Fuel costs (if relevant)
Revenue from power sales	Economic value of power sales
CO_2 allowance costs (if relevant)	Social cost of CO_2 emissions
	Social cost of airborne emissions
	Security of supply cost (if relevant)

[a] O&M: operation and maintenance.

If negative or positive externalities, such as avoided CO_2 emissions, are internalized in the calculations of the LCOE, the resulting 'socioeconomic levelized cost' can be used as a proxy for the socioeconomic long run marginal cost (LRMC) of different alternative solutions (Table 2). The discount rate to be used in this calculation is the so called social discount rate (for a discussion of discount rates see Appendix I).

The best project option would be the one with the lowest socioeconomic levelized cost and a financial levelized cost that can be deemed sufficiently affordable and competitive.

3.2.4. Step 4: Environmental impact assessment

An EIA is generally performed as part of the feasibility study for a specific NPP [22].[20] EIAs are carried out in line with the national environmental requirements in each country's national environmental protection act, environmental policies and strategic environment defence plans. The assessment typically explores compliance with environmental regulations at the country and international levels. In general, an EIA includes the following components:

- The site environmental conditions;
- The environmental impact of the infrastructure under normal operational conditions;
- The risks considered and the methodology used to assess and quantify them;
- Environmental protection measures;
- Environmental monitoring activities.

The EIA provides identification and quantification of environmental externalities, which are important inputs for the economic analysis (step 6).

---

[20] According to IAEA guidelines on project management in NPP construction, if an EIA is not available at the time an NPP feasibility study is being prepared, then environmental issues need to be addressed in the feasibility study to identify issues, possible configuration or operating modifications and/or remediation costs. If an EIA is already available, recommendations from the assessment can be summarized in the feasibility study and conclusions drawn in terms of cost and implications for the plant [16].

3.3. STEP 5: FINANCIAL ANALYSIS

In the context of this publication, the financial analysis is viewed as preparatory to the economic analysis, which assesses the project's worth to society. More specifically, the financial analysis is useful for determining and forecasting the direct costs and revenues of the project over the reference period and, further, to verify its financial performance, regardless of how it is financed or incentivized. The project profitability is calculated from the project standpoint and is linked to the return it can provide compared with the counterfactual scenario. This requires projections of the direct costs and revenues for the with and without the project scenarios.[21] Direct taxes on capital, income or otherwise are usually not considered for the calculation of the financial profitability, which is calculated before such tax deductions.

Furthermore, the calculation of the financial profitability is based on the discounted cash flows method, which implies the adoption of the following operational rules:

(a) Only cash inflows and outflows are considered — that is, depreciation and amortization, reserves, price contingencies[22] and other accounting items that do not correspond to actual flows are disregarded.
(b) An FDR reflecting the opportunity cost of capital is adopted for discounting financial cash flows. The FDR is defined as the rate of interest, reflecting the time value of money, used to determine the present value of future cash flows. Different approaches exist in the practice for calculating the FDR. For a more detailed discussion see Appendix I.
(c) The prices used in the analysis can either be constant (or 'real' — i.e. prices fixed at a base year) or current (or 'nominal' — i.e. prices adjusted by the consumer price index). For consistency reasons, when the analysis is carried out at constant prices, the FDR is expressed in real terms and, when the analysis is carried out at current prices, a nominal rate is used.[23]

3.3.1. Reference period (or time horizon)

The determination of the reference period is a key input for the projection of costs and revenues, and thus for the calculation of financial profitably (as well as for the economic analysis in step 6).

The time horizon of NPP projects is quite long and, in principle, it encompasses four broad phases (Fig. 11):

(a) Pre-development phase: the planning and licensing of the plant, typically lasting 5–10 years.
(b) Construction phase: a range of activities from site preparation to commissioning of the plant. Seven years is the typical duration for NPP construction, but shorter construction times are also achievable [20].
(c) Operation phase: typically lasts 40–60 years, depending on the type of reactor. The exact extent depends on the useful economic life of the plant.
(d) End of life phase: closure of the plant, decontamination, dismantling and the disposal of radioactive waste. The duration of this phase varies from plant to plant and from country to country, depending on the adopted decommissioning strategy (immediate, deferred, entombment). Broadly speaking, it can range from as few as 5 years to as long as 60 years.

---

[21] This is why financial analysis is usually referred to as financial CBA.

[22] Technical or physical contingencies are included in estimates because experience in infrastructural investments has shown that such costs are likely and expected. In other words, they account for costs that are omitted or unforeseen due to a lack of complete project definition and engineering when the CBA is carried out.

[23] The relation between the real and the nominal rates is: $(1+i) = (1+r) \times (1+f)$, where i is the nominal discount rate, r is the real discount rate and f is the inflation rate.

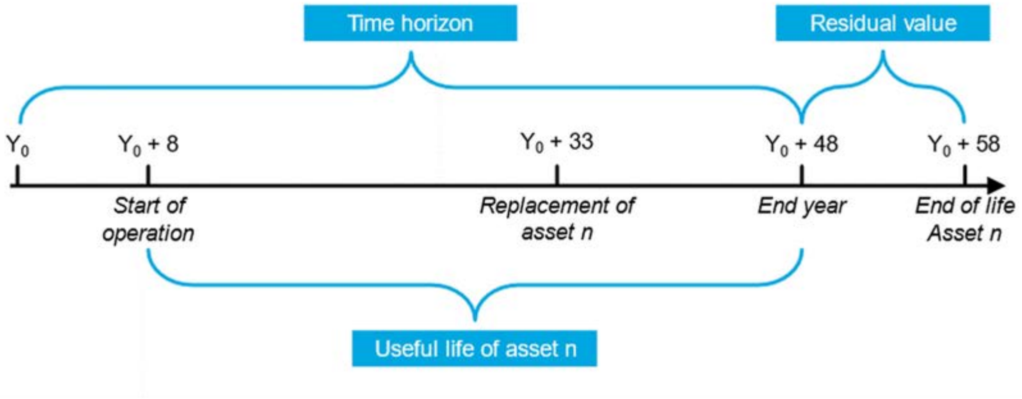


FIG. 11. Timeline for horizon, replacement and residual value.

At the appraisal stage, the time horizon for nuclear plants is arbitrarily set to cover the first three phases (pre-development, construction, operation). In other words, the decommissioning phase is not part of the reference period of the CBA because its start and duration are uncertain at the appraisal stage and decommissioning costs are sustained during the entire operation phase (see Section 3.3.2.3 on decommissioning costs).

If the time horizon adopted in the CBA is longer than the lifetime of a certain part of the power plant equipment, then reinvestments such as refurbishment, renewals and/or replacements are necessary. In contrast, if the time horizon is shorter than the lifetime of a part (including reinvestments), the residual value of this part needs to be considered in the last year of the analysis. For NPPs, the residual value of assets can be assumed to be offset by the decommissioning costs. Therefore, it can be omitted from the CBA.

It is worth noting that projects are always compared over the same time horizon so that they have the same opportunity to accumulate costs and benefits. Therefore, if an alternative investment (e.g. a hydroelectric power plant) is considered in the counterfactual scenario in the absence of the NPP project, the analyst needs to compare the costs and benefits of the two investments over the same time horizon, although they have different time frames.

3.3.2. Private costs

Cost estimates vary greatly from site to site and from plant to plant, depending on their structures, systems, components and regulatory requirements. Various factors may cause changes in the overall cost of nuclear new build projects (see Table 3).

As with any other power generation project, the costs of NPP comprise investment cost (initial cost and replacement costs), costs during the operation phase of the plant and decommissioning costs. The cost categories of NPPs are discussed briefly below;[24] however, it is worth noting that in a CBA context the biggest problem is often not the estimation of costs for the project being appraised.[25] Instead, the challenge is often the specification of costs for the counterfactual scenario, which is just as important in assuring the reliability of the CBA calculations as those of the project itself.

---

[24] In addition to these cost categories, pre-development expenditures occur prior to the building phase. They are mostly incurred by the Government and include, for example, R&D for the site, setting up necessary governmental bodies or streamlining the law. They are crucial as they lay the foundations for any investment, but they are typically considered to be sunk costs when the CBA for a specific plant is developed. Indeed, pre-development costs refer to the development of a nuclear programme rather than the construction of a particular plant.

[25] These costs can be retrieved from the feasibility study or the cost of the reference plant, or can be based on firm quotations from suppliers and contractors.

TABLE 3. COST DRIVERS OF NUCLEAR NEWBUILD PROJECTS [1]

Technical cost drivers	Nuclear boiler technology Site requirements Safety requirements Security requirements Operation and maintenance costs Radioactive waste and spent fuel management Ageing management programme
Management cost drivers	Long term outage management optimization Licensing process Maintaining expertise

3.3.2.1. Capital expenditures

Investment costs are generally defined as the capital expenditure for the fixed and non-fixed assets required for constructing and equipping the investment project. They are usually concentrated at the beginning of the time horizon. However, investment costs may also include replacement costs — that is, capital expenditure required to replace those assets whose economic lifetime is shorter than the reference period (e.g. machinery and/or equipment)[26] — and additional investment costs occurring during the operational phase and related to plant's modernization and/or expansion.[27]

Initial capital expenditures are incurred while the plant is under construction and consist of engineering, procurement, site preparation, construction and commissioning of the NPP. These costs are often referred to as overnight costs and do not include financing costs. Table 4 illustrates a typical NPP capital expenditure breakdown structure.

The IEA and the Organisation for Economic Co-operation and Development's Nuclear Energy Agency (OECD/NEA) have been publishing cost estimates for different power generation technologies on a regular basis [20]. The investment costs for NPPs are higher than those for coal or gas fired plants because they use special materials, incorporate sophisticated safety features and backup control equipment, and have a longer construction time and a more complex licensing process. The high capital costs of an NPP are sometimes prohibitive in some parts of the world. However, while not yet commercially available, innovative reactor designs, with smaller capacity, can potentially address this issue in the future.

In addition to initial capital expenditures, during its operation phase an NPP requires additional costs to replace short life machinery and/or equipment, such as nuclear process control valves (referred to as replacement costs) and costs for technological upgrades, which are foreseen from the planning phase.

---

[26] If such expenditures are covered with additional sources of financing, they need to be included in the total investment costs; otherwise, if financed by the project revenues, they are treated as operating costs.

[27] They only need to be included in the analysis in the year they are planned to occur if they are pertinent to the initial investment project and already scheduled in the ex ante phase.

TABLE 4. TYPICAL NUCLEAR POWER PLANT CAPITAL EXPENDITURE BREAKDOWN STRUCTURE [23]

Expenditure	Share of total (%)[a]
Nuclear stream supply system	12
Electrical and generating equipment	12
Mechanical equipment	16
Instrumentation and control system	8
Construction material	12
Labour on the site [b]	25
Project management services	10
Other services	2
First fuel load	3

[a] Numbers indicate the percentage of the total capital costs.

[b] Jobs created by an NPP project include employees who work at a construction site while it is being built. After its completion, jobs are created when the plant starts its operation. These jobs are permanent and highly skilled.

It is worth noting that for a country that does not yet use nuclear power, the introduction and development of nuclear power may require modification and strengthening of the grid system. These modifications may include new physical connections from the existing grid system to the NPP site, as well as other changes to the grid system and its operation and maintenance to ensure that it can provide a reliable electrical supply to the NPP, ensuring safe and secure operation of the plant [24]. Even in countries that already use nuclear power, grid investments may be required when adding a new NPP to develop and strengthen the existing electricity grid, depending on the NPP size and location. If these costs are easily ascribable to a specific plant, they are added to the capital costs for building the NPP. Otherwise, they are disregarded as part of the infrastructure costs necessary to implement a nuclear power programme rather than a specific plant.

3.3.2.2. Operating expenditures

For an NPP, operating expenditures encompass the following:

(a) *All costs necessary for plant O&M*. Examples of O&M cost items are labour, consumables and material equipment, contractor services, nuclear insurance, licensing and regulatory fees.
(b) *Costs of fuel*. Includes the price of natural uranium,[28] conversion and enrichment services and the cost of fabrication of fresh nuclear fuel.
(c) *Costs for treating and disposing of spent fuel and wastes*.[29]

---

[28] Generally, the fissionable fuel used is uranium, although other materials may also be used.

[29] Nuclear power plant operators are typically required to make provisions for the disposal of any waste, which means that the costs for treatment and disposal are ‘internalized’ as part of their operating costs, rather than being external. These are referred to as the back end components of fuel costs. The factors influencing these costs depend on the strategy adopted

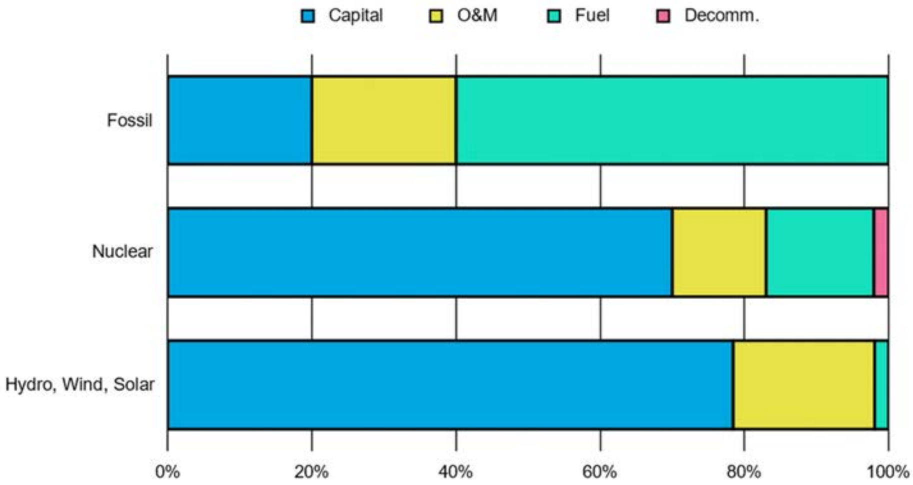


FIG. 12. Illustrative cost structures for power generation technologies [3].

Operating expenditures usually distinguish between ‘fixed costs’, which remain the same regardless of whether or not the plant is generating electricity, and ‘variable costs’, which vary in relation to the production output. These costs are normally expressed in terms of cost per unit of electricity (e.g. \$/MW·h).

According to the IEA and the OECD/NEA cost estimates [20], the operating costs of NPPs are lower than those of almost all fossil fuel competitors (see Fig. 12).

As a final remark, it is worth noting that, in the context of a CBA, the cost of financing (i.e. interest payments) is not usually part of the operating costs.

3.3.2.3. Decommissioning costs

Decommissioning is incurred in the future, after the NPP ceases operation. It includes the costs of decontamination, segmentation of the NPP main components, removal, transportation and storage of the parts, demolition of the reactor building and other buildings, and site restoration (and/or reuse). There are three main decommissioning strategies [26]:

(a) *Immediate dismantling*: the plant is dismantled right after the removal of materials and waste from the plant.
(b) *Deferred dismantling*: after removing materials and waste, the plant is kept in a state of safe enclosure for 30–100 years followed by dismantling.
(c) *Entombment*: the plant is encapsulated on-site and kept isolated until the radionuclides have decayed to levels that allow a release from nuclear regulatory control.

The costs for decommissioning vary from country to country and depending on the adopted strategy. They comprise ~9–15% of the initial capital cost of an NPP [27].

Although decommissioning activities occur some years (even many decades) after the plant final shutdown, the decommissioning payments begin as soon as a nuclear plant starts operating and generating revenues (Fig. 13). Utilities operating NPPs are usually required to set aside funds on a regular basis to cover future decommissioning activities; preferably, in a national fund based on the estimated present day, periodically updated, costs for decommissioning. Therefore, the cost for the final decommissioning

---

for the spent nuclear fuel and other highly radioactive waste management. Facility requirements can vary depending on the strategy and schedule for deployment. [25].

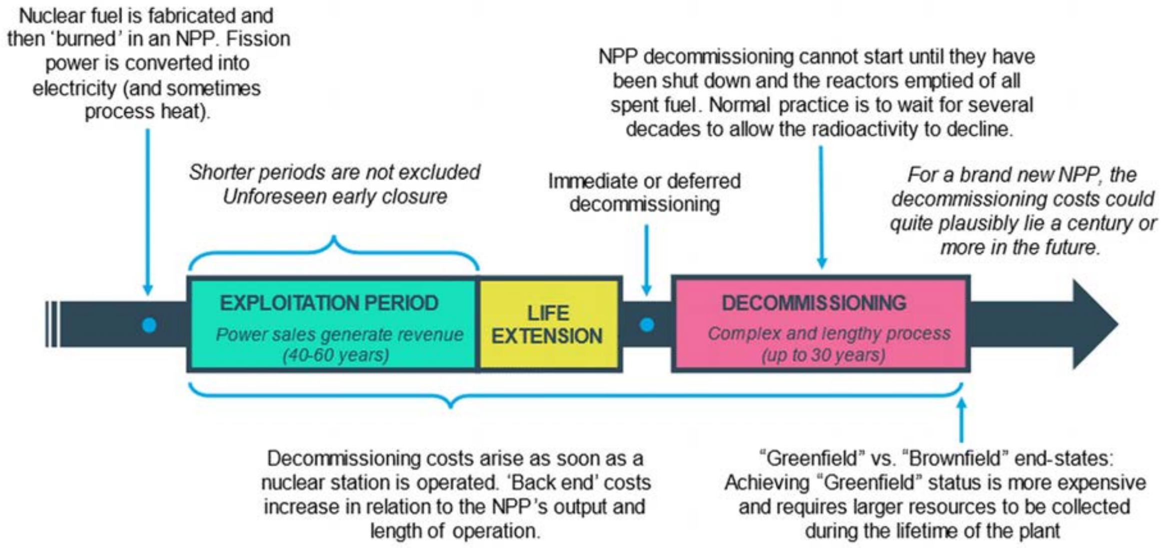


FIG. 13. Decommissioning timeline [28].

and dismantling of the plant constitute cash outflows over the entire reference period and not only when such activities occur. Accordingly, the decommissioning phase is not included in the time horizon for purposes of the CBA (see Section 3.3.1 on the reference period). Nevertheless, if additional funds to those set aside during the operational phase are required to cover the decommissioning costs, this amount needs to be inserted into the last year of the analysis, appropriately discounted.

3.3.3. Operating revenues

In general, the operating revenues associated with an investment project are estimated based on the volume of end products produced, or services supplied, and their relative unit selling prices. In a CBA, subsidies and other financial income — for example, interest from bank deposits — are not included within the operating revenues because they are not directly attributable to the project operations.

During its operational phase, an NPP may generate different revenue streams depending on the country and the energy tariff system. In all cases, an NPP generates revenues from selling electricity. These revenues are the amount of electricity generated by the plant each year (expressed in MW·h) multiplied by the annual electricity price. In addition, there may be revenues from the following:

- *Capacity payments to secure electricity supply* — payments for the guaranteed capacity that the plant provides.
- *Other ancillary services payments* — payments for grid services.
- *Energy allowances for projects falling under the emissions trading system, in the European Union, for instance* — if the emissions trading system allowances or similar certificates compensating for the reduced production of GHG emissions are sold on the national or supranational market (and this gives rise to a real cash flow for the project operator), the resulting revenues have to be included among the project inflows.[30]

---

[30] The current use of emission trading systems is documented in a freely available database accessible at: https://pinedatabase.oecd.org/

NPPs can also potentially be used for non-electric applications, such as seawater desalination and hydrogen production, which would translate into an increase and diversification of the sources of revenue.

In a liberalized market, the price of electricity is volatile. There are two components in pricing uncertainty. First, there is a short term volatile component that is expected to oscillate around some mean value. Second, there is long term uncertainty about the value of that mean value. This second type of uncertainty constitutes a large risk item and always needs to be considered in the sensitivity and risk analysis (see Section 3.5).

3.3.4. Financial performance indicators

The financial profitability of the project is ascertained by calculating two indicators (t refers to time in Eqs (3, 4) and i to the discount rate):

- *The financial net present value (FNPV)*. This is the sum when the expected (incremental) investment, replacement, operating costs and fiscal payments of the project (discounted) are deducted from the discounted value of the expected (incremental) revenues. A positive FNPV means that the discounted revenues exceed the discounted costs. Although the project is a financially viable option, it is not necessarily a socioeconomically viable option. The latter requires that an economic analysis be performed (step 6):

$$\text{FNPV} = \sum_t \left(\frac{\text{total revenues}_t}{(1+i)^t} - \frac{\text{total costs}_t}{(1+i)^t} \right) \tag{3}$$

- *The financial internal rate of return (FIRR)*. The FIRR is the discount rate that makes the net present value of all cash flows equal to zero over the lifetime of the project. The FIRR is given by the solution of Eq. (4). The resulting FIRR is typically compared to the established discount rate — that is, the FDR adopted to calculate the FNPV. If the FIRR is greater than the established discount rate (i), the project is worthwhile from a financial perspective:

$$\sum_t \frac{(\text{total revenues}_t - \text{total costs}_t)}{(1+\text{FIRR})^t} = 0 \tag{4}$$

It is worth reiterating that, in a CBA framework, the calculation of the financial performance indicators is performed incrementally; that is, considering the difference between the cash flows in the with the project and the counterfactual scenarios (see an illustration in Figs 14, 15).

3.3.4.1. Example 1

Project: Constructing a new NPP to replace the amount of electricity generated by an old coal-fired power plant.

Counterfactual: continue operating the coal fired power plant (i.e. status quo).

3.3.4.2. Example 2

Project: Constructing a new NPP to generate an additional amount of electricity to meet increasing demand.

Counterfactual: Build a new gas fired power plant (i.e. do something else).

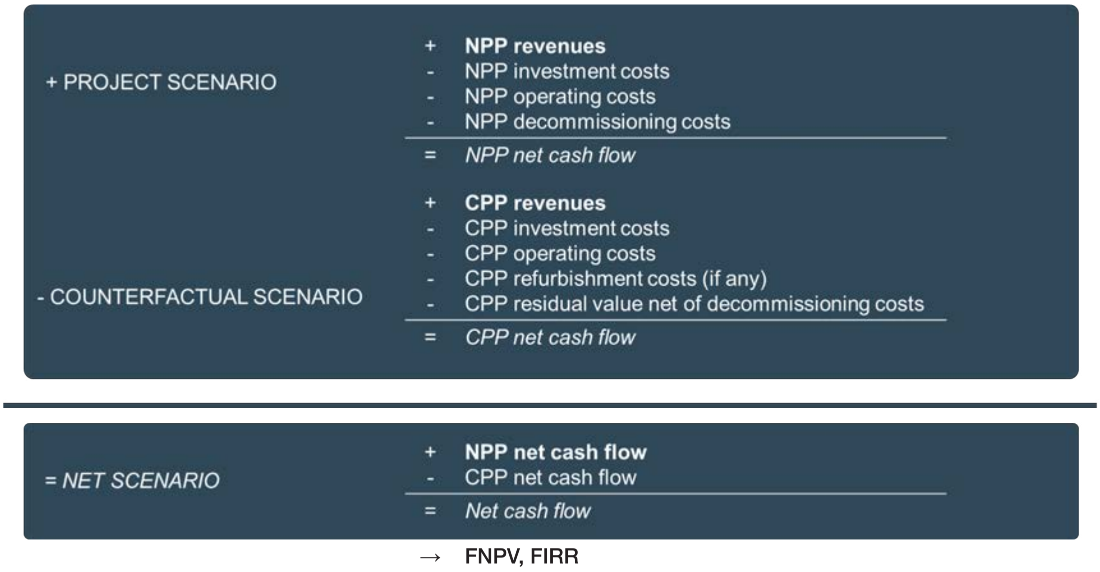


FIG. 14. Calculation of the incremental (or net) financial cash flows in different situations.

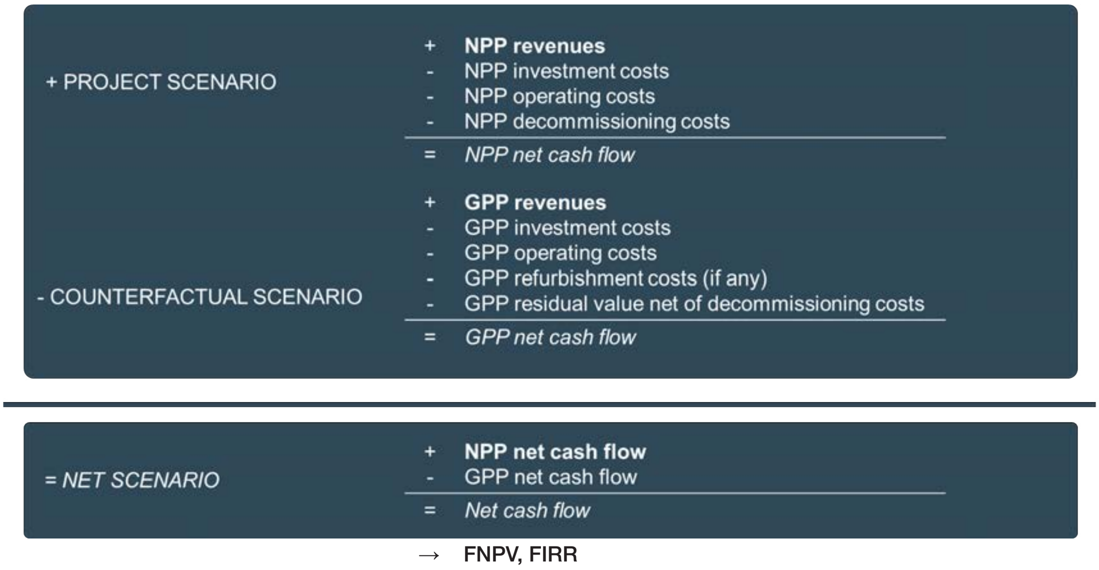


FIG. 15. Calculation of the incremental (or net) financial cash flows in different situations.

3.4. STEP 6: ECONOMIC ANALYSIS

This is the core step[31] of the procedure illustrated in Fig. 5: analysing the net socioeconomic benefits of the project to be implemented. Like other power plants, an NPP has costs (both private and external[32]) and benefits that need to be fully recognized and assessed to evaluate the net benefit.

---

[31] As already said, the wording ‘economic analysis’ is often referred to as CBA, implying an economic or social CBA.

[32] External costs are those borne by the community generally and typically not built into the cost of the electricity.

In purely competitive markets, prices constitute the instrument for efficient resource allocation. However, market prices cannot give the right signals to policy makers if imperfections exist. A variety of circumstances can lead to market prices that do not reflect the social value of projects' inputs and outputs. The most common distortions are the following:

(a) *Fiscal distortions*. Taxes and subsidies are a typical element of price distortions because they do not reflect the opportunity cost of goods or services, but rather a money transfer from the project to public finance, and vice versa. Thus, as they have no relevant effect on society as a whole, they need to be disregarded for the purpose of CBA.[33]

(b) *Unemployment and surplus labour*. When rates are above the market clearing level, there is surplus labour. This can sometimes result from minimum wage laws, union bargaining, or some other factors. In this situation, the number of workers who want to work at a given wage in a particular labour market exceeds the number of employers willing to hire at that wage, resulting in unemployment. This labour surplus scenario is particularly relevant in many low income countries [7].

(c) *Private monopoly*. In a private monopoly, the market price is higher than the marginal cost because the monopolistic firm makes excess profit. Such excess profit represents a distortion that needs to be accounted for in the economic analysis.

(d) *Regulated tariffs*. Occasionally, the price of some utilities, particularly electricity, may deviate from the LRMCs because of regulated tariffs imposed by the authorities.

(e) *In kind contribution*. This is when goods, services, or staff are provided 'in kind' by external parties for the construction or operation of the project. These items do not represent actual disbursement, but they have an economic cost (opportunity cost) for the purposes of CBA.

Moreover, there are situations where markets do not exist at all (e.g. there is not a market for purchasing time).

Economic analysis is therefore an accounting system using shadow prices instead of market prices. Shadow prices are estimated for all relevant economic costs and benefits accruing for the society as a whole. Theoretically, shadow prices can be estimated by solving a general equilibrium optimal planning problem, where prices reflect all the changes provoked by investment in the economy. A relatively standard approach is to move from the analysis of financial profitability to economic analysis by making

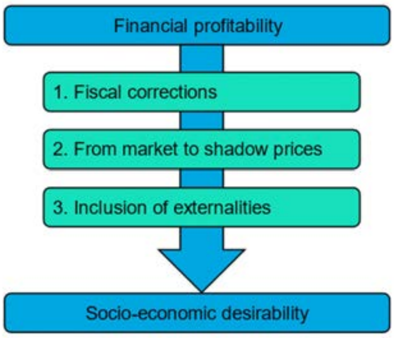


FIG. 16. Step by step procedure to move from a financial to a socioeconomic analysis.

---

[33] There are two caveats to this. First, tax and social security payments made from an employee's gross earnings are part of the output or value produced by the workforce. Therefore, they are not a transfer payment, and they are normally included where relevant in the economic analysis. Second, it could be justifiable to include indirect taxes and subsidies when these are mechanisms to fully internalize certain externalities. For instance, this is the case of taxes on CO_2 emissions levied to discourage the generation of GHG.

a series of adjustments with a view to making fiscal corrections, converting market prices into shadow prices, evaluating non-market impacts and including externalities, as necessary (see Fig. 16). In other words, market prices are usually the starting point for estimating the opportunity costs and the WTP. Where market prices are not suitable (because of distortion) or available (because of a non-existent market), non-market valuation techniques are to be used.

3.4.1. Fiscal corrections

Some components of financial analysis can be seen as transfers from one agent to another within society, with no economic impact. To correct such distortions, observed market prices need to be corrected in the following way:

- — All prices of inputs and outputs need to be net of value added tax and other indirect taxes.
- — All prices of inputs, including labour, need to be gross of direct taxes.[34]
- — Subsidies granted by a public entity to the project promoter are omitted from revenues under economic analysis, as they are pure transfer payments.

However, if specific indirect taxes are intended to correct for externalities (e.g. taxes on CO_2 emissions levied to discourage generation of GHGs), then these can be kept, provided that they adequately reflect the underlying marginal damage cost and there is no double-counting with external costs added in the analysis (see Section 3.4.3).

Table 5 provides an example of how economic costs may deviate from financial ones when taxes are not meant to internalize some externalities.

TABLE 5. FISCAL CORRECTIONS (US $ million)

	Power	Values	Construction supervision
Base cost (*A*)	250	300	20
Physical contingency[a] (*B*)	25	30	1
Total base cost (*C*) = (*A*+*B*)	275	330	21
Price contingency (*D*)	20	25	2
Total, before taxes (*E*) = (*C*+*D*)	**295**	**355**	**23**
Taxes (*F*)	15	25	0
Total (financial) cost (*G*) = (*E*+*F*)	**310**	**380**	**23**
Economic cost (*H*) = (*C*)	**275**	**330**	**21**

[a] To cover unknown risks related to the development and construction of an NPP, an overall contingency allowance is normally allocated and set as a percentage of the base cost. The amount is estimated based on historical records, on expert judgement, or by comparison with other projects.

---

[34] Tax and social security payments made from an employee's gross earnings are part of the output or value produced by the workforce. They are therefore not a transfer payment and need to be included where relevant in the economic analysis.

3.4.2. Conversion of market prices to shadow prices

When observed prices used in the financial profitability analysis (as illustrated in Section 3.3) fail to reflect the social value of a good, they need to be adjusted with shadow prices. A set of standard methodologies are used to correct market prices into shadow prices, depending on the nature of the input and output, as illustrated in Table 6.

TABLE 6. FROM MARKET TO SHADOW PRICES

	Features	Suggested method	Brief explanation
Input (costs)	Major tradable item	Border price rule	The rationale behind this approach is that for goods that move freely across borders, the best alternative to domestic production is imports from abroad. In line with this approach, the shadow prices of imported inputs need to be proxied by cost, insurance and freight prices
	Minor (non-tradable) item	SCF[a]	SCF is a measure of the average distortion of domestic prices as compared to international prices. It is calculated on the basis of national official statistics for import and export values, as well as import taxes and subsidy values, with the following formula: $\text{SCF} = \frac{(M+X)}{\left[\left(M+T_m\right)+\left(X-T_x\right)\right]}$ where M is total imports; X is total exports; T_m is import taxes; T_x is export taxes
	Major non-tradable item	LRMC	The rationale behind this approach is that an increase in one unit of a non-tradable input needs to be reflected in an additional domestic production of that input. The LRMC is therefore a reflection of both the capital and operating costs necessary to add an additional unit of a given input to the domestic economy. This method is typically used to estimate the shadow prices of electricity and water
	Labour	Shadow wage	Ad hoc estimation of shadow wages reflecting the specific conditions of labour markets at the national and even regional level
Output (revenues)	Tradable	Border price rule	The rationale behind this approach is that for tradable output the best alternative to domestic consumption is export. In line with this approach, the shadow prices of exported outputs need to be proxied by FOB[b] prices
	Major non-tradable item	WTP/WTA[c]	See Appendix II
		LRMC	See above

[a] SCF: standard conversion factor. Following the Little and Mirrlees approach, which uses world price numeraire, domestic prices are converted to world prices by using the standard conversion factor.

[b] FOB: free on board, before insurance and freight charges.

[c] WTA: willingness to accept.

TABLE 7. EFFECTS OF USING CONVERSION FACTORS (ILLUSTRATIVE EXAMPLE)

	Market prices (US $)				CF	Shadow prices (US $)			
Years	**0**	**1**	**...**	**10**		**0**	**1**	**...**	**10**
Construction	−150	—	—	—	0.80	−120	—	—	—
Equipment	−100	—	—	—	0.95	−95	—	—	—
Power	—	−500	−500	−500	0.70	—	−350	−350	−350
Skilled labour	—	−150	−150	−150	1.00	—	−150	−150	−150
Unskilled labour	—	−100	−100	−100	0.60	—	−60	−60	−60
Revenue	—	1000	1000	1000	0.80	—	800	800	800
Net cash flow	**250**	**250**	**250**	**250**		**−215**	**240**	**240**	**240**
NPV[a]	**1680**					**1638**			

[a] The discount rate adopted for the NPV is 5%.

Revaluing a project at shadow prices can be straightforward when the necessary opportunity cost information is available. The measure of price distortions is usually assessed and reflected in the so-called conversion factors (CFs), defined as the ratio between shadow and market prices. CFs multiplied by the market prices determine the corresponding shadow prices, as shown in Eq. (5) and detailed in Table 7.

$$\text{CF}=\frac{\text{shadow price}}{\text{market price}} \rightarrow \text{shadow price} = \text{CF} \times \text{market price} \tag{5}$$

For new build power plants, the main components, equipment and fuel are sourced on international and competitive markets. Therefore, the economic analysis can generally base itself on market priced revenues and input costs for capital investment, fuel, fixed operating and maintenance. Nevertheless, there may be distortions affecting market prices of selected items, which vary from country to country and need to be considered on a project by project basis. The following items usually deserve attention.

3.4.2.1. Cost side

(a) *Land prices*. If land for building the new plant is already owned or made available for free by the Government (or another investor) or below market price, the shadow price needs to be calculated to reflect the opportunity cost of land use — that is, the value forgone for the best alternative use of land. If it is reasonable to assume that market price captures the opportunity cost of land, then it can be considered to be reflective of the economic value of land. If land is made available below its true value, its CF is above 1.

(b) *Labour*. Sometimes wages in the market are paid above the market clearing wage. As a result, there is unemployment; thus, the shadow wages need to be calculated, particularly for ‘unskilled’ labour,[35] to reflect the opportunity cost of labour. For workers drawn to the project from unemployment, the

---

[35] The wages of skilled workers are often not distorted by a high unemployment rate at the national level because the reference job market is the international one. In this case, the observed wages reflect the opportunity cost of labour.

shadow wage can be assumed to be equal to or greater than the value of unemployment benefits or the reservation wage.[36]Alternatively, many different techniques exist [29–31]. In cases of high unemployment, the CF of labour is below 1. It is worth noting that labour is always an input for the construction/operation of a new plant and therefore it always represents a cost, even in the economic analysis. Shadow wages still represent a cost, but as long as it is lower than the market wage, it implicitly includes an employment benefit in the form of a socioeconomic cost lower than the financial cost.

(c) *Fuel purchase costs*. This is expressed as 'border prices' in order to better reflect opportunity costs.[37]

(d) *Spent fuel and waste treatment and disposal costs*. To proxy the shadow price of waste treatment and disposal, the LRMC of treatment and disposal infrastructure can be calculated. Alternatively, the border prices can be adopted. If the observed price for the treatment and disposal of spent fuel and the other highly radioactive waste is above the LRMC or the border price, the CF for this cost item is below 1, and vice versa.

(e) *Regulated prices of inputs*. The prices of inputs such as electricity (mainly used during construction) and water may be heavily regulated to protect consumers from the ups and downs of the market. This implies that the observed price is, depending on the situation, below or above the market clearance level. To proxy the shadow price of energy/electricity used as an input for the project, the social LRMC could be calculated. The LRMC reflects both the capital and operating costs necessary to make an additional unit of electricity available to the domestic economy.[38] If the observed electricity price is above the LRMC, the CF of electricity will be below 1, and vice versa.

3.4.2.2. Benefit side

The price formed in the wholesale power market cannot typically be deemed to adequately reflect the marginal cost of electricity generation because of certain market distortions. Therefore, in the economic analysis, the electricity output (in MW·h) of energy plants needs to be valued at its shadow price, which is typically proxied by the WTP or the LRMC.[39] More specifically:

(a) *For projects involving the expansion of electricity production to meet excess demand*. The annual wholesale revenues of the with the project scenario need to be replaced by an economic flow valued as the yearly amount of additional electricity supplied multiplied by the users' WTP for receiving such additional electricity. The WTP can be estimated in different ways. The most common consists of estimating the avoided costs associated with the alternative systems of energy production — for example, self-generation of electricity — that the user would employ to meet the demand not addressed by the existing supply system.

(b) *For projects involving the substitution of the source or fuel for electricity generation (which leads to a variation of electricity costs)*. The opportunity cost of the substituted sources (oil, natural gas, biomass, solar, wind, hydro, etc.) and substituting sources (nuclear) needs to be considered for valuing the changes of energy costs. In other words, the annual wholesale revenues of the with the project scenario need to be replaced by an economic flow valued as the yearly amount of electricity supplied times the LRMC of electricity generation at the new build NP plant. Similarly, the annual wholesale revenues in the counterfactual scenario need to be replaced by an economic flow valued

---

[36] The reservation wage includes the value of time in leisure, household production or self-employment, job search opportunity costs, commuting and other costs to the employee.

[37] This is not only valid for uranium but also for crude oil, diesel, heavy fuel oil, coal and natural gas, which may be cost items in the counterfactual scenario. They all are internationally tradable goods.

[38] In many instances, the LCOE generation of the reference baseload technology is used as a proxy for LRMC, assuming that in the long run all production factors (including capital) are 'variable'.

[39] In many instances, the LCOE generation of the reference baseload technology is used as a proxy for LRMC, assuming that in the long run all production factors (including capital) are 'variable'.

as the yearly amount of electricity supplied[40] multiplied by the LRMC of electricity generation at the displaced plant. For projects where it is not possible to identify what specific electricity source/fuel will be displaced by the construction of a new NPP, a shortcut method for the benefit evaluation is to assess the variation of the energy opportunity cost against a counterfactual one where the weighted average electricity production mix of the market is taken into account [8]. Hence, the average of opportunity costs of each source/fuel weighted by the share of electricity produced by each source over the total production needs to be computed.

(c) *For projects involving the substitution of imports with self-production of nuclear electricity*. The annual wholesale revenues of the with the project scenario need to be replaced by an economic flow valued as the yearly amount of electricity supplied multiplied by the difference between the LRMC of producing nuclear electricity domestically and the LRMC of the substituted imported electricity, including transport costs where relevant. In this case, the electricity produced by the NPP does not displace a specific electricity source, but rather the mix of sources used for producing electricity in the import country. Therefore, the LRMC of producing electricity with the project needs to be compared to the weighted average LRMC of imported electricity.

The LRMC can be estimated from a private and a societal perspective, depending on whether the external costs associated with the electricity generation are included in the calculation. If the social LRMC is used as the shadow price of the electricity output, the externalities are not added to avoid double counting. Conversely, if the private LRCM is used to value the electricity output in the economic analysis, the externalities are added as separate items.

3.4.3. Inclusion of externalities

After correcting observed market prices, it is essential to identify the costs and benefits for which market values are not available — that is, externalities.[41] Above all, these would be impacts on human health and environmental effects. In this case, the determination of a positive or negative externality would be from the perspective of an NPP. For instance, avoided GHG emissions are a benefit for an NPP as compared to a coal based plant, but would be a cost if a CBA for a coal based project is performed comparing it to an NPP. The main externalities associated with NPPs are below:

- Release of GHG emissions;
- Release of airborne pollutant emissions;
- Release of radioactive emissions;
- Waste stream;
- Accidents;
- Security and reliability of supply.

Before proceeding, it is worth noting that an externality exists if two conditions are met. First, some negative or positive impact is generated by an economic activity and imposed on third parties [32]. Second, that impact is not priced in the marketplace [32]. The second condition implies that if the effect is negative, no compensation is paid by the generator of the externality to the sufferer; inversely, if the effect is positive, the generator of the externality is not supposed to appropriate the gains to the third party through a price charge or otherwise [32].

Therefore, if externalities are fully ‘internalized’ (e.g. by means of taxes or wage premiums), they do not need to be added in. Otherwise, double counting could occur. This explains why, in many instances, the external costs of radioactive effluents and waste stream are not included in the economic analysis

---

[40] Differently from the expansion case (see point (a)), the amount of electricity supplied in the with and without the project scenarios is the same.

[41] Appendix III provides a review of external costs studies in the energy field.

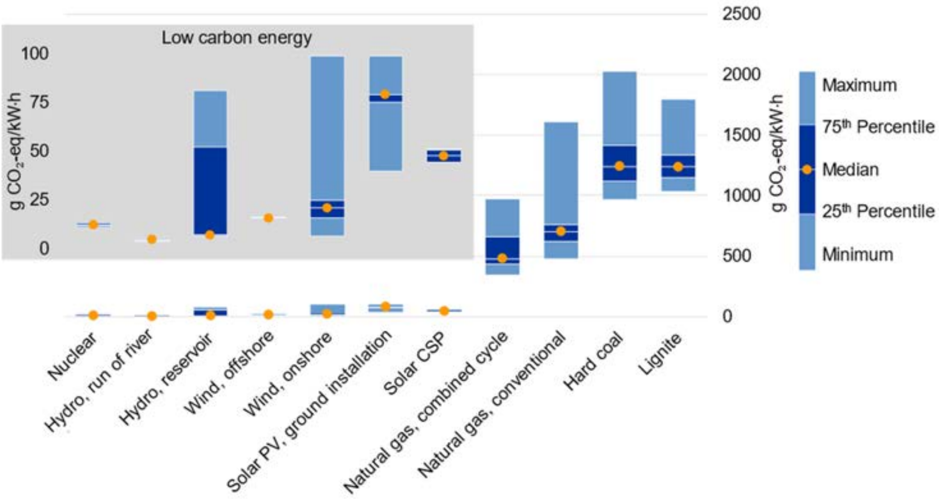


FIG. 17. Life cycle GHG emissions (in g CO_2 equivalent/kW·h) of electricity technologies [4]. The grey background highlights energy sources with the lowest emissions.

for an NPP. However, if externalities are only partially compensated or appropriated, there is room to estimate the part of the externality that is not internalized.

3.4.3.1. Greenhouse gas emissions

The different stages of a power plant's life cycle, from the construction of the plant to its operation and dismantling, provoke the emission of a volume of GHGs[42], either directly (e.g. fuel combustion or production process emissions) or indirectly through purchased electricity and/or heat. As Fig. 17 shows, nuclear power, along with hydro and wind power, emits the lowest quantity of GHGs per unit of electricity on a life cycle basis.[43] In contrast, GHG emissions are substantially higher for fossil fuel technologies, including those with carbon capture and storage [3, 4].

Mean life cycle GHG emissions from NPPs are in the range of 10–12 g CO_2 equivalent per kW·h, mainly from mining and milling uranium ore and enrichment.[44] This amount can be further improved by using improved technologies for fuel preparation and using reactor designs with longer operation periods and higher efficiency [3].

To determine whether the NPP produces a positive or negative variation in GHG emissions, the relative external cost needs to be assessed against the counterfactual scenario — that is, compared to what would have happened in the absence of the nuclear project. More specifically, the economic valorization of GHG emissions consists of the following steps:

(a) *The quantification of emissions saved due to the NPP as compared to the counterfactual scenario*. In principle, the feasibility study, particularly the EIA report when required, reports the absolute quantities of life cycle GHG emissions generated by the NPP. If this is the case, these could be considered for the purpose of the economic analysis. However, the absolute value of GHG emissions

---

[42] Greenhouse gases include multiple gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

[43] The calculation is based on a life cycle assessment approach that compares the full GHG impact of producing a final product, in this case a kilowatt-hour (kW·h) of electricity, with different technologies. This approach accounts for all the impacts over the life of each technology.

[44] A carbon dioxide equivalent or CO_2 equivalent is a metric used to compare the emissions from various GHG on the basis of their global warming potential (GWP). GHGs other than CO_2 are converted into CO_2 equivalent (CO_2 eq) by multiplying the volume of emissions of the specific GHG with a factor equivalent to its GWP in terms of carbon dioxide.

due to the project needs to be subtracted from GHG emissions in the counterfactual scenario. This gives the emissions variation of the project — that is, the relative GHG emissions of the project when comparing the difference in emissions between the with and the without project scenarios. Depending on the data available, the volume of emissions saved can be expressed as a tonne or gram of CO_2 equivalent per year or per kW·h. If project specific data are not available, it is good practice to use default factors based on sector specific activity data and through the application of documented emission factors (for a comprehensive review of default factors see Annex 1 of Ref. [33] and also Ref. [34]). Emissions are estimated by multiplying activity data, such as the volume of fuel used or product generated, by a project specific or an industry default emission factor. As a minimum, the calculation of relative GHG emissions from construction and operation of the new plant is needed. However, a more accurate calculation is to consider total life cycle emissions, which include upstream emissions associated with fuel supply and transport and downstream ones.

(b) *The monetization of emissions saved.* A possible way to incorporate the GHG effect in the economic analysis of energy projects is to value the cost of emissions through the market price of permits that had to be bought by the operator to internalize the externality. According to this approach, the avoided costs of buying permits from the reduction of emissions would represent the economic value of this benefit. However, due to distortions in the emission trading systems, as highlighted for example by the European Investment Bank [35], the price of allowances still cannot be regarded as a reliable economic cost of emissions. Therefore, the method suggested for monetizing the GHG benefit consists of multiplying the volume of emissions saved by the project by their unit economic costs. As illustrated in Table 8, different estimates of the economic cost of a CO_2 equivalent are available in the literature. In general, there are two major approaches in which climate change costs can be calculated: using damage costs or abatement (avoidance) costs. The former values each of the individual effects of climate change — for example, sea level rise, crop failure, health cost — and sums these together. The latter centres around the costs of avoiding the effects of climate change up to a desired extent — for example, the target of the Paris Agreement. Apart from methodological complexities, the biggest argument for the use of abatement costs rather than the damage costs approach is the fact that countries are already signatories to the Paris Agreement.

Regardless of the values adopted, an important remark is to adjust CO_2 eq price levels to the price level of the specific CBA. Moreover, the values need to be escalated over the reference period on the basis of the expected real GDP growth.[45]

Figure 18 illustrates the overall series of activities to quantify and monetize the climate change benefit for new build NPPs.

3.4.3.2. Airborne pollutant emissions

Nuclear power plants do not emit significant amounts of air pollution (non-GHG) during operation.[46] Therefore, if it will replace more pollutant intensive power generation methods such as fossil fuel based plants, the new build NPP will generate a benefit by avoiding polluting compounds.[47]

As for the valuation of GHG emissions, a monetary value reflecting the cost of airborne pollution needs to be attributed to the avoided volumes of air pollutants resulting from the project along the entire

---

[45] In the NEEDS project, evidence was found that real increase of unit damage values during the reference period can be assumed with an elasticity with respect to GDP per-capita growth between 0.7 and 1.0.

[46] There are no emissions of GHG, other pollutant gases or particulates from the NPPs themselves. However, the use of fossil fuels at other stages of the nuclear energy chain (e.g. for uranium mining, fuel preparation, transportation) lead to very small emissions, which have to be accounted for.

[47] Airborne pollutants include particulate matters (PM2.5), sulfur dioxide (SO_2), oxides of nitrogen (NOx), volatile organic compounds (VOCs) and ammonia (NH_3). These pollutants cause health damage, damages to buildings and materials, crop losses and costs for further damages for the ecosystem (biosphere, soil, water).

TABLE 8. ECONOMIC COST OF CO_2 EQUIVALENT [33, 36–39]

	Range of carbon price		Notes
	2020	2030	
European Investment Bank (and European Commission, Directorate-General for Climate Action (DG CLIMA))	80	250	€$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2016 prices, central estimates. Abatement cost approach
European Commission, Directorate-General for Mobility and Transport (DG MOVE)	n.a.[a]	60–189, central value 100	€$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2016 prices. Abatement cost approach
High-Level Commission on Carbon Pricing	40–80	40–80	US $\$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2016 prices. Abatement cost approach
Word Bank[b]	40–80	40–80	US $\$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2016 prices. Abatement cost approach
International Monetary Fund	n.a.	75	US $\$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2017 prices. Abatement cost approach
International Panel for Climate Change	n.a.	135	US $\$\cdot t^{-1}\cdot CO_2$ eq^{-1}, in 2017 prices. Abatement cost approach

[a] n.a.: not applicable.

[b] The World Bank is in line with the High-Level Commission on Carbon Prices [38]. The World Bank estimates values beyond 2030.

FIG. 18. Calculation flow for climate change benefit.

time horizon (including plant construction, operation and post-closure) versus the counterfactual scenario. More specifically, the economic valorization of airborne emissions consists of the following steps.

(a) Quantification of airborne pollutant emissions saved thanks to the NPP as compared to the counterfactual scenario

This is performed according to the same logic as for GHG emissions; that is, based on the absolute values reported in the EIA section of the feasibility study, and their differences (with and without the project scenarios). Where project specific data are not available for estimating the counterfactual volumes of air emissions, it is good practice to use default emission factors. Emissions can be estimated by multiplying activity data, such as the volume of fuel used or (4product generated, by a project specific or industry default emission factor. For example, emission factors for different energy generation processes

TABLE 9. KEY LIFE CYCLE EMISSIONS (kg/kW·h) [40, 41]

	New Energy Externalities Development for Sustainability (NEEDS)		Cost Assessment for Sustainable Energy Systems (CASES)	
	2025	2050	2020	2030
Ammonia	6.74E-07	5.81E-07	7.29E-07	6.09E-07
Dinitrogen monoxide	5.85.E-07	4.86.E-07	3.16.E-07	1.63.E-07
PM10	2.04.E-06	1.48.E-06	1.85.E-06	1.53.E-06
PM2.5	3.96.E-06	3.16.E-06	4.42.E-06	3.21.E-06
Nitrogen oxide	2.66.E-05	2.26.E-05	3.05.E-05	2.16.E-05
Sulfur dioxide	2.14.E-05	1.81.E-05	3.92.E-05	2.19.E-05

Note: Both the NEEDS and CASES values refer to pressurized water reactors (PWRs) of the European pressurized reactor type.

can be found in the New Energy Externalities Development for Sustainability (NEEDS) [40] and Cost Assessment of Sustainable Energy Systems (CASES)[48] [41] projects, which are summarized in Table 9.

(b) The monetization of emissions saved

Distinct from GHGs, air pollutants can result in different impacts and, therefore, different costs, depending on the location and characteristics of the source of pollution. This requires linking of incremental pollution emissions to changes in ambient concentrations, and then linking of changes in ambient concentrations to changes in health/environmental effects, and finally monetizing of the value of human life and environmental assets. In practice, the benefit transfer method is applied. For instance, for Europe, monetary damage values can be found in the NEEDS [40] and CASES [42] projects. The NEEDS project provides unit damage costs (in terms of health, biodiversity, crop yield, material damage) for air pollutants (expressed in $€_{2000}$) multiplied by the quantity of pollutants emitted by a power plant, which is technology specific (estimated in a previous step). The CASES project, on the other hand, provides country and technology specific data for external costs (for health, biodiversity, crop yield, material damage).[49] Therefore, such external costs simply need to be multiplied by the amount of electricity generated by the plant. For the United States of America, the externality study conducted by the Nuclear Regulatory Commission (NRC) uses a very similar methodology to Externalities of Energy (ExternE) [43].

The IAEA's computer tool Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS) can be helpful to calculate the physical damage for the environment and human health, as well as the external costs of atmospheric emissions from the major energy sources.

3.4.3.3. Radioactive emissions

In the nuclear energy sector, safety and radiation protection norms, standards and regulations, based upon the as low as reasonably achievable principle, reduce external costs due to release of radioactive effluents drastically [41].

---

[48] CASES database: http://www.feem-project.net/cases/downloads_deliverables.php

[49] Data are only available for countries that were part of the European Union when the project was carried out.

During normal operation (i.e. not including unintended accidents — discussed in the next section) of NPPs and other facilities of the nuclear fuel cycle, the release of radionuclides[50] into the environment is constantly monitored to ensure that they stay under certain stringent limits imposed by regulations[51]. In addition, NPP operators pay insurance coverage to provide protection against various risks (e.g. losses due to plant shutdown or closure, occupational health and safety claims), as they are liable for any damage to third parties that their operations may cause.

Therefore, the capital and operating costs of NPPs and other facilities of the nuclear fuel cycle already internalize a major portion of the potential external costs [45]. If these costs related to safety and radiation protection are disregarded, an alternative way to account for the external cost of radionuclides released to the air and aquatic environment is provided by the ExternE methodology (see Refs [46, 47]).

Suppose the external cost of radiation impact is included in the CBA. In that case, it is worth noting that the radioactive emissions are not unique to nuclear energy but also characterize other power plants, such as coal fired plants that release radioactive materials into the environment (in this case, in the form of fly ash). Thus, the external cost of radioactive emissions in the counterfactual scenario also needs to be estimated. Hence the ExternE studies are also a reference for non-nuclear power technologies.

3.4.3.4. Waste streams

A biproduct of NPPs generating electricity is radioactive waste. Radioactive waste is classified depending on the half-life and the level of radioactivity of the nuclides it contains. According to the IAEA's safety standards, there are six classes of radioactive waste (illustrated in Fig. 19). Intermediate level waste and high level waste, mainly from spent nuclear fuel, are the most problematic categories.

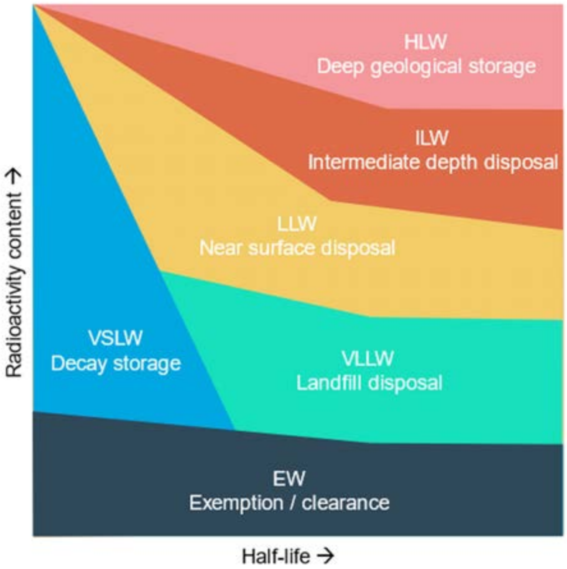


FIG. 19. Waste classes [48]. EW — exempt waste; VSLW — very short lived waste; VLLW — very low level waste; LLW — low level waste; ILW — intermediate level waste; HLW — high level waste.

---

[50] They include the radioisotopes of the noble gases krypton, xenon and radon, of tritium and ^{14}C, and also of fission product and fuel aerosols.

[51] Regulations typically follow the recommendations by the International Commission on Radiological Protection (ICRP) about permissible radiation exposures to humans from nuclear installations, distinguishing between occupationally exposed persons and individual members of the public.

The annual quantity of radioactive waste produced by a nuclear plant is limited. On average, the generation of electricity from a 1000 MWe nuclear power station produces a few hundred cubic metres of low and intermediate level waste per year and some 30 t of spent nuclear fuel. However, all of this waste needs to be managed safely and disposed of in a way that does not harm humans or the environment.

The solution adopted to isolate radioactive substances from the biosphere is disposal in near surface repositories for waste with low radionuclide content and geological repositories for waste with higher long lived radionuclide content, providing long term containment of the radioactive wastes that go on emitting radiation for several hundreds of thousands of years. As for spent fuel, it is typically stored temporarily on-site at NPPs before it is either reprocessed[52] or sent for final disposal, which is delayed to allow radioactivity to decay.[53]

In line with the intergenerational equity principle[54] (which affirms that the generation that benefits from nuclear power needs to deal with its radioactive waste without imposing undue burdens on future generations), and the 'polluter pays' principle (which makes operators liable for the cost of managing, storing and disposing of nuclear waste), the cost of waste management (either reprocessing and disposal) needs to be internalized to a large extent. The degree of internalization is largely dependent on the country's legislative and regulatory framework, as well as on the methodology adopted to estimate waste management cost [49]. The latter, in turn, depend on the adopted waste management strategy, which implies different stages and facilities for implementation. For direct disposal, the overall cost set includes the interim storage cost, waste encapsulation cost and disposal cost. Instead, the overall cost set for reprocessing and recycling strategies requires interim storage costs, reprocessing costs and encapsulation costs, along with final disposal costs. However, an OECD/NEA study [25] on back end cycle economics showed that the fuel cycle cost differences between the different strategies are relatively small.

Table 10 [50] shows the amount of money that plant operators/nuclear utilities in some different countries are required to set aside for waste management.

Although nearly every government claims to apply the above mentioned principles, most countries only enforce them partially and national authorities end up assuming responsibilities and paying for long term nuclear waste management and disposal. As a result, only a fraction of the cost for managing, storing and disposing of nuclear waste is internalized. The critical issue is estimating the remaining part, a cost sustained by the society, which is often neglected. Assuming an external cost of 2 €cent/kW·h for waste management [51] allows an estimate of insufficient payments by plant operators for future waste management [52].

3.4.3.5. Accidents

Accidents are events in contrast to normal operation. Accidents can be triggered by natural hazards, technological failures and human errors.

A comparison of fatality rates per unit of electricity output from different energy chains for 1970–2008 concluded that renewables, modern nuclear plants and hydropower[55] have lower fatality rates than coal based plants [53]. Despite the low likelihood, the potential exists for major nuclear power accidents. Unlike with most other technologies, major nuclear accidents such as those at Chornobyl (former USSR, present day Ukraine) and Fukushima (Japan), or relevant ones such as that at Three Mile

---

[52] Reprocessing separates the uranium and the plutonium from waste products, as these elements can be reused in conventional reactors. While the amount of high level waste to be disposed of is reduced through reprocessing when compared to an open fuel cycle, significantly greater quantities of long lived low and intermediate level waste are generated during reprocessing.

[53] The approach to managing spent fuel (either reprocessing, direct final disposal or temporary storage until a suitable choice of disposal is made) is selected at the national level.

[54] The Joint Convention places an obligation on its signatories to formulate strategies for the effective management of their radioactive waste. The goal is to avoid placing unnecessary burdens on future generations.

[55] It only refers to hydropower plants in OECD countries. Hydro dam failures in non-OECD countries have led to numerous casualties.

TABLE 10. RADIOACTIVE WASTE MANAGEMENT COSTS [50]

	US $/kW·h	Notes
China	0.0037	Levy on electricity
Czech Republic	0.002	Under the Atomic Energy Act 2002, the nuclear plant operator is required to put aside funds for waste disposal, lodging these with the Czech National Bank
France	0.0015	Set aside by the nuclear utility
Japan	0.004	Up to 2016
Spain	0.0076	Levy on electricity sales
Sweden	0.0051[a]	Nuclear utilities make payments into the Swedish Nuclear Waste Fund
USA	0.001	Nuclear utilities make payments into the Nuclear Waste Fund. The Department of Energy stopped collecting the waste fees in May 2014

[a] Sweden's rate is for the period 2018–2020.

Island (USA), have broad and long term socioeconomic costs. Most of these costs are not incurred by the owner of the NPP but are largely borne by society as a whole.

The most common approach for estimating the cost of a potential accident is to calculate the summation of the probability of the occurrence of a scenario (P_i) leading to an accident multiplied by the damage cost from that accident (C_i) over all plausible scenarios (i) [47]. This expressed in Eq. (6) as:

$$\text{Expected value of accident} = \sum P_i \times C_i \tag{6}$$

The probability of nuclear accidents is typically estimated by applying a probabilistic safety assessment, which evaluates the potential causes of an accident, the probabilities of occurrence and the corresponding expected environmental releases [44].[56] Alternatively, the probability of nuclear accidents can be estimated based on the historical record of accidents. Statistics on past energy related accidents are available from a variety of sources, such the OECD/NEA and the Energy-related Severe Accident Database (ENSAD) database[57], among others [54, 55].

Damage costs vary considerably from accident to accident, depending on the severity. When an accident does not entail the release of 'sizable amounts' of radioactive material, the damage costs reflect the expenses sustained by the plant owner to repair or replace the damaged assets and manage the emergency, as well as the cost of lost production (if relevant). In contrast, for severe accidents causing the release of 'sizable amounts' of radioactive material, both the damage costs (e.g. cost of lost reactors, lost power, clean-up) and external costs (fatal cancers, displacement costs, loss of agricultural production) need to be estimated based on the historical unit cost values for the various types of consequences.

As an example, Table 11 provides the illustrative central estimation provided by Rabl and Rabl [51]. Dividing the cost of an accident by the number of years between accidents (25) and the annual electricity production (2100 TW·h/year), and discounting the value at a 5% rate, Rabl and Rabl derive a range

---

[56] Comprehensive probabilistic safety assessment studies go beyond the determination of the probability and compute also the consequences.

[57] See: http://www.ensad.ch/.

TABLE 11. ASSUMPTIONS AND ESTIMATION OF EXTERNAL COST OF A SEVERE ACCIDENT (€, 2010) [51]

	Assumption	Cost	Billion €
Lost reactors	6 GW	Cost of reactors	30.0
Cost per reactor	5bn[a] €/reactor		
Lost power production	90 TW·h	Cost of lost power	18.00
Value per kW·h	0.2 €/kW·h		
Cost of clean-up	30.00	Cost of clean-up	30.00
Fatal cancers	10 000	Cost of cancers	18.80
Cost per cancer	5mn[b] €/cancer		
Discount factor to account for delay between accident and occurrence of cancer	0.38		
Displaced persons	500 000	Cost of displaced persons	250.00
Cost per displaced person	0.5mn €/person		
Area lost for agricultural production	1 000 km^2	Cost of lost agriculture	7.50
Yield, cereals	500 t·km^{-2}·year^{-1}		
Price, cereals	150 €/t		
Loss	75 000 €·km^{-2}·year^{-1}		
Loss duration	100 years		
Total cost of accidents, if now			**354.30**

[a] bn — billion.
[b] mn — million.

of ~0.001–0.023 €/kW·h, with a central value of ~0.004 €/kW·h for the external cost of accidents (at 2010 prices).

As calculations of the economic consequences of a severe nuclear accident require a series of assumptions on the probability and the cost of accidents and entail empirical and methodological challenges, estimates of the expected value of a major accident need to be treated with great caution. Table 12 shows that there is a large range of estimates in the literature associated with the cost of major nuclear accidents.

3.4.3.6. Security and reliability of supply

Security of energy supply is a widely touted objective of energy investment projects. It is defined as the resilience of an energy system to unique and unforeseeable events that threaten the physical integrity

TABLE 12. COMPARISON OF COST OF MAJOR NUCLEAR ACCIDENTS [46], [56–60]

Study	Unit	Cost
ORNL (1993) [56]	US $/MW·h	0.06–0.08
ExternE (1995) [46]	ECU/MW·h[a]	0.002–0.1
NewExt (2004) [57]	€/MW·h	0–0.006
IER (2013) [58]	€/MW·h	0.23
D'Haeseleer (2013) [59]	€/MW·h	0.3–3
Matsuo (2016) [60]	JPY/MW·h	300

[a] ECU — European Currency Unit, which was the former currency unit of the European Communities before being replaced by the euro in 1999.

of energy flows (power disruptions) or that lead to discontinuous price rises [61]. Therefore, security of energy supply can be schematically related to the following:

- The probability of interrupted electricity generation,[58] which can be reduced through the diversification of generation technologies and input fuels;
- Price volatility, which can be reduced through diversification of input fuels;
- Dependence on electricity imports.

Nuclear power can improve the security and reliability of supply, as highlighted in an OECD/NEA study [62], especially in power grids with an important share of variable renewable generation. Situations where an NPP may have a positive contribution in terms of security and reliability include:

(a) *Stability of uranium price as compared to volatile fossil fuel price.* Uranium has three advantages [63, 64]. First, today's market provides a high degree of security of supply. Second, it has lower exhaustion risk compared to fossil fuels, such as oil. Third, it is easily storable because of its high energy density. These make the cost of nuclear produced electricity largely stable, and uranium price changes have a lower impact on it compared to, for example, fuel for fossil energy sources.

(b) *Decreased dependence on imported electricity.* If the construction of a new NPP intends to decrease dependence on imported electricity by substituting part (or all) of the imports with domestically produced electricity, the substitution may lead to a more secure and cheaper electricity supply in the country.

(c) *High capacity factor and high reliability.* NPPs, along with coal and gas power plants, can achieve a high capacity factor[59] of ~90%, providing continuous reliable power [18]. In contrast, variable generation sources, such as wind and solar, place additional requirements on the electricity system for load balancing and backup (see Fig. 20). The 'system costs' for these technologies can be three to ten times higher than for other generators, depending on their penetration rates in the overall electricity mix. [65].[60]

---

[58] Stable, reliable and resilient power grids help in limiting the frequency and duration of power interruptions.

[59] The actual energy output of an electricity generating plant divided by the energy output that would be produced if it operated at its rated power output for the entire year.

[60] However, despite these generally higher costs, there may be cases where integrating small scale intermittent renewables can be less costly than expanding the transmission and distribution grid.

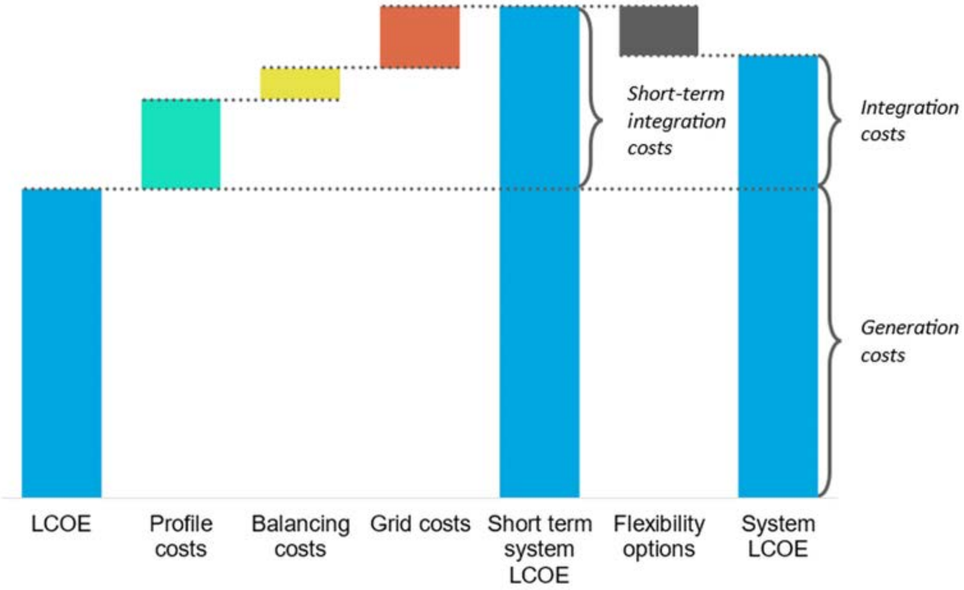


FIG. 20. Illustration of system cost. Adapted from Refs [18, 66].

On the other hand, due to the risk of a power plant or grid connection line outage, investing in a large reactor may also make a negative contribution to security and reliability if the alternative scenario would be multiple smaller dispatchable units.

In some cases, therefore, the benefit of increased security and/or reliability of supply can be added to the benefit stream of the NPP. Different methodologies have been proposed in the CBA literature to estimate the benefit from improved security and reliability of supply. Here, the main methods are briefly recalled:

(1) *Avoided cost*. The avoided cost of ensuring security of supply through the next best alternative or with the considered source. For example, in Europe, an indication of the social value given to gas supply disruptions can be computed by assessing what it costs society to guarantee that the so-called 'N-1 principle' (failure of the single largest gas infrastructure) always complies with Ref. [67].

(2) *Avoided compensations*. If a compensation system for users covering the losses incurred due to a disruption of energy supply exists, then the compensation paid for the quantity of energy not supplied or for the time of disruption can be taken as a proxy of the users' WTP for improved reliability.

(3) *Averting behaviour*. If users employ alternative systems of energy production/supply (e.g. generators) in order to ensure continuity of service, even during periods of disruption, then the total avoided costs associated with these alternative systems can be considered as a proxy of the value of improved reliability.

(4) *Stated WTP*. The WTP of users for a reduction in the frequency/duration of power interruptions can be estimated through an ad hoc contingent valuation.

(5) *Benefit transfer*. This consists of transferring the value of the WTP of users for a reduction in the frequency/duration of power interruptions estimated in one country to another. This method is not always feasible.

(6) *Social cost of non-served energy*. This consists of computing the economic cost of electricity not supplied, which is avoided in the case of improved reliability of the power system. The European Commission considers this to be a second best option, and the cost can be obtained by dividing the annual gross value added by the annual volume of electricity consumed in the economy, possibly distinguishing between different economic sectors (e.g. industry, commerce and services, agriculture, transport, residential, etc.) [8].

3.4.4. Economic performance indicators

The project's socioeconomic performance is measured by a selected number of key indicators; primarily, the economic net present value (ENPV), the economic internal rate of return (EIRR) and the benefit–cost ratio (BCR):

(a) *Economic net present value*. The difference between the present value of benefits and the present value of costs at their shadow prices. This provides a measure of the overall impact of a project against a counterfactual. A project is desirable from a socioeconomic perspective if the NPV is positive. The ENPV formula is described by Eq. (7) (*t* refers to time and *i* is the applicable discount rate).

$$\text{ENPV} = \sum\nolimits_t \left(\frac{(\text{total benefits})_t}{(1+i)^t} - \frac{(\text{total socioeconomic costs})_t}{(1+i)^t} \right) \tag{7}$$

(b) *Benefit–cost ratio*. The ratio of the discounted benefits and the discounted costs valued at their shadow prices provides a measure of the benefits relative to costs. If the BCR of a project is greater than 1, the project is desirable from a socioeconomic perspective.

(c) *Economic internal rate of return*. The EIRR discount rate equates the present value of benefits to the present value costs of a project. The EIRR can also be defined as the discount rate that makes a project's NPV equal to zero. A project is desirable from a socioeconomic perspective if its EIRR is greater than the usual discount rate. This means that the project gives the society higher return than could be earned by investing the resources elsewhere.

All projects with a positive ENPV are worthwhile, in principle. If the ENPV is negative, the social costs of the project exceed its benefits and, therefore, the project needs to be rejected because social welfare would be worse off with it. However, the ENPV is dependent on the project size and, therefore, it is not suitable for ranking projects with different financial scales. Instead, the EIRR or BCR needs to be used for that purpose.

It is worth reiterating that the key economic performance indicators described above need to be estimated according to an incremental approach, as illustrated in Figs 21 and 22.

3.4.4.1. Example 1

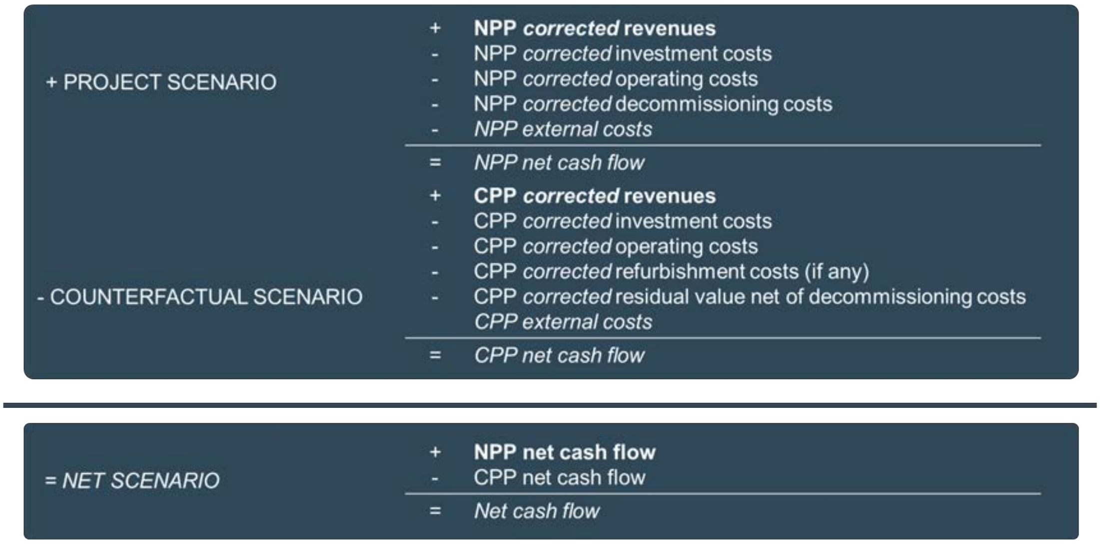
Project: constructing a new NPP to replace the amount of electricity generated by an old coal fired power plant.

Counterfactual: continue operating the coal fired power plant (i.e. status quo).

3.4.4.2. Example 2

Project: constructing a new NPP to generate an additional amount of electricity to meet increasing demand.

Counterfactual: build a new gas fired power plant (i.e. do something else).



+ PROJECT SCENARIO

+ **NPP *corrected* revenues**
- NPP *corrected* investment costs
- NPP *corrected* operating costs
- NPP *corrected* decommissioning costs
- *NPP external costs*

= *NPP net cash flow*

- COUNTERFACTUAL SCENARIO

+ **CPP *corrected* revenues**
- CPP *corrected* investment costs
- CPP *corrected* operating costs
- CPP *corrected* refurbishment costs (if any)
- CPP *corrected* residual value net of decommissioning costs

CPP external costs

= *CPP net cash flow*

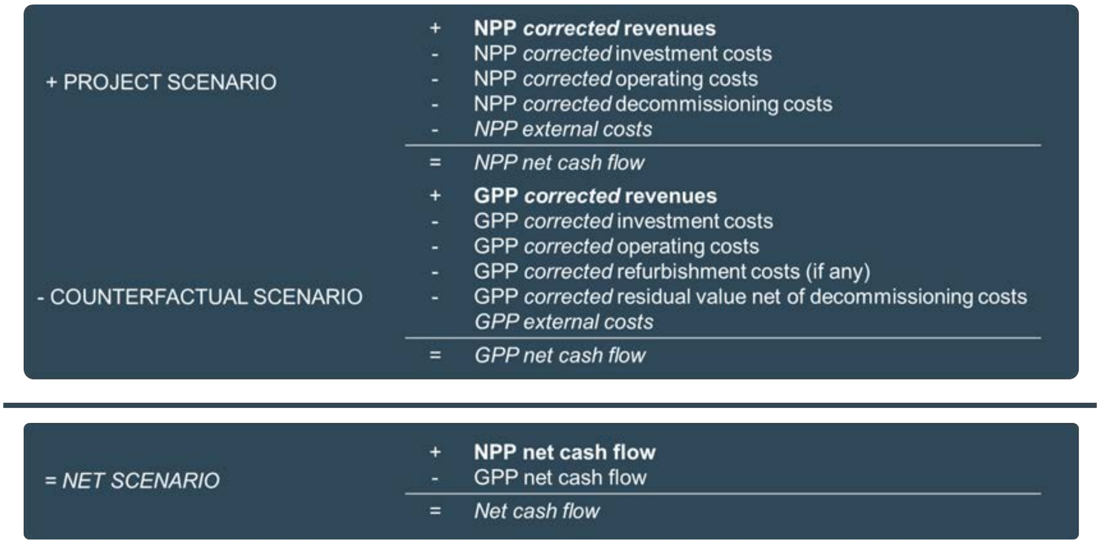
= *NET SCENARIO*

+ **NPP net cash flow**
- CPP net cash flow

= *Net cash flow*

→ **ENPV, BCR**

FIG. 21. Calculation of the incremental (or net) economic cash flows in different situations (ENPV, BCR, EIRR). Note: 'corrected' means valued at shadow price instead of market price. An NPP's positive effects in terms of GHG and air emissions take the form of avoided costs compared to the counterfactual situation — that is, the external environmental costs with the NPP are lower than those in the counterfactual scenario.



+ PROJECT SCENARIO

+ **NPP *corrected* revenues**
- NPP *corrected* investment costs
- NPP *corrected* operating costs
- NPP *corrected* decommissioning costs
- *NPP external costs*

= *NPP net cash flow*

- COUNTERFACTUAL SCENARIO

+ **GPP *corrected* revenues**
- GPP *corrected* investment costs
- GPP *corrected* operating costs
- GPP *corrected* refurbishment costs (if any)
- GPP *corrected* residual value net of decommissioning costs

GPP external costs

= *GPP net cash flow*

= *NET SCENARIO*

+ **NPP net cash flow**
- GPP net cash flow

= *Net cash flow*

→ **ENPV, BCR**

FIG. 22. Calculation of the incremental (or net) economic cash flows in different situations (ENPV, BCR, EIRR). Note: 'corrected' means valued at shadow price instead of market price. An NPP's positive effects in terms of GHG and air emissions take the form of avoided costs compared to the counterfactual situation — that is, the external environmental costs with the NPP are lower than those in the counterfactual scenario.

3.5. STEP 7: SENSITIVITY AND RISK ANALYSIS

Risk is classically defined as the probability of an adverse event multiplied by the severity of the outcome. Risks can be related to a number of different and concurrent causes. A broad distinction exists between exogenous and endogenous sources of uncertainty. An example of an exogenous event is the changes to the project caused by an unpredictable event such as an extreme weather event. An example of an endogenous event is unexpected technical difficulties leading to a delay or cost overrun during project implementation. Whereas exogenous events are hard to predict[61] and outside the control of the project manager, endogenous risks can be prevented and minimized ex-ante. Table 13 presents the typical risks in the energy sector.

In a CBA context, the risk assessment aims to investigate how sensitive the financial and economic performance are to the input data and modelling approach used by the analyst, as well as the key assumptions adopted. Indeed, a CBA is based on hypotheses, forecasts and estimates of variables. The values entered in a CBA are considered the most probable. However, they can deviate significantly from actually realized values [68].

TABLE 13. TYPICAL RISKS [1]

Category	Risk type	Examples
Exogenous	Regulatory and policy risks	Changing environmental requirements, economic instruments (e.g. renewable energy source support schemes, European Union emissions trading system design), energy policies (e.g. concerning the discontinuation of certain types of energy sources and fuels), systems of incentives, etc. Other risks that may directly affect NPP are changes to the national radioactive waste and spent fuel management and decommissioning policy
	Market risks	Unexpected adverse changes in the national economy that may cause unexpected evolution of prices and/or demand shortfalls. Market risks are normally linked to highly fluctuating fuel costs, carbon dioxide policies and electricity prices
	Climatic risks	Related to inadequate analysis or/unexpected adverse changes in climatic conditions affecting energy demand (e.g. for heating and/or cooling), and extreme weather events
Endogenous	Administrative and procedural risks	Related to difficulties/delays in obtaining building or other permits, utility approvals, land acquisition (costs higher than predicted, higher costs for the acquisition of rights of way, procedural delays), procurement process
	Social risks	Related to issues with the general public. Public opposition could undermine the viability of a nuclear power generation project during or even after the implementation phase
	Design and construction risks	Related to inadequate site surveys and investigation, inadequate design cost estimates, project cost overruns, delays due to unexpected technical difficulties during site preparation or plant construction, delays in complementary works outside the project promoter’s control, adverse meteorological events such as flooding, landslides, etc., accidents
	Technical and safety risks	Related to the specific project technology and the specific safety backup systems designed to intervene if normal operation of the plant is disrupted

---

[61] Beyond the maximum magnitude of the external events considered in the engineering design.

A number of techniques exist for quantitative analysis of the uncertainty that underpins the estimated indicators. The operationalization of such techniques is discussed further in the following sections. Regardless of the technique, the first common step is the identification of risks, consisting of the following:

(a) Listing of adverse events to which the project is exposed;
(b) For each adverse event, indication of:
    (i) The possible causes of the occurrence;
    (ii) The negative effects generated for the project;
    (iii) The link with the variables entering the CBA.

3.5.1. Sensitivity tests

A sensitivity analysis isolates the effect of individual (input) variables on the overall project performance (i.e. key economic and financial indicators) and allows for the identification of the 'critical' variables of the project. Such variables are those whose variations, in absolute terms, have the largest impact on the project's financial and economic indicators.

The analysis is carried out by changing, one by one, all the assumptions and parameters entered into the CBA by an arbitrary percentage to record the effect of those changes on the performance indicators. Having established the criterion for deciding whether the variation in the performance indicators is sufficiently large, the most critical variables for the CBA can be identified. Conventionally, the assumptions and parameters for which a percentage change in their value leads to a greater percentage change (absolute value) in the performance indicators are considered to be critical. For instance, if a 1% change in the value of a key input to the CBA (e.g. carbon price of 1 t of GHGs) leads to a greater than 1% change in the ENPV, the variable is considered to be critical. A good practice is to consider at least the following variations around the best estimate: ±1%, ±5% and ±10%. In this way, it is possible to detect the non-linear and non-symmetric effects of the variables on the project outcomes.

As an example, Table 14 shows the impact of different variations (±1%, ±5%, ±10%) in a given key input on the ENPV. A similar table can be produced to detect the impact of variations on the financial performance indicators. In the example, it is possible to note that the variable 'CO_2 price' is set as critical because the induced change in the performance indicators is over proportional to the variations of ±5% and ±10%; although, because of non-linearity in the CBA model, it is less than 1 for variation of ±1%.

TABLE 14. RESULTS OF SENSITIVITY TESTS

Variable	ENPV elasticity (due to a ±1% variation)	ENPV elasticity (due to a ±5% variation)	ENPV elasticity (due to a ±10% variation)	Judgment
Investment cost	*3.9%*	*6.9%*	*10.9%*	*Critical*
O&M costs	1.0%	4.5%	9.0%	Not critical
Fuel costs	1.0%	2.4%	4.4%	Not critical
Waste management costs	*2.1%*	*5.1%*	8.1%	*Critical*
Decommissioning costs	0.4%	3.4%	6.4%	Not critical
Electricity produced	*1.2%*	*5.2%*	*10.2%*	*Critical*
CO_2 price	0.5%	*5.5%*	*10.2%*	*Critical*

TABLE 15. SWITCHING VALUES FOR ECONOMIC NET PRESENT VALUE

Variable	Note	Switching value
Investment cost	Minimum increase before the ENPV equals 0	20%
O&M costs	Minimum increase before the ENPV equals 0	110%
Fuel costs	Minimum increase before the ENPV equals 0	95%
Waste management costs	Minimum increase before the ENPV equals 0	45%
Decommissioning costs	Minimum increase before the ENPV equals 0	90%
Electricity produced	Maximum decrease before the ENPV equals 0	−40%
CO_2 price	Maximum decrease before the ENPV equals 0	−33.0%

Generally, in the sensitivity analysis, CBA results need to be tested against changes in the following assumptions and parameters. It is worth noting that the analysis is carried out using disaggregated variables (i.e. demand and prices are assessed separately):

- Number of years necessary for the realization of the infrastructure;
- Discount rates (both financial and social);
- Electricity produced;
- Investment costs (as disaggregated as possible);
- Operation costs (as disaggregated as possible);
- Market price or opportunity cost of energy sources and products (either for the financial or the economic analysis);
- Energy mix displaced by the project;
- Estimated WTP for energy consumption;
- Assumed economic value of GHG emissions and pollutants produced;
- Assumed quantities of GHG emissions and pollutants produced;
- Value of life considered for the valuation of the risk of accidents.

A further extension of the sensitivity analysis is the use of switching values (Table 15). A switching value is the percentage increase in a specific cost item (or equally, the percentage decline in a specific benefit item) required for the ENPV (or the FNPV) to become zero. In other words, it is the percentage change in a variable required for the estimated ENPV (or the FNPV) to change sign. If the switching value is relatively high, a very substantial change in the variable is required before the ENPV (or FNPV) changes sign. Conversely, if the switching value is relatively low, a small change in the variable is required to change the ENPV (or FNPV) sign.

3.5.2. Scenario analysis

Whereas the sensitivity analysis is a way of testing each independent variable separately, scenario analysis captures the variability of a set of variables at once. Scenario analysis involves taking the lower or upper value of the range of estimates for each input variable, assumption and parameter entering the CBA, and combining them to define the lower or upper bound of the performance indicators. Lower bound and upper bound are also referred to as the worst and best case scenarios. In other words, scenario analysis identifies the extreme lower and upper values of the performance indicators. These extreme scenarios are both highly improbable as it is not likely that all of the assumptions would take the worst or best values at the same time.

3.5.3. Probabilistic risk analysis

A probabilistic risk analysis is typically split into two steps. The first is the attribution of a suitable probability distribution for each critical variable (identified through sensitivity tests) that best describes the range of uncertainty around the expected value. The probability distribution for each variable can be derived from different sources, such as, experimental data, distributions found in the literature for similar cases and consultation of experts. For NPPs, the probability distributions of most of the critical variables can be derived from modelling activity, which is embedded in the planning of NPPs. Table 16 presents the most commonly used probability distributions.

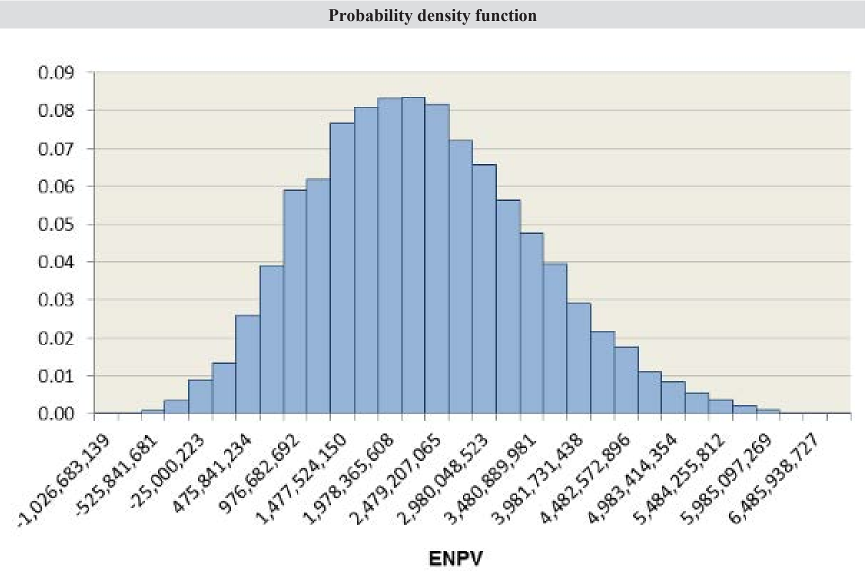
The second step is running a Monte Carlo simulation, which generates random values from the underlying probability distribution function of each critical variable considered. This process is repeated thousands of times to generate a probability distribution of the NPV (and/or the internal rate of return). This step is implemented through commercial software or even Microsoft Excel add-ins. The result of the Monte Carlo simulation is expressed in terms of the probability distribution and cumulative probability of the performance indicators. Figure 23 provides a visual example.

The characteristics of the probability density function are described by a set of summary statistics that enable the analyst to infer significant judgments about the level of risk of the project. In particular:

(a) *The range of variations*. The window of minimum and maximum values, within which the performance indicators under consideration may vary. In general, a project with a narrower range of variability in its performance indicators is preferable, under otherwise identical conditions.
(b) *The mean value*. The estimated expected value of the performance indicator under consideration. It is interpreted as the outcome expected to occur over a large number of potential project realizations.

TABLE 16. PROBABILITY DISTRIBUTIONS [1]

Distribution	Description	Examples of variables described by the distribution
Normal or bell curve distribution	This distribution is symmetric. The analyst defines the mean or expected value and a standard deviation to describe the variation about the mean. Values in the middle near the mean are most likely to occur	Inflation rates and energy prices
Log-normal distribution	In this distribution, values are positively skewed. It is used to represent values that do not go below zero and have unlimited positive potential	Real estate property values, stock prices and oil reserves
Uniform distribution	All values have an equal chance of occurring. The analyst simply defines the minimum and maximum	Fuel cost
Triangular distribution	The user defines the minimum, most likely and maximum values	Fuel cost
PERT distribution	The analyst defines the minimum, most likely and maximum values. However, values between the most likely and the extremes are more likely to occur than in the triangular distribution. The extremes are not as emphasized	Duration of construction
Discrete distribution	The analyst defines specific values that may occur and the likelihood of each	Volume of electricity produced



ENPV value in the deterministic CBA	
€1 119 million €	
Estimated parameters of the distribution	
Mean (expected value)	€2 195
Median	€2 117
Standard deviation	€1 149
Minimum	€−1 026
Maximum	€6 485

Estimated probabilities	
Probability (Pr) ENPV ≤ base value	0.184
Probability (Pr) ENPV ≤ 0	0.014

FIG. 23. Results of a Monte Carlo simulation.

(c) *The standard deviation*. The variation around the mean value of the performance indicator under consideration. No rule exists for interpreting the standard deviation as ‘high’ or ‘low’ in absolute terms. However, the standard deviation can provide useful information when compared with those of similar projects.

The cumulative distribution function provides the probability that the considered performance indicator is equal to or smaller than any given value in the range of variations of the considered performance indicator. Thus, it can be used to observe the cumulative probability that corresponds to some feasibility threshold, namely:

(1) When considering the NPV, the cumulative curve indicates the probability (Pr) that the expected NPV is equal to or lower than zero and the probability that the expected NPV is equal to or lower than the reference NPV. If Pr {expected NPV ≤ 0} ≈ 0, then the project can be judged to be not risky. If Pr {expected NPV ≤ reference NPV} ≈ 0, then the project can be judged to be somewhat risky.
(2) When considering the IRR, the cumulative curve indicates the probability that the expected IRR is smaller than the adopted discount rate. Hence, if Pr {expected IRR ≤ DR} ≈ 0, then the project can be judged to be not risky.

4. ILLUSTRATIVE CASE STUDY

The case study described in this section aims to illustrate the CBA process for a nuclear new build project in a fictitious country, Ladonia.

The country (Ladonia) and its profile, economy, power sector and climate policies are all fictitious. No identification with actual countries is intended. The data supporting the case study, including costs and cost breakdowns, are provided for illustrative purposes only. They do not necessarily reflect current trends in generation costs and cost drivers.

4.1. THE FICTITIOUS COUNTRY: LADONIA

4.1.1. Country

Ladonia sits on the Northern Ocean and borders Southia, Ostia and Westia. It has a population of ~30 million, spans an area of 300 000 km^2 and has a coastline that stretches over 500 km.

4.1.2. Economy

Ladonia is an average natural resource enriched country, possessing industrial minerals and hydrocarbons. Services account for 30% of its GDP, followed by extractive industries (20%), taxes (20%), manufacturing (15%) and agriculture (15%).

Over the past decade, Ladonia’s economy has grown at 8–10% annually, driven by the mining and oil and gas sectors, making it the second fastest growing economy in its region. In addition to the impact of the mining and oil sectors, manufacturing output was high, while agricultural production levels remained stable. Ladonia’s growth target for this year is 6.5%, driven primarily by the industrial sector; in particular, the mining and oil and gas sectors. Manufacturing is also expected to post higher growth.

In the medium term (three to five years), GDP is projected to grow at 6–7% annually on average, as the effects of oil on growth decline and non-oil growth strengthens. Inflation is expected to remain in the central bank’s target range of 5–10%, while the fiscal deficit is expected to remain constant at 5% of GDP.

Overall, the Government of Ladonia has done a good job for the economy, and long term forecasts for the country from a political and economic point of view are positive. Its population is growing, it is young and dynamic, relatively well educated and its middle class is developing. Most economic indicators are green and pointing toward sustained growth.

The main objectives of the Government’s economic policy over the long term are to contribute to high employment, with fair distribution of income and delivery of high quality public services. The country regularly attracts foreign direct investments, and the Government aims to increase these investments. Evolving towards a diverse service centred economy, with a free market, low trade barriers, reduced dependence on oil and gas, and low ecological footprints, would help serve this objective.

Finally, it may be noted that Ladonia benefits from an investment grade sovereign debt rating, issued by all three main rating agencies, and currently set at BBB (with a stable outlook) by Fitch, Baa3 (positive) by Moody’s and BBB– (stable) by S&P. The country therefore has access to international debt capital markets.

Table 17 describes the fictitious country’s key economic indicators.

4.1.3. Power grid

The long term planning of Ladonia’s electric power sector is key in achieving the Government’s vision for Ladonia’s economy.

TABLE 17. KEY ECONOMIC INDICATORS

GDP (last year)	US $60 billion
GDP per capita (last year)	US $2000
Estimated annual growth (this year)	6.5%
Sovereign debt rating (current)	Investment grade

Before the late 1990s, Ladonia's power sector was a vertically integrated monopoly, which had the Power Authority of Ladonia (PAL) generating and transmitting electricity to every region of the country. Power sector reform in the late 1990s saw PAL split into separate generation (PAL-G) and transmission (PAL-T) operations, which also made it possible for other independent power producers to enter the market.

Demand for electricity in Ladonia has increased by ~52% over the last decade, while installed generation capacity has more than doubled over the same period. Despite this, the country still suffers from persistent power supply challenges.

As of today, Ladonia has 9150 MW of generation capacity, producing an average 60 180 GW·h of electricity per year. Most of this electricity is produced from gas and coal (Table 18).

Ladonia's average demand for electricity is expected to double over the next two to three decades, reaching 120 000 GW·h. In addition to the projected demand, key considerations in the design of Ladonia's future power include:

- Load curve profile;
- Grid capabilities and upgrade costs;
- Long term evolution of oil and gas reserves and prices;
- Domestic and international financing for Ladonia's long term infrastructure projects;
- Competitiveness and affordability of the generated electricity;
- Socioeconomic impacts;
- Public opinion concerning energy sources in Ladonia.

4.1.4. Climate policies

The Government of Ladonia has been working towards developing a policy framework that integrates adaptation, mitigation and other climate related policies within broader development policies and plans to safeguard developmental gains from the impacts of climate change and build a climate resilient economy.

This year, the Government adopted a strategic long term plan for a prosperous, modern, competitive and climate neutral economy by 2050. The Post-2020 Climate Action Plan aims to attain low carbon climate resilience through GHG emission reduction in the energy, transportation and manufacturing sectors. In the energy sector, the objectives set in the plan are the following:

- To improve energy efficiency in power plants and industrial facilities;
- To increase the share of carbon free electricity;
- To limit the carbon intensity of the electricity produced.

The plan's expected outcome is a 30–50% reduction in GHG emissions, relative to a business as usual scenario starting in 2020, over the next two to three decades.

TABLE 18. ENERGY MIX IN A REPRESENTATIVE YEAR

Energy source	Installed capacity (MW)	Remarks
Coal	2400	Coal is purchased from neighbouring Westia at a very low price
Gas (CCGT[a])	3900	CCGTs (and OCGTs[b]) rely on gas from the country's own oil and gas fields
Gas (OCGT)	600	Ladonia's two OCGTs (2×100 MW) are owned by independent power producers
Nuclear (PWR)	1800	The 2×900 MW PWR units were connected to the grid almost 30 years ago
Solar (PV[c])	150	A 450 MW solar photovoltaic plant is currently under construction
Wind (offshore)	150	Ladonia has an offshore wind potential equivalent to its current power consumption
Wind (onshore)	150	Ladonia has numerous suitable locations for onshore wind turbines. This capacity could be easily scaled up
Total	9150	
Annual exports (in GW·h)	250	Ladonia exports a variable volume of electricity (mainly) to Westia
Annual imports (in GW·h)	500	Ladonia (mainly) imports its electricity from Southia

Note: Except when mentioned otherwise, all power plants belong to PAL-G.

[a] CCGT: combined cycle gas turbine.

[b] OCGT: open cycle gas turbine.

[c] PV: photovoltaic.

4.2. THE NUCLEAR POWER PROJECT

As part of its long term strategy to promote sustainable growth, the Government has recently started to entertain plans to broaden its nuclear programme and, more specifically, to build a new NPP. To this end, the Government has commissioned a series of studies to assess the feasibility of the NPP. In what follows, the main information resulting from these studies is briefly summarized.

4.2.1. Project objectives

The general objectives for the new NPP are aligned with the country's long term prospects and the development strategy, which prioritize the production of reliable and affordable electricity, based on a clear positioning of the sector in a low carbon future and increased independence of supply.

More specifically, the construction of the new nuclear plant is aimed at expanding the electricity supply to meet growing demand. Moreover, adding power generation capacity to the existing system, where power shortages exist, the energy security will be improved by ensuring the continuity of electricity supplies to the distribution network during both peak and off-peak periods.

4.2.2. Demand and supply analysis

From an average 60 180 GW·h of electricity per year, Ladonia's demand is expected to double over the next two to three decades, reaching 120 000 GW·h between 2030 and 2040. This represents an average growth rate of between 3.2% and 6.2% per year, which provides a supportive environment for the construction of new capacity in addition to the existing 9150 MW installed (at present, there is a gap in installed capacity of between 400 MW and 800 MW, while the construction of only 450 MW of solar capacity is scheduled).

Further, the Government's long term plans to reduce dependence on oil and gas and lower the country's ecological footprint will undoubtedly increase pressure on the coal fired plants in operation (2400 MW), and possibly on certain gas fired ones (600 MW of OCGTs) are in operation). The need for new low carbon production capacity is therefore not expected to decrease.

4.2.3. Options analysis

An option analysis was performed to confirm and assess the following options:

(a) *Siting of the NPP*. Two possible sites were considered. The first, Riviera, is located on the River Ladon, 100 km south of the country's capital and 200 km from the ocean. The second, Océane, is located on the ocean, 300 km south of the country's capital. The comparison favoured a seawater cooled NPP.

(b) *Sizing of the NPP*. Depending on the choice of the reactor under consideration, the installed capacity of one unit can vary between 1000 MWe and 1800 MWe, which could imply a dramatic variation in the plant's total installed capacity (based on two units) in the context of the total capacity installed in Ladonia. Therefore, a detailed analysis of the total capacity that would 'best' fit within the national electricity system (present and planned, as implied by the Post-2020 Climate Action Plan) was carried out to assist with the right sizing of the NPP. As a result of this study, the best option was determined to be 1000 MWe.

(c) *Choice of reactor*. Five different reactor types were considered. The selection of one type was based on a thorough technical analysis, coupled with a range of other qualitative parameters concerning the vendor, including an analysis of its record in delivering NPPs on time and on budget, its willingness to invest and hold an equity stake in the project company, and its ability to mobilize competitively priced long term financing and support from its authorities.

(d) *Technical specifications of the NPP.* Comprehensive and detailed technical analyses were performed by specialist engineering consultancies to finalize the detailed design of the plant that will ultimately best fit the conditions on the site retained for the construction of the NPP.

The selected option is summarized in Table 19.

4.2.4. Project identification

4.2.4.1. Technical features

The NPP entails the development, financing, construction and operation of a new NPP with the key technical features described in Table 20.

The NPP will be developed using proven light water technology and a generation III PWR reactor, which has already been licensed in other countries and has a proven operational record.

TABLE 19. SELECTED OPTIONS

	Compared option	Selected option
Siting	River cooled power plant, on the River Ladon, 100 km south of the country’s capital and 200 km from the ocean	Seawater cooled power plant, on the ocean, 300 km south of the country’s capital
Sizing	2 ×1500 MWe	2 ×1000 MWe
Reactor	PWR — technology A, river cooled	PWR — technology B, seawater cooled
Technical specifications	Two co-sited, *n*th of a kind, generation III+ units	Two co-sited, *n*th of a kind, generation III+ units

TABLE 20. KEY PROJECT PARAMETERS

No. of units	2
Installed capacity per unit	1 000 MWe
Total installed capacity	2 000 MWe
Annual availability (average)	85%
Annual electricity output	14 482 GW·h

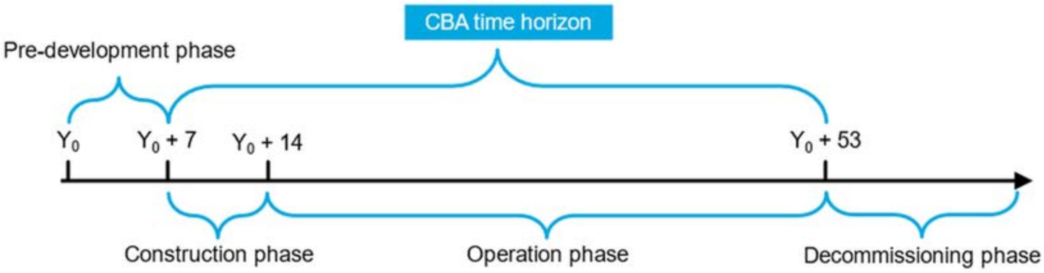


FIG. 24. CBA time horizon.

4.2.4.2. *Time horizon*

The financial and economic analyses are performed using a 47-year reference period (Fig. 24), including a 7-year construction phase and 40 years of operation. It is assumed that the CBA is carried out just before the plant is built and, for simplicity, in this example, the expenses sustained in the pre-development phase were not accounted for.

As explained in Section 3.3.1, the cooldown period and decommissioning phase are not included in the time horizon because their duration is uncertain and decommissioning expenses occur over the entire operation phase.

TABLE 21. NUCLEAR POWER PLANT CAPITAL EXPENDITURE (US $ million)

Year	*Total*	1	2	3	4	5	6	7
Total construction costs	*9 400*	1343	1343	1343	1343	1343	1343	1343
Land	*282*	40	40	40	40	40	40	40
Skilled labour	*940*	134	134	134	134	134	134	134
Unskilled labour	*2 350*	336	336	336	336	336	336	336
Energy	*376*	54	54	54	54	54	54	54
Water	*188*	27	27	27	27	27	27	27
Imported material/equipment	*2 632*	376	376	376	376	376	376	376
Domestic material/equipment	*2 632*	376	376	376	376	376	376	376

4.2.4.3. Project costs

The project's investment costs are estimated to reach US $4.7 million per megawatt of installed capacity. The total undiscounted investment cost (capital expenditure) amounts to US $9.4 million. A breakdown of the investment costs, in constant prices, for the NPP is presented in Table 21.

The plant's anticipated fixed operating costs are estimated at US $100 000 per megawatt of installed capacity, and its variable operating costs at US $11.5/MW·h. The total undiscounted operating costs (operational expenditure — OPEX) amount to US $14 850 million. A breakdown of the operating costs, in constant prices, for the NPP is presented in Table 22.

The plant's anticipated decommissioning costs are estimated to be 15% of the total construction costs — US $1410 million, undiscounted. Therefore, the annual amount of funds that the plant operator has to set aside for decommissioning is US $35 million. This annual cost occurs from the start of the operation phase until the closure of the plant.

4.2.4.4. Project revenues

The electricity wholesale price is US $0.01/kW·h. Considering an annual electricity output of 14 892 GW·h, the project's annual revenues are estimated to reach US $1489 million. The total undiscounted revenues amount to US $59 568 million. Figure 25 shows the cash inflows and outflows (undiscounted values) over the NPP's lifetime.

4.2.5. Counterfactual scenario

Since the project intends to increase the energy supply to meet the country's increasing demand for electricity, the counterfactual scenario consists of the next best alternative power source to meet increased demand. In this specific case, by building a new 1000 MWe NPP the Government will forgo the opportunity to develop a 1000 MWe modern coal power plant (CPP) (Table 23).

TABLE 22. NUCLEAR POWER PLANT OPERATIONAL EXPENDITURE (US $ million)

	Total	Fixed	Variable
Total operating cost	14 850	8 000	6 850
Fuel	1 302	0	1 302
Skilled labour	1 737	1 600	137
Unskilled labour	4 343	4 000	343
Energy	708	160	548
Water	297	160	137
Imported material/equipment	2 547	1 040	1 507
Domestic material/equipment	2 547	1 040	1 507
LLW[a] management	685	0	685
ILW[b] and HLW[c] management	685	0	685

[a] LLW: low level waste.

[b] ILW: intermediate level waste.

[c] HLW: high level waste.

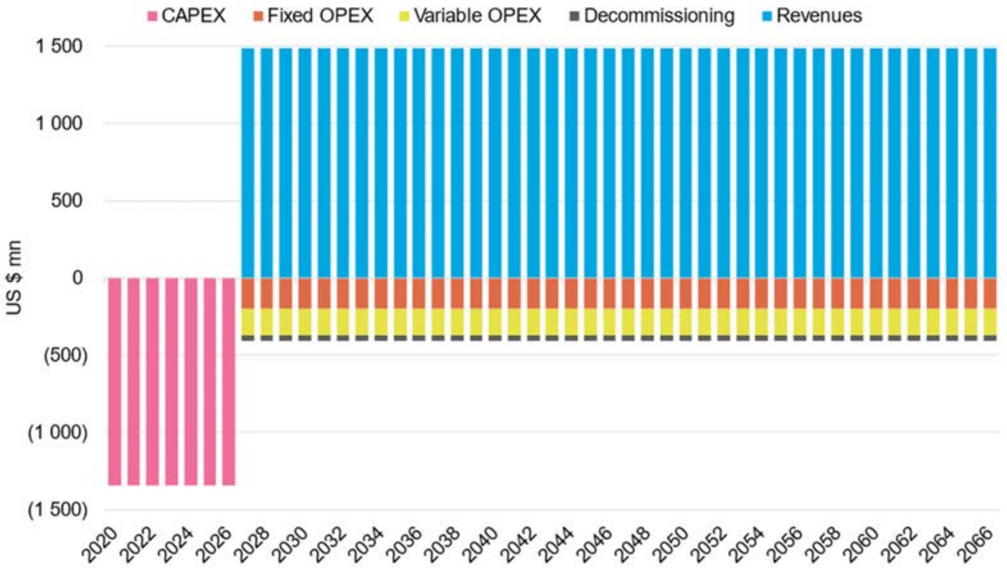


FIG. 25. Cash inflows and outflows over the NPP's lifetime.

TABLE 23. COUNTERFACTUAL VS PROJECT SCENARIOS

	Counterfactual scenario	Project scenario
Siting	Seawater cooled power plant, on the ocean, 300 km south of the country's capital	Seawater cooled power plant, on the ocean, 300 km south of the country's capital
Sizing	2×1000 MWe	2×1000 MWe
Reactor	Integrated gasification combined cycle	PWR
Technical specifications	Two co-sited coal fired units, supercritical design	Two co-sited, *n*th of a kind, generation III+ units
Financial LCOE[a]	US $46.66/MW·h	US $60.91/MW·h

[a] The LCOE includes decommissioning costs.

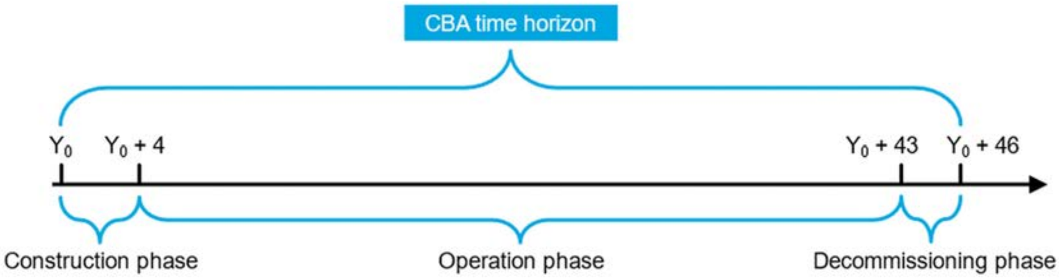


FIG. 26. CPP's lifetime phases over the CBA time horizon.

4.2.5.1. Time horizon

Figure 26 shows the key phases considered in the context of this illustrative case study.

In the counterfactual scenario, the CPP has a construction period of 4 years, is expected to generate electricity for 40 years, and has a decommissioning period of 3 years once the plant is closed down.

4.2.5.2. Project costs

The investment costs the CPP are estimated to reach US $2.2 million per megawatt of installed capacity. The total undiscounted investment cost (capital expenditure) amounts to US $4.4 million. A breakdown of the investment costs, in constant prices, for the CPP is presented in Table 24.

The CPP's anticipated fixed operating costs are estimated at US $37 000 per megawatt of installed capacity, and its variable operating costs at US $25.84/MW·h. The total undiscounted operating costs (operational expenditure — OPEX) amounts to US $18 352 million. A breakdown of the operating costs, in constant prices, for the NPP is presented in Table 25.

TABLE 24. COAL POWER PLANT CAPITAL EXPENDITURE (US $ million)

Year	*Total*	1	2	3	4	5	6	7
Total construction costs	*4400*	1100	1100	1100	1100	0	0	0
Land	*44*	11	11	11	11	0	0	0
Skilled labour	*220*	55	55	55	55	0	0	0
Unskilled labour	*1320*	330	330	330	330	0	0	0
Energy	*88*	22	22	22	22	0	0	0
Water	*44*	11	11	11	11	0	0	0
Imported material/equipment	*704*	176	176	176	176	0	0	0
Domestic material/equipment	*1980*	495	495	495	495	0	0	0

TABLE 25. COAL POWER PLANT OPERATIONAL EXPENDITURE (US $ million)

	Total	Fixed	Variable
Total operating cost	*18 352*	2 960	15 392
Fuel	*8 466*	0	8 466
Skilled labour	*450*	296	154
Unskilled labour	*2 700*	1 776	924
Energy	*2 214*	59	2 155
Water	*184*	30	154
Imported material/equipment	*1 131*	207	924
Domestic material/equipment	*3 209*	592	2 617

After 40 years of operation, the plant is considered to have used up most of its service potential, rendering its market value insignificant. This is why the residual value is conservatively set at zero and only the cost of decommissioning and dismantling the plant is computed in the last three years of the time horizon — that is, when the decommissioning cost will materialize.[62] The plant's anticipated decommissioning costs are estimated to be 10% of the total construction costs — US $440 million, undiscounted.

---

[62] Differently from NPPs, there is no country regulation obliging the operator of a CPP to set aside money annually for decommissioning activities.

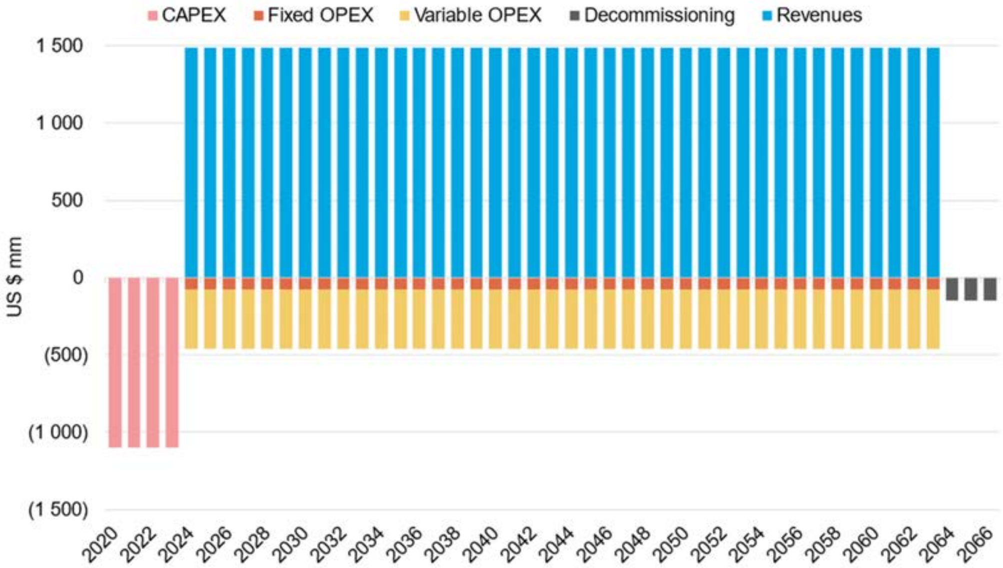


FIG. 27. Cash inflows and outflows over the CPP's lifetime.

4.2.5.3. Project revenues

Even in the counterfactual scenario, the electricity wholesale price is US \$0.01/kW·h. Considering an annual electricity output of 14 892 GW·h, the project's annual revenues are estimated to reach US \$1489 million. The total revenues amount to US \$59 568 million. Figure 27 shows the cash inflows and outflows (undiscounted values) over the NPP's lifetime.

4.3. COST–BENEFIT ANALYSIS

4.3.1. Financial profitability

The financial analysis presented here serves as a basis for the economic assessment and, as such, it follows the indications of Section 3.3.[63] The analysis is carried out using constant prices. These are the observed market prices. Based on the costs and revenue assumptions described in the sections above, and considering a real discount rate of 4%, the project's profitability indicators (before tax, real) are calculated — see the cash flow tables in Appendix IV. The indicators (reported in Table 26) were calculated for each scenario (NPP and counterfactual) independently and for the incremental cash flows, showing the difference between the with the project scenario and the counterfactual one.

The incremental analysis shows that, from a purely financial viewpoint, the NPP is less profitable than a modern CPP. Indeed, under the same installed capacity, the investment cost of the NPP is far higher than that of the CPP. However, the financial analysis does not consider externalities, which may ultimately justify the NPP.

4.3.2. Socioeconomic analysis

The following socioeconomic analysis seeks to assess the project from a societal perspective.

---

[63] The financial analysis conducted here is, for instance, different from the one conducted in the context of a study focusing on the bankability of nuclear projects, which also considers financing costs.

TABLE 26. FINANCIAL PERFORMANCE INDICATORS

	FNPV (US $ million)	FIRR (%)
NPP (with the project scenario)	8 554	8.6%
CPP (counterfactual scenario)	13 902	17.9%
Incremental	−5 349	−1.1%

4.3.2.1. Direct costs and benefits

Most of the project cost estimates used in the financial analysis are, in this case, deemed to reflect social opportunity costs adequately. The procurement of materials, works and engineering services is to follow an international, open, competitive procedure in line with the applicable public procurement rules.

Corrections to financial prices were made for the following items:

(a) The non-skilled labour component in the investment cost (in particular in the building and construction component) and in the operating costs was adjusted by applying a shadow wage correction factor of 0.7 to account for the high unemployment level in the project area. The same correction factor is applied in both the with the project scenario and the counterfactual scenario.
(b) The cost of electricity (used during plant construction) was replaced with the LRMC of electricity production in the status quo. The resulting correction factor is 1.4 in both the with the project scenario and the counterfactual scenario.
(c) The imported material (used during both plant construction and operation) was adjusted by applying the weighted average border price plus the transportation cost. The resulting correction factor is 0.9 for both nuclear fuel and coal. The same correction factor is thus applied in both the with the project scenario and the counterfactual scenario.
(d) The fuel cost was adjusted by applying the border price plus the transportation cost. The same methodology applies for nuclear fuel in the with the project scenario and coal in the counterfactual scenario. The resulting correction factor is 0.8 for both nuclear fuel and coal.

On the benefit side, as the same annual electricity output is expected from both the NPP and the CPP and no variation in wholesale electricity prices is expected from the project, the private benefit of electricity generation cancels out when the incremental approach is adopted. Nevertheless, differences in the external costs need to be accounted for (see below).

4.3.2.2. Externalities

The externalities brought by the NPP are as follows.

(a) Avoidance of CO_2 emissions

Carbon reduction related to investment in a new NPP has to be estimated relative to the counterfactual where the CPP is added to the system. Then carbon reduction is equal to the level of emissions that would occur if a CPP were to be added rather than an NPP. The calculated lifecycle emissions factor of the NPP and the CPP is, respectively, 0.0096 t/MW·h and 0.8123 t/MW·h, which has to be multiplied by the electricity output to give the level of emissions. Considering an annual electricity output of 14 892 GW·h for both the NPP and the CPP, the associated annual emissions are respectively 142 712 t and 12 million t of CO_2. Adding 2 GW of nuclear capacity instead of 2 GW of coal fired capacity would reduce annual CO_2 emissions by ~11.9 million t. GHG emissions reductions can be monetized using the social cost of carbon. For the purposes of this analysis, Ladonia's estimates of the shadow price of CO_2 is used — US $50 per tonne of CO_2. Therefore, the annual net avoidance of CO_2 is valued at approximately US $605 million compared to the counterfactual and the total benefit of CO_2 reduction is valued at roughly US $23 907 million (undiscounted).

(b) Avoidance of airborne pollution

Airborne pollution reduction related to investment in a new NPP has to be estimated relative to the counterfactual, where a CPP is added to the system. Then air pollution reduction is equal to the level of emissions that would occur if a CPP were to be added rather than an NPP. The calculated emissions factors for the NPP and the CPP are presented in Table 27.

Those quantities were multiplied by the annual electricity output and the respective costs per tonne shown in Table 28.

TABLE 27. LIFECYCLE EMISSION FACTORS

Pollutant	Unit	NPP	CPP
Ammonia	t/MW·h	7.29E-10	1.57E-08
Non-methane VOCs[a]	t/MW·h	5.56E-09	4.08E-08
Nitrogen oxide	t/MW·h	3.05E-08	4.85E-07
PPMco	t/MW·h	8.29E-09	7.08E-07
PPM25	t/MW·h	1.85E-09	1.50E-08
Sulfur dioxide	t/MW·h	3.92E-08	4.41E-07
Cadmium, Cd	t/MW·h	5.45E-12	1.36E-11
Arsenic, As	t/MW·h	2.00E-12	7.01E-11
Nickel, Ni	t/MW·h	1.14E-11	9.74E-11
Lead, Pb	t/MW·h	8.77E-12	4.76E-11
Mercury, Hg	t/MW·h	4.65E-13	2.23E-11
Chromium, Cr	t/MW·h	8.97E-11	5.10E-11
Chromium, Cr-VI	t/MW·h	2.24E-12	1.63E-12
Formaldehyde	t/MW·h	2.06E-11	3.24E-10
Dioxin	t/MW·h	3.16E-18	5.50E-17

[a] VOCs: volatile organic compounds.

TABLE 28. SOCIAL COST OF AIR EMISSIONS

Pollutant	Cost (US $/t)
Ammonia	8 416.70
Non-methane VOCs	568.80
Nitrogen oxide	3 693.50
PPMco	1 395.30
PPM25	22 608.60
Sulfur dioxide	9 331
Cadmium, Cd	101 365.90
Arsenic, As	641 190.60
Nickel, Ni	2 785.60
Lead, Pb	336 913.40
Mercury, Hg	9 685 440
Chromium, Cr	16 043
Chromium, Cr-VI	80 214.90
Formaldehyde	242.10
Dioxin	44 795 160 000

As a result, the annual avoidance of airborne pollution is valued at approximately US $100 000 compared to the counterfactual and the total benefit (over the entire time horizon) is valued approximately US $4.2 million (undiscounted).

(c) Radioactive emissions in normal operation

Radioactive emissions related to investment in a new NPP in normal operation have to be estimated relative to the counterfactual where CPP is added to the system. The calculated emissions factors for the NPP and the CPP are presented in Table 29.

Those quantities were multiplied by the annual electricity output and the respective costs per tonne shown in Table 30. As a result, the production of radioactive emissions compared to the counterfactual is nil.

(d) Accidents

To proxy the cost of nuclear accidents an average cost (of 1.8 US $/MW·h) was calculated from a pool of past studies.

TABLE 29. RADIOACTIVE EMISSIONS

Emission	Unit	NPP	CPP
Aerosols, radioactive, unspecified	kBq/kW·h	4.05E-08	9.66E-08
Carbon-14	kBq/kW·h	2.47E-04	4.08E-04
Hydrogen-3, tritium	kBq/kW·h	6.34E-02	2.33E-03
Iodine-129	kBq/kW·h	1.80E-07	4.10E-07
Iodine-131	kBq/kW·h	1.53E-05	2.38E-05
Iodine-133	kBq/kW·h	2.10E-10	5.12E-10
Krypton-85	kBq/kW·h	9.88E-02	1.89E-04
Noble gases, radioactive, unspecified	kBq/kW·h	1.73E+00	3.94E+00
Radon-222	kBq/kW·h	8.64E+02	7.42E+00
Thorium-230	kBq/kW·h	1.81E-05	2.08E-07
Uranium-234	kBq/kW·h	5.70E-05	6.54E-07
Uranium-235	kBq/kW·h	2.77E-06	3.17E-08

TABLE 30. SOCIAL COST OF RADIOACTIVE EMISSIONS

Emission	Cost (US $/kBq)
Aerosols, radioactive, unspecified	0.000 436 6
Carbon-14	0.002 371 8
Hydrogen-3, Tritium	0.000 000 9
Iodine-129	0.013 972 5
Iodine-131	0.004 431 9
Iodine-133	0.000 000 6
Krypton-85	0.000 000 0
Noble gases, radioactive, unspecified	0.000 000 1
Radon-222	0.000 000 0
Thorium-230	0.006 549 6
Uranium-234	0.001 746 6
Uranium-235	0.001 424 7

(e) Security of supply benefit

In the context of this study, only the advantage of nuclear fuel's price stability against the price changes for coal is considered in the sensitivity analysis by making the coal price vary over a broad range of values. Adding an NPP reduces the amount of unserved energy in the event of a major gas or coal supply interruption, which is an issue in Ladonia. Benefits in terms of reduced unserved energy in the event of fuel supply interruptions are typically quantified by estimating the decrease in the costs of insuring against fuel supply interruption [2].

4.3.3. Socioeconomic desirability

The socioeconomic analysis of the project is carried out using the constant shadow prices. Based on the estimated social cost and the benefits described in the above sections, and considering a real social discount rate of 5%, the project's profitability indicators can be calculated — see the cash flow tables in Appendix V. The indicators were calculated for both the NPP and the counterfactual scenario independently and for the incremental cash flows (Table 31 and Fig. 28) — that is, the difference between the with the project scenario and the counterfactual one.

The incremental analysis shows that from a societal viewpoint, the NPP is more desirable than a modern CPP. Indeed, assuming the same installed capacity, the net benefits of the NPP are greater than those of the CPP. Although the CPP is more financially profitable, society is better off with the NPP.

TABLE 31. SOCIOECONOMIC PERFORMANCE INDICATORS

	ENPV (US $ million)	EIRR (%)
NPP (with the project scenario)	6470	9.3%
CPP (counterfactual scenario)	3204	9.9%
Incremental	3266	8.7%

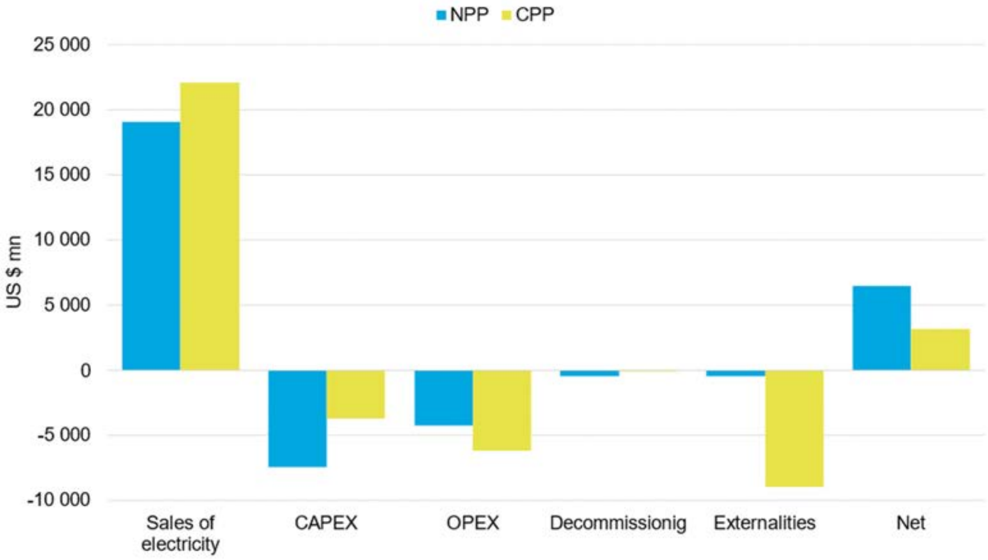


FIG. 28. Discounted cash inflows and outflows.

4.4. SENSITIVITY AND RISK ANALYSIS

4.4.1. Sensitivity tests

The sensitivity tests are performed by calculating the percentage change of the ENPV because of a 5%, 10% and 15% change in key assumptions. Their results are summarized in Table 32. If the absolute percentage change in ENPV is higher than respectively 5%, 10% and 15%, then the respective variable is deemed to be critical. The sensitivity analysis reveals that the project's economic performance is very

TABLE 32. RESULTS OF THE SENSITIVITY TESTS

	−15%	−10%	−5%	Baseline	5%	10%	15%	Judgment
NPP average availability	785.8	1612.5	2439.3	3266.0	4092.7	4919.5	5746.2	Very critical
CPP average availability	4443.2	4050.8	3658.4	3266.0	2873.6	2481.2	2088.8	Very critical
NPP construction cost per MW·h	4451.1	4056.0	3661.0	3266.0	2871.0	2476.0	2081.0	Very critical
CPP construction cost per MW·h	2704.5	2891.7	3078.8	3266.0	3453.2	3640.3	3827.5	Critical
Electricity wholesale price	3716.9	3566.6	3416.3	3266.0	3115.7	2965.4	2815.2	Not critical
NPP fixed OPEX	3590.6	3482.4	3374.2	3266.0	3157.8	3049.6	2941.4	Not critical
NPP variable OPEX	3580.8	3475.9	3370.9	3266.0	3161.1	3056.2	2951.2	Not critical
CPP fixed OPEX	3130.9	3176.0	3221.0	3266.0	3311.0	3356.1	3401.1	Not critical
CPP variable OPEX	2477.2	2740.1	3003.1	3266.0	3529.0	3791.9	4054.9	Critical
NPP decommissioning cost	3333.7	3311.1	3288.6	3266.0	3243.4	3220.9	3198.3	Not critical
GHG emission factors	3279.7	3275.1	3270.6	3266.0	3261.4	3256.9	3252.3	Not critical
Air emission factors	3266.0	3266.0	3266.0	3266.0	3266.0	3266.0	3266.0	Not critical
Cost of CO_2	1935.0	2378.6	2822.3	3266.0	3709.7	4153.4	4597.1	Very critical
External cost of airborne pollution	3265.8	3265.9	3265.9	3266.0	3266.1	3266.2	3266.2	Not critical
External cost of NPP accidents (MW·h)	3317.5	3300.4	3283.2	3266.0	3248.8	3231.7	3214.5	Not critical

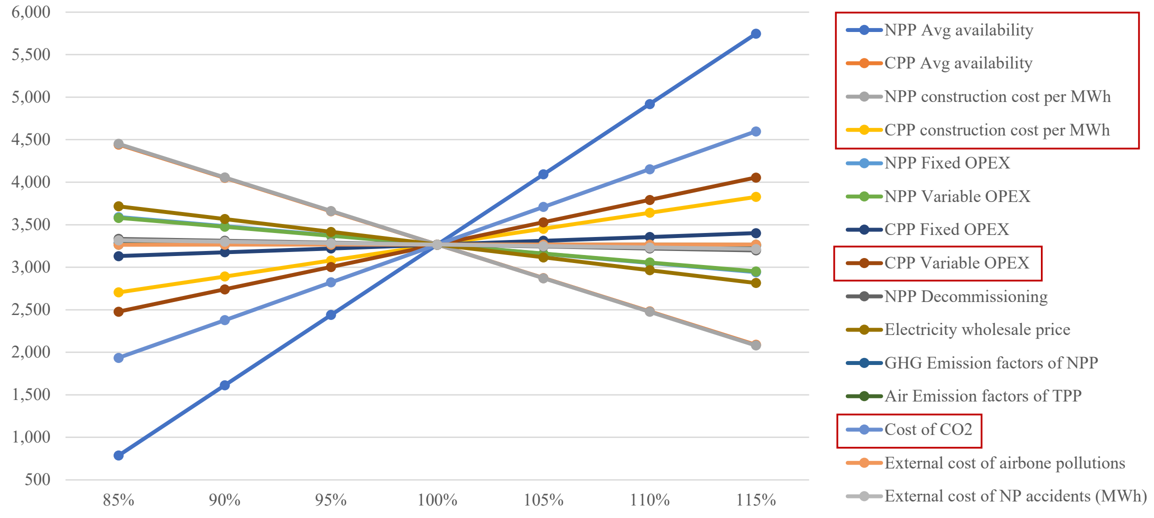


FIG. 29. Sensitivity graph.

TABLE 33. SWITCHING VALUES

Critical variables	Value for which ENPV = 0
NPP average availability	21%
CPP average availability	−44%
NPP construction cost per MW·h	−44%
CPP construction cost per MW·h	93%
CPP variable OPEX	66%
Cost of CO_2	39%

sensitive to changes in assumed average availability of the two plants, the NPP investment cost and the cost of CO_2. Other two slightly critical variables are the investment cost and the operating cost of the CPP.

Figure 29 illustrates the variation in the ENPV for any given variation of the CBA inputs.

For each critical variable, a switching value has been computed — that is, the value for which the ENPV becomes zero, or in other words the maximum (negative) variation range over which the project would be still breaking even economically. The results are summarized in Table 33.

None of the above switching values realistically threaten the assessment of the project's economic profitability.

TABLE 34. RESULTS OF THE SCENARIO ANALYSIS

	Optimistic value	Baseline value	Pessimistic value
NPP average availability	0.87	0.85	0.72
CPP average availability	0.77	0.85	0.87[a]
NPP construction cost per MW·h	4.23	4.70	5.64
CPP construction cost per MW·h	2.4	2.20	2.0[a]
CPP variable OPEX	29.7	25.8	22.0[a]
Cost of CO_2	60.0	50.0	40.0
ENPV	7850.90	3266.01	−3943.51
EIRR	17.3%	9%	1.1%

[a] Pessimistic values from the NPP standpoint.

4.4.2. Scenario analysis

The tests that form the sensitivity analysis study the impact of combinations of values taken by the critical variables. In particular, combinations of ‘optimistic’ and ‘pessimistic’ values of the critical variables are tested. The economic performance indicators in the two scenarios are reported in Table 34.

4.5. CONCLUDING REMARKS

The CBA (at 5% real discount rate) demonstrates that a nuclear power solution generates greater net socioeconomic benefits to Ladonia when compared to a new coal based power plant. Although the latter is cheaper — that is, the construction cost is less than half of that for an NPP — the private and external costs over the entire time horizon lead to greater benefits from the nuclear plant. The net benefits of the nuclear plant are primarily explained by lower GHG emissions and lower variable OPEX as compared to the counterfactual scenario. A sensitivity analysis shows that the project’s ENPV more than doubles in the high fuel (+15%) and CO_2 (+20%) price scenario and conversely reduces by more than half in the low fuel (−15%) and CO_2 (−20%) price scenario.

5. CONCLUSION

Cost–benefit analysis is an economic appraisal tool assessing the costs and benefits associated with an investment decision, for instance, the construction of a new NPP. If the benefits exceed the costs, the Government has the incentive to work towards implementing the project. On the other hand, if the total costs exceed the total benefits, then such a project would, in theory, not be justified from a societal standpoint. In a CBA, the costs and benefits are accounted for as fully as possible, allowing estimation of the net economic benefit associated with the project relative to a without the project scenario (i.e. the status quo or an alternative investment proposal).

The CBA framework suggested in this publication is built around four key steps:

(1) A preparatory step to characterize the project, its objectives, alternatives to the project, and the broad context.
(2) A financial analysis, including estimates of the project's costs and an analysis of the project's financial profitability. This is a preparatory step for the economic analysis.
(3) An economic analysis, taking a broader view to include additional benefits and costs to society. The economic analysis is performed from the point of view of society to appraise the project's contribution to the economic welfare of the region or the country.
(4) Sensitivity and risk analysis to assign a confidence level to key financial and economic indicators and identify the circumstances in which the project will generate value for its stakeholders and society at large.

A worked example has been provided to illustrate the application of the CBA framework. The case study illustrates how environmental benefits — emissions and pollution reductions, for instance — have been factored into the analysis.

Cost–benefit analysis methodologies need to be tailored to the specific situation of each Member State. The context prevailing at the national, and perhaps regional, level — the options available for producing electricity, the market structure and the degree of competition — as well as public decision makers' commitments, social preferences and consideration of externalities, can vary widely and will require different approaches.

Appendix I

DISCOUNT RATES

I.1. INTRODUCTION TO DISCOUNTING

The rate used as a basis for converting future costs and benefits into present values is known as the discount rate. The discount factor for a benefit or cost accruing at any time *t* periods in the future is illustrated in Eq. (8):

$$\mathrm{DF}_t = \frac{1}{(1+r)^t} \tag{8}$$

The rationale for discounting is twofold. First, it is based on the principle of time preference — that is, generally people prefer to receive goods and services now rather than later. For individuals, time preference can be measured by the real interest rate on money lent or borrowed. These real rates of return give some indication of the individual pure time preference rate. Similarly, society as a whole may prefer to receive goods and services sooner rather than later, and to defer costs to future generations. The rate at which society values the present compared to the future is called STP rate. Second, there is an opportunity cost of consuming the resources today; that is, the future resources forgone from not investing today. Through investing, resources today can produce a greater amount of resources for use in the future.

It is worth distinguishing between the discount rate used for the financial analysis and the discount rate used in economic analysis. The former is usually referred to as the FDR, while the latter is known as the social discount rate (SDR). The FDR can be defined as the opportunity cost of capital, representing the maximum rate of return on capital obtained from alternative investment projects with a similar risk profile. A commonly used approach to calculate the FDR consists of estimating the actual cost of capital. A proxy for this estimation is represented by:

(a) The real return on government bonds;
(b) The long term real interest rate on commercial loans;
(c) The weighted average capital cost (WACC)[64] or the pre-tax WACC formulas (Eqs (9), (10)).

With respect to (c):

$$\text{pre-tax WACC} = \left(W_{\mathrm{d}} \times \text{cost of debt}\right) + \left(W_{\mathrm{e}} \times \text{cost of equity}\right) \tag{9}$$

$$\text{WACC} = \left(W_{\mathrm{d}} \times \text{cost of debt} * (1 - \text{tax})\right) + \left(W_{\mathrm{e}} \times \text{cost of equity}\right) \tag{10}$$

where W_{d} is the weight of debt and W_{b} is the weight of equity.

The cost of debt is the interest rate charged by banks. Data for the calculation can be obtained from financial platforms, such as Bloomberg, Thomson Reuters, etc. Depending on the financial structure of the project (mix of debt and equity), the resulting WACC can be quite different depending on the FDR, leading to different results in the financial analysis (see Table 35).

The social discount rate can be defined as the social view on how to value future benefits and costs against present ones. There are two primary approaches to determine the social discount rate in the

---

[64] See more in Ref. [1].

TABLE 35. WEIGHTED AVERAGE CAPITAL COST ILLUSTRATION

	Option A	Option B	Option C
Debt (weight)	0.0%	30.0%	50.0%
Cost of debt	4.0%	4.0%	4.0%
Equity (weight)	100.0%	70.0%	50.0%
Cost of equity	6.5%	6.5%	6.5%
Pre-tax WACC	**6.5%**	**5.8%**	**5.3%**
Tax rate	12.7%	12.7%	12.7%
WACC	**6.5%**	**5.6%**	**5.0%**

literature: the SOC approach and the STP approach. The SOC is based on the idea that public investments displace private investments. According to this approach, the return from the public investment needs to be at least as large as the one that could be obtained from a private investment. Therefore, the social discount rate is derived from market data, usually as a weighted average cost of capital. The STP approach, in contrast, focuses on society's willingness to trade off present consumption for future consumption. Therefore, the social discount rate depends on the rate of pure time preference, on how quickly consumption grows and, in turn, on how quickly utility falls as consumption increases. The social rate of time preference is given in Eq. (11) by:

$$\text{STP} = \rho + g\varepsilon \tag{11}$$

where

ρ is the rate of pure time preference (impatience — utility today is perceived as being better than utility tomorrow) plus catastrophe risk;
g is the rate of growth of real consumption per capita;
ε is the percentage decrease in the additional utility derived from each percentage increase in consumption.

This equation is known as the Ramsey formula.

In an idealized perfectly competitive market, the two approaches would give the same rate. However, in real economies, market imperfections generally dictate that the discount rate derived from the opportunity cost of capital differs from that derived from the STP rate. One commonality between much of the literature on SOC and STP is that the rate of discounting is the same regardless of where it occurs in time. That is, discounting is exponential, which implies that the costs and benefits accruing to generations in the distant future appear relatively unimportant in present value terms.

For a thoughtful review of theoretical and empirical discussions on social discount rate see Refs [9, 69].

I.2. DECLINING DISCOUNT RATES

Since the level of the SDR is critical in determining whether a public project will pass a CBA test, for intergenerational projects (i.e. projects that have long lived costs and benefits for as yet unborn generations, such as NPPs) many argue that time varying or declining discount rates need to be adopted. The rationale for declining discount rates is manifold. The first reason results from uncertainty about the future; specifically, uncertainty pertaining to growth rates in the economy accumulating over time. Other reasons for using time declining SDR include the evidence that individuals' discount functions are approximately hyperbolic rather than exponential [70] and the fact that people of a current generation may fail to account appropriately for the effects of long term projects on the welfare of future generations.

Since the beginning of the 2000s, two branches of the literature have emerged concerning declining discount rates [71]. The first branch extends the Ramsey formula (for computing the SDR) to allow for uncertainty in the rate of consumption growth (see Refs [72, 73] for an extended discussion). The second branch is based on the approach initially developed by Weitzman [74–76], who argued that the uncertainty about future discount rates justifies using a decreasing term structure of discount rates today.

Some governments — such as those of Denmark, France, Norway and the UK — currently recommend the use of a declining rate over time (see next section). Other countries — such as those of Germany and Ireland — suggest the use of a lower social discount rate for long term environmental investments for which benefits are expected to spread over centuries.

I.3. SOCIAL DISCOUNTING IN PRACTICE

There are many factors to be considered and decisions to be made when it comes to choosing the appropriate social discount rate. Therefore, discounting practices vary considerable from county to country. Table 36 presents the prescribed or suggested discount rates in several countries and the methods upon which the rates are based.

TABLE 36. SOCIAL DISCOUNT RATE

Theoretical basis	Country	Social discount rate (real)	Declining	Source
SOC	Australia	7% with a sensitivity range of 3–10%	No	[77]
	Canada	8%, with sensitivity test over the range 3–10%	No	[78] (confirmed by the policy on CBA issued in 2018[a])
	Denmark	Risk free rate: 3% (risk premium of 1%)	After 35 years reduced to 3% and to 2% from year 71 onwards	[79]
	Norway	Risk free rate: 2% (risk premium of 1%)	After 100 years reduced to 1%	[69]
	New Zealand	From 4% to 7% depending on the sector	No	[80] (confirmed by Ref. [81])

TABLE 36. SOCIAL DISCOUNT RATE (cont.)

Theoretical basis	Country	Social discount rate (real)	Declining	Source
SOC	Netherlands	0% (risk premium of 3% for macroeconomic risk)	No	[69]
	Philippines	10%	No	[82]
	USA (Department of Energy)	3%	No	[83]
STP	European Union	5% for Cohesion countries and 3 % for other Member States	No	[8]
	France	Risk free rate: 2.5% (risk premium of 2% multiplied by a sector specific beta value)	Risk free rate falling to 1.5% after 2070	[84]
	Sweden	3.5%	No	[85]
	USA	3% (STP), with sensitivity up to 7% (SOC)[b]	No	[69]
	UK	3.5%	After 30 years — 3% for years 31–75, 2.5% from year 76 onward	[86]
	Latin American countries	On average, SDR is 3.77%, ranging from 2.14% for Paraguay to 5.83% for Chile	No	[87]

---

[a] See: https://www.canada.ca/en/treasury-board-secretariat/services/federal-regulatory-management/guidelines-tools/policy-cost-benefit-analysis.html

[b] See: https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf

Appendix II

WILLINGNESS TO PAY APPROACH FOR EVALUATING DIRECT AND EXTERNAL EFFECTS

II.1. INTRODUCTION

As illustrated in Section 3.4.2 of the main text, the WTP approach, together with that of the WTA, can be applied to quantify both the direct benefits and the negative or positive external effects of the project.

The WTP is defined as the maximum amount people would be willing to pay to gain something that they view as desirable or, alternatively, the maximum amount that people would be willing to pay to avoid something they view as undesirable. Instead, the WTA is defined as the minimum amount of money people would be willing to accept to give away something that they view as desirable. In principle, the equilibrium values of WTP and WTA are equivalent. However, empirical studies (e.g. Refs [88, 89] show that individuals tend to give higher estimates of WTA than of WTP because they tend to demand higher compensation to give up what they already have than they are willing to pay to obtain the same item. Therefore, the next section refers to WTP, which is the most widely used approach in the practice of CBA.

II.2. METHODS TO EMPIRICALLY ESTIMATE WTP

Three main methodological categories are discussed below.

II.2.1. Stated preferences approaches

Stated preferences approaches consist of deducting the economic value of a non-market good or service by eliciting people's preferences, in monetary terms, through a survey. This approach has two broader categories:

(1) The contingent valuation method, which questions the WTP for a non-market good/service;
(2) The choice modelling method, which unbundles various attributes of the non-market good/service and values each attribute separately.

For a detailed discussion of contingent valuation method, see Chapter 16 in Ref. [9], and for choice modelling see Ref. [90].

II.2.2. Revealed preferences approaches

Revealed preferences approaches can be used when the social value of a non-market good is correlated with the value of another good for which there is a market. In other words, the valuation of non-market impacts is based on observing the actual behaviour and, especially, the purchases made in real markets. The main methods belonging to this family of approaches are:

(a) The hedonic pricing method, which derives the value of an attribute, or a change in an attribute, whenever its value is capitalized into the price of a market asset, such as houses and wages;
(b) The travel cost method, which consists of evaluating a good through the full travel cost incurred to consume it;

(c) The averting or defensive behaviour method, which assumes that people spend money to eliminate or mitigate the effect of a negative externality.

For a detailed discussion see Chapter 15 in Ref. [9].

II.2.3. Value (or benefit) transfer approach

The value (or benefit) approach consists of taking a unit value for a non-market good estimated in a study and using this estimate, after some adjustments, to evaluate benefits (or costs) that arise when a project is implemented elsewhere. The simplest approach to transferring value estimates is the so called unit value transfer with income adjustments. The steps needed to implement this approach are:

(a) Review of the existing literature on the subject under consideration;
(b) Assessment of the selected studies for their comparability (similarity of the environmental benefit (or cost) valued and other socioeconomic characteristics that can affect the evaluation);
(c) Calculation of values and their transfer to the new context of evaluation, taking into account differences in income and the cost of living between countries.

A more sophisticated approach to value transfer is the so called function transfer. For a detailed discussion, see Refs [91, 92]. Some databases have been set up to facilitate value transfer. This is the case with the Environmental Valuation Reference Inventory (EVRI database)[65] developed by Environment Canada and the US Environmental Protection Agency.

---

[65] See: https://www.evri.ca/

Appendix III

EXTERNAL COSTS OF ELECTRICITY

III.1. EXTERNAL COSTS

According to Ref. [65], the overall costs of electricity consist of three main components:

(1) Costs associated with energy production;
(2) Costs related to the distribution grid;
(3) External costs.

The literature defines the external costs of electricity generation by mainly focusing on the negative impacts of the technical processes related to the production of electrical energy and heat on human health and the environment.

In some cases, external costs (or a portion of them) may be internalized through electricity/pollution taxes or higher wages for risky jobs. However, rarely, all external costs connected with electricity generation are fully internalized and therefore need to be carefully analysed and estimated. To calculate the external costs, one needs to carry out an impact pathway analysis, which consists of the following steps [52]:

(1) Emission: determination of the volume of pollution emitted by a given source, usually expressed in the units of physical emission per production unit (e.g. kg/KW·h);
(2) Dispersion: determination of a change in the measures of environmental quality as the function of emission (e.g. the concentration of emissions, g/m^3);
(3) Impact: estimation of the type and size of environmental change (e.g. with reference to human health, crops yield, buildings) using dose–response functions;
(4) Cost: transformation of physical effects into monetary value of external costs, which implies the estimation of the monetary value of damages (e.g. cost of health loss).

In what follows, a review of the main attempts at the estimation of external costs in the power industry with a focus on Europe and the USA is provided. For a more comprehensive review see Refs [44, 51, 65, 93].

III.2. EUROPE: EXTERNE AND ECOSENSEWEB

One of the most comprehensive attempts to estimate the external costs in the power sector was performed as a series of European projects between the early 1990s and 2005 under a common name, External Costs of Energy (ExternE)[66]. After 2005, there were other projects, such as New Elements for the Assessment of External Costs from Energy Technologies (NewExt)[67], Externalities of Energy: Extension of accounting framework and policy applications (ExternE-POL)[68], New Energy Externalities

---

[66] See: http://www.externe.info/externe_2006/

[67] See: https://www.psi.ch/en/ta/projects/new-elements-for-the-assessment-of-external-costs-from-energy-technologies-newext. Project financed by the European Union, Directorate-General Research, Technological Development and Demonstration (RTD).

[68] See: http://www.externe.info/externe_d7/?q=node/59

Development for Sustainability (NEEDS)[69] and Cost Assessment of Sustainable Energy Systems (CASES)[70], which were aimed at further developing the methodology of ExternE.

In this context, EcoSense computer software was developed to value the health and environmental impacts (on crops, building materials, forests and ecosystems) accompanying the generation of electricity in European countries. EcoSenseWeb is now an integrated atmospheric dispersion and exposure assessment model that implements the impact pathway approach developed within the ExternE, NEEDS and CASES projects.

In addition to EcoSenseWeb[71] there are two tools for simplified approximate assessments: EcoSenseLE and RiskPoll. The former provides tables of typical damage costs for a variety of emission sites in Europe. The latter is a package comprising several models with different input requirements and levels of accuracy.

III.3. EXTERNAL COSTS OF POWER IN THE UNITED STATES OF AMERICA

The externality study by the US NRC [43] adopts a very similar methodology to the ExternE project. The core of the analysis of local air pollution damage carried out by the NRC uses an integrated assessment model (the Air Pollution Emissions Experiments and Policy) that calculates the damage associated with population exposures to certain pollutants[72] in six categories: health, visibility, crop yields, timber yields, building materials and recreation.

When it comes to damage from NPPs, the NRC study refers to the results of two previous studies: the ExternE [46] for France and a study by Oak Ridge National Laboratory and Resources for the Future [94] for two sites in the United States of America.

More recently, Ref. [95] used the AP2 model[73] to estimate the external cost associated with air pollution exposure for PM2.5, SO_2, NOx, NH_3 and VOCs from electric power generation, oil and gas extraction, coal mining and oil refineries.

---

[69] See: http://www.needs-project.org/

[70] See: http://www.feem-project.net/cases/

[71] See: http://www.externe.info/externe_d7/?q=node/

[72] Sulfur dioxide (SO_2), volatile organic compounds (VOCs), nitrogen oxides (NOx), fine particulate matter (PM2.5), coarse particulate matter (PM10), and ammonia (NH_3).

[73] This is an updated version of the Air Pollution Emission Experiments and Policy analysis model.

Appendix IV

FINANCIAL PROFITABILITY

TABLE 37. CALCULATION OF THE FINANCIAL RETURN ON THE PROJECT

Nuclear power plant (with the project scenario)

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
CAPEX^{a}	−1343	−1343	−1343	−1343	−1343	−1343	−1343	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioning	0	0	0	0	0	0	0	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
Fixed OPEX^{b}	0	0	0	0	0	0	0	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200
Variable OPEX	0	0	0	0	0	0	0	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171
Revenues	0	0	0	0	0	0	0	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
Net cash flow	−1343	−1343	−1343	−1343	−1343	−1343	−1343	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083

TABLE 37. CALCULATION OF THE FINANCIAL RETURN ON THE PROJECT (cont.)

2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200	−200
−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171	−171
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083	1083

Coal based power plant (counterfactual scenario)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
CAPEX	−1100	−1100	−1100	−1100	0	0	0	0	0	0	0	0	0	0	0
Decommissioning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fixed OPEX	0	0	0	0	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74
Variable OPEX	0	0	0	0	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385
Revenues	0	0	0	0	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
Net cash flow	−1100	−1100	−1100	−1100	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030

TABLE 37. CALCULATION OF THE FINANCIAL RETURN ON THE PROJECT (cont.)

2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74
−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030

2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	−147	−147	−147
−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	−74	0	0	0
−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	−385	0	0	0
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	0	0	0
1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	1030	−147	−147	−147

TABLE 37. CALCULATION OF THE FINANCIAL RETURN ON THE PROJECT (cont.)

Incremental scenario

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CAPEX	−243	−243	−243	−243	−1343	−1343	−1343	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioning	0	0	0	0	0	0	0	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
Fixed OPEX	0	0	0	0	74	74	74	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126
Variable OPEX	0	0	0	0	385	385	385	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214	214
Revenues	0	0	0	0	−1489	−1489	−1489	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net cash flow	−243	−243	−243	−243	−2373	−2373	−2373	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52

TABLE 37. CALCULATION OF THE FINANCIAL RETURN ON THE PROJECT (cont.)

2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	111	111	111
−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−126	−200	−200	−200
214	214	214	214	214	214	214	214	214	214	214	214	214	−171	−171	−171
0	0	0	0	0	0	0	0	0	0	0	0	0	1489	1489	1489
52	52	52	52	52	52	52	52	52	52	52	52	52	1 229	1 229	1 229

[a] CAPEX: capital expenditure.

[b] OPEX: operational expenditure.

Appendix V

SOCIOECONOMIC DESIRABILITY

TABLE 38. CALCULATION OF THE SOCIOECONOMIC RETURN ON THE PROJECT

Nuclear power plant (with the project scenario)

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
CAPEXa	−1226	−1226	−1226	−1226	−1226	−1226	−1226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fixed OPEX[b]	0	0	0	0	0	0	0	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169
Variable OPEX	0	0	0	0	0	0	0	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164
Decommissioning	0	0	0	0	0	0	0	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
Revenues	0	0	0	0	0	0	0	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
Externalities	0	0	0	0	0	0	0	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34
Net cash flow	−1226	−1226	−1226	−1226	−1226	−1226	−1226	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087

TABLE 38. CALCULATION OF THE SOCIOECONOMIC RETURN ON THE PROJECT (cont.)

2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169	−169
−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164	−164
−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34	−34
1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087	1087

Coal based power plant (counterfactual scenario)

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
CAPEX	−992	−992	−992	−992	0	0	0	0	0	0	0	0	0	0	0
Fixed OPEX	0	0	0	0	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61
Variable OPEX	0	0	0	0	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355
Decommissioning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Revenues	0	0	0	0	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
Externalities	0	0	0	0	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605
Net cash flow	−992	−992	−992	−992	469	469	469	469	469	469	469	469	469	469	469

TABLE 38. CALCULATION OF THE SOCIOECONOMIC RETURN ON THE PROJECT (cont.)

2035	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61
−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489
−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605
469	469	469	469	469	469	469	469	469	469	469	469	469	469	469	469

2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	−61	0	0	0
−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	−355	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	−147	−147	−147
1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	1489	0	0	0
−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	−605	0	0	0
469	469	469	469	469	469	469	469	469	469	469	469	469	−147	−147	−147

TABLE 38. CALCULATION OF THE SOCIOECONOMIC RETURN ON THE PROJECT (cont.)

Incremental scenario

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
CAPEX	−234	−234	−234	−234	−1226	−1226	−1226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fixed OPEX	0	0	0	0	61	61	61	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108
Variable OPEX	0	0	0	0	355	355	355	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191	191
Decommissioning	0	0	0	0	0	0	0	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35
Revenues	0	0	0	0	−1489	−1489	−1489	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Externalities	0	0	0	0	605	605	605	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571	571
Net cash flow	−234	−234	−234	−234	−1695	−1695	−1695	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618

TABLE 38. CALCULATION OF THE SOCIOECONOMIC RETURN ON THE PROJECT (cont.)

2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−108	−169	−169	−169
191	191	191	191	191	191	191	191	191	191	191	191	191	−164	−164	−164
−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	−35	111	111	111
0	0	0	0	0	0	0	0	0	0	0	0	0	1489	1489	1489
571	571	571	571	571	571	571	571	571	571	571	571	571	−34	−34	−34
618	618	618	618	618	618	618	618	618	618	618	618	618	1234	1234	1234

[a] CAPEX: capital expenditure.

[b] OPEX: operational expenditure.

Appendix VI

IAEA NUCLEAR POWER COST–BENEFIT ANALYSIS TOOLKIT

The IAEA Nuclear Power Cost–Benefit Analysis Toolkit provides access to publications, tools and materials shared by participants in IAEA technical meetings and training workshops covering CBA of nuclear projects and programmes. The toolkit[74] includes two simple applications, G@U and DISCERN, supporting economic appraisal under uncertainty.

VI.1. G@U

G@U (Generation Costs and Revenue Requirements under Uncertainty) can be used to assess the impact of cost uncertainties — for example, construction, fuel and O&M expenditures — on power generation economics as measured by LCOE and other revenue requirement metrics. Its functionalities include:

- Attaching uncertainties (probability distributions) to input variables;
- Latin hypercube sampling and Monte Carlo simulation;
- Determining point estimates and probability distributions for key economic indicators.

VI.2. DISCERN

DISCERN propagates uncertainties in simple models implemented in Microsoft Excel (as it stands end of 2022); that is, models based on standard Excel functions and not involving macros or routines coded in the Visual Basic for Applications (VBA) programming language. The tool provides an interface for defining uncertain inputs — and their probability distributions — and outputs of interest. Based on these pieces of information, DISCERN applies Latin hypercube sampling techniques to generate different combinations of input variables. Each combination is communicated to the Excel based model, which calculates the key outputs. A comma separated values (.csv) file compiling the results of the Monte Carlo simulation is generated at the end of this process.

---

[74] The toolkit is available on-line at https://nucleus.iaea.org/sites/CBA

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Economic Assessment of the Long Term Operation of Nuclear Power Plants: Approaches and Experience, Nuclear Energy Series No. NP-T-3.25, IAEA, Vienna (2018).

[2] KENNEDY, D., New nuclear power generation in the UK: cost benefit analysis, Energ. Policy **25** (2007) 3701–3716,
https://doi.org/10.1016/j.enpol.2007.01.010

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Climate Change and Nuclear Power 2018, Non-serial Publications, IAEA, Vienna (2018).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Climate Change and Nuclear Power 2020, Non-serial Publications, IAEA, Vienna (2020).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparation of a Feasibility Study for New Nuclear Power Projects, IAEA Nuclear Energy Series No. NG-T-3.3, IAEA, Vienna (2014).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), IAEA, Vienna (2015).

[7] ASIAN DEVELOPMENT BANK, Cost–Benefit Analysis for Development: A Practical Guide, ADB, Mandaluyong City (2013).

[8] EUROPEAN COMMISSION, Guide to Cost–Benefit Analysis of Investment Projects, EU, Luxembourg (2015).

[9] BOARDMAN, A., GREENBERG, D., VINING, A., WEIMER, D., Cost–Benefit Analysis: Concepts and Practice, 5th edn, Cambridge University Press, Cambridge (2018),
https://doi.org/10.1017/9781108235594

[10] STIGLITZ, J.E., SEN, A., FITOUSSI, J.P., Report by the Commission on the Measurement of Economic Performance and Social Progress, Commission on the Measurement of Economic Performance and Social Progress, Paris (2009).

[11] WEIMER, D., VINING, A. R., Policy Concepts and Practice, 6th edn, Routledge, New York, NY (2017) Ch. 15.

[12] DODGSON, J. S., SPACKMAN, M., PEARMAN, A., PHILLIPS, L. D., Multi-Criteria Analysis: A Manual, Communities and Local Government Publications, Wetherby (2009).

[13] NORMAN, L., KIRKPATRICK, C., Relevance and consistency of environmental impact assessment and cost–benefit analysis project appraisal, Proj. Apprais. **11** (1996) 229–236,
https://doi.org/10.1080/02688867.1996.9727548.

[14] WILSON, R., CROUCH, E.A.C., Risk Benefit Analysis, 2nd edn, Harvard Center for Risk Analysis, Cambridge, MA (2002).

[15] WEISBROD, G., WEISBROD, B., Measuring Economic Impacts of Projects and Programs, Economic Development Research Group, Boston, MA (1997).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Fuel Cycle Information System, IAEA-TECDOC-1613, IAEA, Vienna (2009).

[17] ANGELINI, F., MILHAN, C, CBA Methology: Evaluation Methods and Challenges for Project Appraisal, Jaspers, Brussels (2018).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power for Sustainable Development, IAEA, Vienna (2017).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Model for Analysis of Energy Demand (MAED-2), Computer Manual Series 18, IAEA, Vienna (2006).

[20] INTERNATIONAL ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, Projected Cost of Generating Electricity 2015, OECD, Paris (2015).

[21] INTERNATIONAL ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, Projected Cost of Generating Electricity 2020, OECD, Paris (2020).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Project Management in Nuclear Power Plant Construction: Guidelines and Experience, IAEA Nuclear Energy Series No. NP-T-2.7, IAEA, Vienna (2012).

[23] WORLD NUCLEAR ASSOCIATION, Economics of Nuclear Power, WNA, London (2017).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Electric Grid Reliability and Interface with Nuclear Power Plants, IAEA Nuclear Energy Series No. NG-T-3.8, IAEA, Vienna (2012).

[25] OECD NUCLEAR ENERGY AGENCY, The Economics of the Back End of the Nuclear Fuel Cycle, OECD, Paris (2014).

[26] OECD NUCLEAR ENERGY AGENCY, Selection of Strategies for Decommissioning of Nuclear Facilities: A Status Report Prepared on Behalf of the WPDD by Its Task Group on Strategy Selection, OECD, Paris (2006).

[27] WORLD NUCLEAR ASSOCIATION, Economics of Nuclear Power, WNA, London (2020), https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx

[28] DARDOUR, S., "Waste management and decommissioning costs under uncertainty", presentation at IAEA Technical Meeting on Funding for Waste Management and Decommissioning, Vienna, 2018, IAEA, Vienna (2018).

[29] HAVEMAN, R.H. & FARROW, S., Labor expenditure and benefit–cost accounting in times of unemployment, J. Benefit-Cost Anal. **2** (2011) 7, https://doi.org/10.2202/2152-2812.1081

[30] DEL BO, C.F., FIORIO, C.V., FLORIO M., Shadow wages for the EU regions, Fisc. Stud. **32** (2011) 109–143, https://doi.org/10.1111/j.1475-5890.2011.00129.x

[31] BARTIK, T.J., Including jobs in benefit–cost analysis, Annu. Rev. Resour. Econ. **4** (2012) 55–73, https://doi.org/10.1146/annurev-resource-110811-114520

[32] PEARCE, D., "Energy policy and externalities: an overview", Externalities and Energy Policy: The Life Cycle Approach, Workshop Proceedings, 15–16 November 2001, OECD, Paris (2002).

[33] EUROPEAN INVESTMENT BANK, EIB Project Carbon Footprint Methodologies, EIB, Luxembourg (2020).

[34] CALVO BUENDIA, E., et al. (Eds), Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IPCC, Geneva (2019).

[35] EUROPEAN INVESTMENT BANK, The Economic Appraisal of Investment Projects at the EIB, EIB, Luxembourg (2013).

[36] EUROPEAN COMMISSION, DG CLIMA, Climate Change and Major Projects, EU, Luxembourg (2016).

[37] WORLD BANK, Shadow Price of Carbon in Economic Analysis: Guidance Note, WB, Washington, D.C. (2017).

[38] CARBON PRICING LEADERSHIP COALITION, Report of the High-Level Commission on Carbon Prices, WB, Washington, D.C. (2017).

[39] INTERNATIONAL MONETARY FUND, Fiscal Monitor: How to Mitigate Climate Change, IMF, Washington, D.C. (2019).

[40] NEEDS, Deliverable N.6.1–RS1a, External Costs from Emerging Electricity Generation Technologies, NEEDS, New York, NY (2009).

[41] MAYER-SPOHN, O., BLESL, M., Deliverable N. D.6.1, Documentation of the Life Cycle Inventory Data in CASES, EU (2007).

[42] CASES, D.06.1 Database of Full Costs for EU, with External and Private Costs (file XLS,1.8 MB) (Last update September 2008).

[43] NUCLEAR REGULATORY COMMISSION, Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use, National Academies Press, Washington, D.C. (2010).

[44] OECD NUCLEAR ENERGY AGENCY, Nuclear Electricity Generation: What Are the External Costs?, OECD, Paris (2003).

[45] OECD NUCLEAR ENERGY AGENCY, Nuclear Energy in a Sustainable Development Perspective, OECD, Paris (2000).

[46] EUROPEAN COMMISSION, ExternE: External Cost of Energy, Vol. 5, Nuclear, EU, Brussels–Luxembourg (1995).

[47] EUROPEAN COMMISSION, ExternE: Externalities of Energy, Methodology, 2005 Update, EU, Luxembourg (2005).

[48] INTERNATIONAL ATOMIC ENERGY AGENCY, Status and Trands in Spent Fuel and Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-T-1.14, IAEA, Vienna (2018).

[49] INTERNATIONAL ATOMIC ENERGY AGENCY, Cost Considerations and Financing Mechanisms for the Disposal of Low and Intermediate Level Radioactive Waste, IAEA-TECDOC-1552, IAEA, Vienna (2007).

[50] WORLD NUCLEAR ASSOCIATION, National Policies and Funding, WNA, London (2020), https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/appendices/radioactive-waste-management-appendix-4-national-f.aspx

[51] RABL, A., RABLE, V. A., External costs of nuclear: greater or less than the alternatives?, Energ. Pol. **57** (2013) 575–584, https://doi.org/10.1016/j.enpol.2013.02.028

[52] RABL, A., SPADARO, J., Damage costs of air pollution and policy implications, Compr. Anal. Chem, **73** (2016) 881–915, https://doi.org/10.1016/bs.coac.2016.01.011

[53] BURGHERR, P., HIRSCHBERG, S., Comparative risk assessment of severe accidents in the energy sector, Energ. Pol. **74** (2014) S45–S56, https://doi.org/10.1016/j.enpol.2014.01.035

[54] OECD NUCLEAR ENERGY AGENCY, Comparing Nuclear Accident Risk with those from Other Energy Sources, OECD, Paris (2010).

[55] SOVACOOL, B. K., The costs of failure: a preliminary assessment of major energy accidents, 1907–2007, Energ. Pol. **36** (2008) 1802–1820, https://doi.org/10.1016/j.enpol.2008.01.040

[56] OAK RIDGE NATIONAL LABORATORY, Cost Estimate Guidelines for Advanced Nuclear Power Technologies, US DOE, Washington, D.C. (1993).

[57] EUROPEAN COMMISSION, NewExt: New Elements for the Assessment of External from Energy Technologies, Final Report, EU, Luxembourg (2004).

[58] INSTITUT FÜR ENERGIEWIRTSCHAFT UND RATIONELLE ENERGIEANWENDUNG, Die Risiken der Kernenergie in Deutschland im Vergleich mit Risiken anderer Stromerzeugungstechnologien, internal report, Institute Institute of Energy Economics and the Rational Use of Energy, Stuttgart, 2013.

[59] D'HAESELEER, W., Synthesis on the Economics of Nuclear Energy, Study for the European Commission, DG Energy, Leuven (2013).

[60] MATSUO, Y., Study on the methodology of assessing accident risk costs for nuclear power plants, Enerugi Keizai, **41** 4 (2016) 12–38.

[61] OECD NUCLEAR ENERGY AGENCY, The Security of Energy Supply and the Contribution of Nuclear Energy, OECD, Paris (2010

[62] OECD NUCLEAR ENERGY AGENCY, The Security of Energy Supply and the Contribution of Nuclear Energy: Executive Summary, OECD, Paris (2019).

[63] INTERNATIONAL ATOMIC ENERGY AGENCY AND OECD NUCLEAR ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[64] INTERNATIONAL ATOMIC ENERGY AGENCY AND OECD NUCLEAR ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, NEA#7413, OECD, Paris (2018).

[65] OECD NUCLEAR ENERGY AGENCY, The Full Costs of Electricity Provision, OECD, Paris (2018).

[66] OECD NUCLEAR ENERGY AGENCY, The Costs of Decarbonization: System Costs with High Shares of Nuclear and Renewables, OECD, Paris (2019), https://doi.org/10.1787/9789264312180-en

[67] COUNCIL OF THE EUROPEAN UNION, REGULATION (EU) No. 994/2010 OF THE EUROPEAN PARLIAMENT, EU, Luxembourg (2010).

[68] FLYVBJERG, B., Policy and planning for large-infrastructure projects: problems, causes, cures, Environ. Plan. B **34** (2007) 578–597, https://doi.org/10.1068/b32111

[69] OECD, Cost–Benefit Analysis and the Environment: Further Developments and Policy Use, OECD, Paris (2018).

[70] LAIBSON, D., Golden eggs and hyperbolic discounting, Q. J. Econ. **112** (1997) 443–477, https://doi.org/10.1162/003355397555253

[71] WEITZMAN, M.L., et al., Should governments use a declining discount rate in project analysis?, Rev. Environ. Econ. Pol. **8** (2014) 145–163, https://doi.org/10.1093/reep/reu008

[72] GOLLIER, C., KOUNDOURI, P., PANTELIDIS, T., Declining discount rates: economic justifications and implications for long-run policy, Econ. Pol. **23** (2008) 757–95, https://doi.org/10.1111/j.1468-0327.2008.00211.x

[73] GOLLIER, C., Pricing the Planet's Future: The Economics of Discounting in an Uncertain World, Princeton, NJ (2012), https://doi.org/10.23943/princeton/9780691148762.001.0001

[74] WEITZMAN, M L., Why the far-distant future should be discounted at its lowest possible rate, J. Environ. Econ. Manag. **36** (1998) 201–208, https://doi.org/10.1006/jeem.1998.1052

[75] WEITZMAN, M L., Gamma discounting, Am. Econ. Rev. **91** (2001) 260–271, https://doi.org/10.1257/aer.91.1.260

[76] WEITZMAN, M L., Subjective expectations and asset-return puzzles, Am. Econ. Rev. 97 (2007) 1102–30, https://doi.org/10.1257/aer.97.4.1102

[77] AUSTRALIAN GOVERNMENT, Cost–Benefit Analysis: Guidance Note, PMC, Canberra (2020).

[78] TREASURY BOARD SECRETARY, Canadian Cost–Benefit Analysis Guide Regulatory Proposals, TBCS, Ottawa (2007).

[79] MOUTER, N., Why Do Discount Rates Differ? Analyzing the Differences Between Discounting Policies for Transport Cost–Benefit Analysis in Five Countries, internal report, MKBA, Delft, 2015.

[80] NEW ZEALAND GOVERNMENT, Public Sector Discount Rates for Cost Benefit Analysis, Prepared by the Treasury, NZT, Wellington (2008).

[81] NEW ZEALAND GOVERNMENT, Guide to Social Cost Benefit Analysis, Prepared by the Treasury, NZT, Wellington (2015).

[82] NATIONAL ECONOMIC AND DEVELOPMENT AUTHORITY, Revisions on ICC Guidelines and Procedures Updated Social Discount Rate for the Philippines, NEDA, Manila (2016).

[83] US DEPARTMENT OF COMMERCE, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis — 2013, DOC, Washington, D.C. (2013).

[84] QUINET, E., L'évaluation socioéconomique des investissements publics, Tome 1, Commissariat Generale a la strategie et a la Prospective, Paris, 2013.

[85] TRAFIKVERKET, English Summary of ASEK Recommendations, Trafikverket, Borlänge, 2018.

[86] HM TREASURY, The Green Book: Central Government Guidance on Appraisal and Evaluation, HMT, London (2018).

[87] MOORE, M. A., BOARDMAN, A. E., VINING, A. R., Social discount rates for seventeen Latin American countries: theory and parameter estimation, Public Finance Rev. 48 (2020) 43–71,
https://doi.org/10.1177/1091142119890369

[88] COURSEY, D.L, HOVIS, J.J., SCHULZE, W.D., The disparity between willingness to accept and willingness to pay measures of value, Q. J. Econ. **102** (1987) 679–690,
https://doi.org/10.2307/1884223

[89] TUNCEL, T., HAMMITT, J., A new meta-analysis on the WTP/WTA disparity, J. Environ. Econ. Manag. **68** (2014) 175–187,
https://doi.org/10.1016/j.jeem.2014.06.001

[90] HESS, S., DALY, A. (Eds), Handbook of Choice Modelling, Edward Elgar, Cheltenham (2014),
https://doi.org/10.4337/9781781003152

[91] NEEDS, Technical Paper T 5.2.–RS 1c, Overview and Evaluation of Benefit Transfer Techniques and their Reliability, NEEDS, New York, NY (2008).

[92] NEEDS, Deliverable N. 2.1–RS 3a, Value Transfer Techniques and Expected Uncertainities, NEEDS, New York, NY (2009).

[93] BIELECKI, A., ERNST, S., SKRODZKA, W., WOJNICKI, I., The externalities of energy production in the context of development of clean energy generation, Environ. Sci. Pollut. Res. **27** (2020) 11506–11530,
https://doi.org/10.1007/s11356-020-07625-7

[94] ORNL/RFF, Estimating Externalities of Nuclear Fuel Cycles. Report No.8 of External Costs and Benefits of Fuel Cycles: A Study by the US Department of Energy and the European Commission, US DOE, Washington, D.C. (1995).

[95] JARAMILLO, P.J., MULLER, N.Z., Air pollution emissions and damages from energy production in the US: 2002–2011, Energ. Pol. **90** (2016) 202–211,
https://doi.org/10.1016/j.enpol.2015.12.035

GLOSSARY

cash flow. This refers to the flow of money to an economic agent. A receipt of cash is referred to as *cash inflow*, while a payment is a *cash outflow*.

counterfactual scenario. This reflects what would happen in the absence of the project against which the incremental benefits and costs of the *with the project scenario* can be measured. It has the same meaning as *without the project scenario*.

direct effects. These accrue in *primary markets*, that is, markets that are directly affected by the project under evaluation.

discount rates. These convert future costs and benefits into present values. The rates to discount financial values and the economic values usually differ (see Appendix I).

discounting. This is the process of converting future inflows and outflows to present values using a discount rate.

externalities. These are costs or benefits generated by the production or consumption of a good and imposed on a third party without any payment or compensation being provided. In project analysis, externalities might be seen as effects related to an investment project not reflected in its financial accounts, typically impacts on human health and the environment. Externalities can be positive or negative.

economic analysis. This ascertains the economic desirability of an investment decision from the perspective of society in the region or country considered. It has the same meaning as social CBA.

economic impact analysis (or macroeconomic impact assessment). This focuses on the total effects on the level of economic activity associated with an intervention (direct indirect and induced effects on output, income and employment). This kind of analysis goes well beyond the limits of CBA.

external cost. This is a cost not included in the market price of a good or service (e.g. electricity) but borne by the community. It has the same meaning as a negative externality.

financial analysis. This refers to a preparatory step for the *economic analysis*. Therefore, it is somehow different from a 'standard financial analysis', conducted by investors, for example, to evaluate a project's ability to generate value for its shareholders.

indirect effects. These are defined as quantity or price changes occurring in secondary markets, that is, markets that are indirectly affected by the project under evaluation.

LCOE. This refers to the *levelized cost of electricity*, that is, the per MW·h cost of generating electricity over the lifetime of the generation asset. LCOE may or may not internalize externalities (see Section 3.4.3).

market distortion. This refers to a situation in which prices do not reflect supply, demand and market equilibrium under conditions of perfect competition.

market price. This is the price at which a good or service is actually exchanged for money. It is the price that is relevant for the *financial analysis*. Sometimes it is referred to as the *observed price*.

net present value. This is the sum of the discounted cash inflows (positive) and outflows (negative).

opportunity cost (of a purchased input). This is its marginal social value in its best non-project alternative use for intermediate goods and services or its value in use (as measured by *willingness to pay*) if it is a final good or service.

present value. This is related to the *time value of money*: money today is worth more than the same amount in the future.

residual value. This refers to the *net present value* of an asset at the end of the final year of the reference period (time horizon).

shadow price. This refers to the price of a good or service not observable in any market. Shadow prices are used in *economic analysis* when observed prices fail to reflect the social cost accurately or when the observed prices do not exist.

willingness to pay. This refers to the amount consumers are willing to pay for a good or service.

LIST OF ABBREVIATIONS

BCR	benefit–cost ratio
CBA	cost–benefit analysis
CEA	cost effectiveness analysis
CF	conversion factor
CPP	coal power plant
EIA	environmental impact assessment
EIRR	economic internal rate of return
ENPV	economic net present value
FDR	financial discount rate
FIRR	financial internal rate of return
FNPV	financial net present value
FS	feasibility study
GDP	gross domestic product
GHG	greenhouse gas
LCOE	levelized cost of electricity
NPP	nuclear power plant
NPV	net present value
O&M	operation and maintenance
OCGT	open cycle gas turbine
PWR	pressurized water reactor
SDR	social discount rate
SOC	social opportunity cost of capital
STP	social time preference
VOC	volatile organic compound
WACC	weighted average capital cost
WTP	willingness to pay

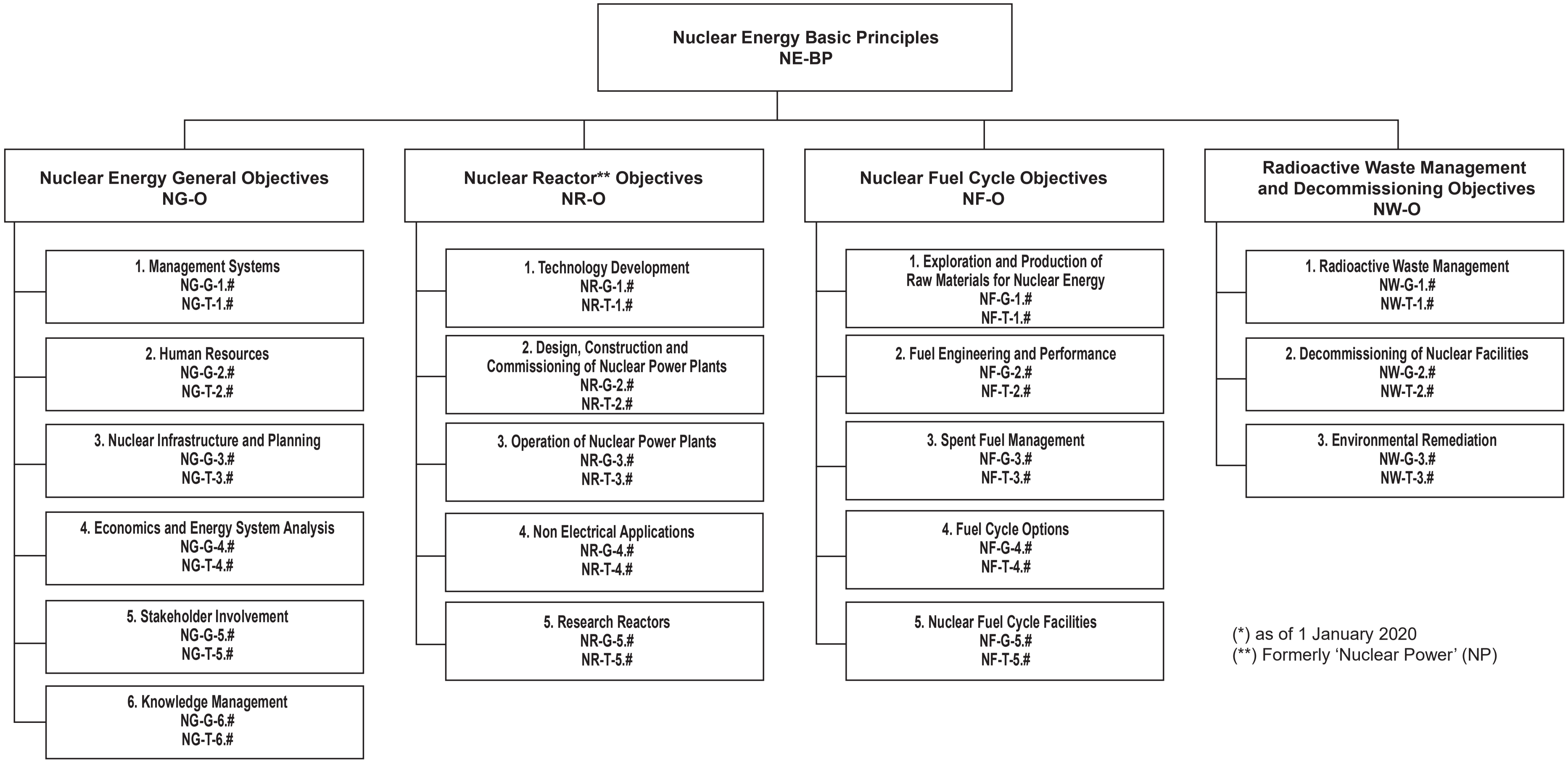
CONTRIBUTORS TO DRAFTING AND REVIEW

Alexeeva, V.	International Atomic Energy Agency
Angelini, F.	European Investment Bank
Bradley, E.	International Atomic Energy Agency
Dardour, S.	International Atomic Energy Agency
English, E.	International Atomic Energy Agency
Florio, M.	University of Milan, Italy
Genco, M.	Centre for Industrial Studies, Italy
Gritsevskyi, A.	International Atomic Energy Agency
Kang, K.S.	Consultant, Republic of Korea
Kupitz, J.	Consultant, Germany
Manzoor, A.	Consultant, Pakistan
Mathet, E.	International Atomic Energy Agency
Omoto, A.	Consultant, Japan
Paillere, H.	International Atomic Energy Agency
Pancotti, C.	Centre for Industrial Studies, Italy
Rollat, X.	Consultant, France
Subbotnitskiy, D.	International Atomic Energy Agency
Van Heek, A.	International Atomic Energy Agency
Welsch, M.	International Atomic Energy Agency
Yuasa, Y.	International Atomic Energy Agency
Zair, R.	National Office of Electricity and Drinking Water, Morocco

Consultants Meetings

Vienna, Austria: 10–12 July 2019; 30 June 30–12 July 2021

Structure of the IAEA Nuclear Energy Series*



(*) as of 1 January 2020
(**) Formerly ‘Nuclear Power’ (NP)

Key

BP: Basic Principles
O: Objectives
G: Guides and Methodologies
T: Technical Reports
Nos 1–6: Topic designations
#: Guide or Report number

Examples

NG-G-3.1: Nuclear Energy General (**NG**), Guides and Methodologies (**G**), Nuclear Infrastructure and Planning (topic **3**), **#1**
NR-T-5.4: Nuclear Reactors (**NR**), Technical Report (**T**), Research Reactors (topic **5**), **#4**
NF-T-3.6: Nuclear Fuel (**NF**), Technical Report (**T**), Spent Fuel Management (topic **3**), **#6**
NW-G-1.1: Radioactive Waste Management and Decommissioning (**NW**), Guides and Methodologies (**G**), Radioactive Waste Management (topic **1**) **#1**

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield
15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group
Gray's Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:
Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:
www.eurospanbookstore.com/iaea

For further information:
Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

International Atomic Energy Agency
Vienna, 2024
www.iaea.org