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# Analysis of Main Areas of Interests and Key Indicators as a Base for Comparative Evaluation of Nuclear and Non-Nuclear Energy Options for Small Countries

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**Abstract.** Paper presents analysis of main areas of interest and key indicators that can be used as a base for a comparative evaluation of nuclear to non-nuclear energy options in small countries. Considerations address mainly small countries without nuclear power that are interested in nuclear energy as an option for the future energy generation mix system development, as well as small countries, users of nuclear technology.

The performed analysis is based on the methodology developed in the frame of International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Collaborative Project of International Atomic Energy Agency "Key Indicators for Innovative Nuclear Energy Systems (KIND)". The INPRO KIND methodology allows innovative nuclear systems, evolutionary nuclear systems and non-nuclear energy options to be compared.

Specific key indicators (KIs) have been considered on the base of the recommended as useful for this case, taking into account the comprised by INPRO main areas of interest – economic, infrastructure, etc.

The analyzed key indicators are foreseen to be a base for future comparative evaluation of nuclear and non-nuclear energy options, taking into consideration country specifics.

**Keywords:** INPRO KIND methodology, key indicators, nuclear energy system, non-nuclear energy option.

## 1 Introduction

In the frame of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) [1], an assessment methodology for Innovative Nuclear Energy Systems has been developed [2]. The International Project on Innovative Nuclear Reactors and Fuel Cycles, as indicated [1] is intended "to help ensure that nuclear energy is available to contribute to meeting the energy needs of the 21st century in a sustainable manner." INPRO methodology provides a holistic and comprehensive approach to assess innovative nuclear systems in areas of economics, infrastructure, waste management, proliferation resistance, safety and environment.

The INPRO Collaborative Project on Key Indicators for Innovative Nuclear Energy Systems (KIND) has focused its efforts on developing of "guidance and tools for comparative evaluation of the status, prospects, benefits, and risks associated with development of innovative nuclear technologies for a more distant future." (Kuznetsov et al., 2015, [3, 4]).

The INPRO KIND methodology can be applied for comparative evaluations not only for innovative nuclear systems, but also for evolutionary nuclear systems and non-nuclear energy options.

The present study analyzes the main areas of interest and key indicators that can be used as a base for a comparative evaluation of nuclear to non-nuclear energy options in small countries. Considerations address mainly small countries without nuclear power that are interested in nuclear energy as an option for the future energy mix system development (so called "newcomers", according to the classification of the INPRO methodology users [2]), as well as small countries, users of nuclear technology (so called "technology user countries" [2]).

## 2 Brief Description of the Concept of the Key Indicators, Developed into the KIND INPRO Project

To achieve the objective of the INPRO Collaborative Project on Key Indicators for Innovative Nuclear Energy Systems (KIND), as explained in Kuznetsov et al. [3], "a limited number of Key Indicators to reflect the status, prospects, benefits, and risks associated with innovative technologies and nuclear energy systems (NESs) on their basis has been developed and advanced methods of expert judgment aggregation within the assessments involving quantifiable data and expert opinions, to enable effective comparative evaluation of innovative NES based on the defined set of KI have been adapted and verified".

The bases of the KIND approach for comparative evaluation are the key indicators, included into the INPRO assessment areas according to the INPRO methodology [2].

The INPRO methodology recommends indicators to be ar-

ranged in a hierarchical structure, known as objectives tree. This structure simplifies weighing of the criteria and analyzing of the results of comparative evaluation. The first level of the objectives tree represents the major objectives in achieving sustainable energy system development (so called high level objectives). Recommended by the methodology high level objectives are *Cost*, *Performance* and *Acceptability*. Each of these objectives should be divided into different assessment areas that are the second level of the objectives tree. In this study, assessment areas included in each high-level objective as follows: *Economics for Cost*; *Waste management, Safety and Environment for Performance*; *National security, Public acceptance and Infrastructure for Acceptability*. Key indicators included in each area are the third level of the objective tree.

KIs are indicators that represent different features of the compared options [2]. The high level objectives, main areas of interest and key indicators could be chosen by the users of the methodology according to the country specifics (technology user countries, newcomers, etc.), the selected options to be compared (different nuclear technologies, nuclear and non-nuclear options, etc.), on the base of the methodology recommendations and experts' considerations about desired features. KIs are the input for the comparative evaluation between different energy systems and the selection of appropriate key indicators is a first very important step in the successful assessment process.

## 3 Selected Assessment Areas (or Areas of Interest) and Key Indicators as a Base for Comparative Evaluation of Nuclear and Non-Nuclear Energy Options For Small Countries

Considerations of the appropriate key indicators have been performed after analyzing a number of different key indicators, proposed in the INPRO methodology and in particular ones recommended for the case of nuclear and non-nuclear options comparison. The selected KIs reflects also country specifics - mainly small countries with limited capacity and resources of the Balkan region that are interested in nuclear energy as an option for the future energy mixture system development.

### 3.1 Economics

The area of Economics is considered of high importance for small countries with limited resources. The Economic Basic Principle in INPRO Methodology states: "Energy and related products and services from nuclear energy systems shall be affordable and available." [5].

There are two important key indicators selected in this area:

- The first KI in the Area of Economics *(E.1) – Levelized unit energy cost (LUEC),* defined as the price per unit of production over the assumed lifetime of the unit. LUEC includes the cost of different factors, such as startup (initial investment for constriction of plant), operation, nuclear fuel, maintenance, administration, decommissioning, radioactive waste, RAW disposal.
- The second KI *(E.2) – Startup cost* is included by definition in *E.1*, but the importance and specific conditions for providing initial funds for such big projects in small countries with limited capacity require additional consideration (without duplication in E.1), as this criterion reflects financial availability of the corresponding option.

### 3.2 Waste management

The area of Waste management is also important to be considered. This area reflects nuclear systems only but spent fuel and RAW management are very sensitive aspects for the society when considering nuclear energy option. Based on the Waste management Basic Principle in INPRO Methodology [2] "Generation of radioactive waste in an INES shall be kept to the minimum practicable", the KI *Specific (long term) RAW inventory (WM.1),* has been selected.

### 3.3 Safety

By comparing nuclear and non-nuclear energy options in the area of safety, a KI – *Risks of accidents (S.1)* could be used to compare the probability of severe accidents which could be evaluated by sub indicators such as accident rate, fatalities rate, etc. The data could be obtained by reliable sources, papers, materials, for example "The OECD's analysis, *Comparing Nuclear Accident Risks with Those from Other Energy Sources"* [6].

### 3.4 Environment

As a very sensitive issue in the environmental concern for the EU could be specified climate change from greenhouse gas emissions. One of the EU targets 2020 is 20% reduction in greenhouse gas emissions compared to 1990 levels and in 2030 climate & energy framework – at least 40% cuts in greenhouse gas emissions (from 1990 levels). As appropriate KI – *Greenhouse gas emissions (E.1)* could be selected.

#### National security

In this area as a first KI – *Degree of dependence on supplier(s) (NS.1)* has been selected. The energy dependence shows the dependence of the country on imports of energy and resources.

By evaluation of this KI, areas of technology, construction, operation, maintenance, fuel supply reliability, etc. could be taken into account. Here oversea or domestic suppliers should be taken into consideration as well as attention could be paid on diversification of energy sources.

The second KI *Electricity delivery reliability (NS.2)* has been considered as an important parameter in the area. Here the compared energy alternatives should be evaluated from the point of view of provision of a reliable source of electric power, guaranteeing the electric power, energy

balance of the country; risks for the supply of power resource, possibilities for export of electric power, etc.

### 3.5 Public acceptance

The KI selected – *Survey of public acceptance (PA.1)* could be based on survey conducted in local areas or countries which reflects people opinion on energy programs and systems.

### 3.6 Infrastructure

Based on the INPRO Basic Principle in the area of Infrastructure "A country shall be able to adopt, maintain or enlarge a nuclear energy system for the supply of energy and related products without making an excessive investment in national infrastructure" [7] and on the user requirements defined in this area, the recommended important KI indicators are:

I.1 *Status of legal framework;* This KI evaluates the status of the legal framework which should cover "the issues of nuclear liability, safety and radiation protection, environmental protection, control of operation, waste management and decommissioning, security and non-proliferation" (in correspondence with the INPRO criteria [7]) at both the national and international level.

I.2 *Status of state organizations;* This criterion, according to the INPRO methodology, "evaluates the status of state organizations with responsibilities for safety and radiation protection, environmental protection, control of operation, waste management and decommissioning, emergency preparedness and response, security and non-proliferation." [7].

3.1 *Availability of infrastructure to support owner/operator;* This criterion evaluates support infrastructure defined in the INPRO methodology as "primarily the industrial infrastructure, especially the hardware such as facilities and equipment needed to support a nuclear power programme during its lifetime and to a lesser extent the infrastructure provided by the government in areas such as transportation. The owner/operator of nuclear facilities is not part of the support infrastructure itself, but needs goods and services provided by industry and government. The government is responsible for some of the hardware related support infrastructure, such as offices needed for regulatory activities, facilities for emergency response and means of transportation (ports, roads, bridges, etc.)" [7].

I.4 *Government policy;* The national energy policy issued by the government is a key point to establish and maintain the nuclear or non-nuclear energy systems, so KI – Government policy (I.4) is included in the area of Infrastructure.

I.5 *Availability of human resources.* For both "technology user countries" and "newcomers" of significant importance is also the availability of human resources – their sustainable and high level training and qualification in order to be able to face the challenges which pose the nuclear technologies. The human resources need to be sufficient and qualified to be utilized when introducing a new energy system project. This concern is reflected by KI Availability of human resources (I.5) in the area of Infrastructure.

Table 1 presents the summary of High level objectives, Assessment areas and Key indicators selected as a base for comparative evaluation of nuclear and non-nuclear energy options for small countries.

Table 1.

| High-level objectives | Assessment areas | Key Indicators | KIs abbr. |
|---|---|---|---|
| **Cost** | **Economics** | *Levelized energy product or service cost* | *E.1* |
| | | *Start-up cost (initial investment for construction of plant)* | *E.2* |
| **Performance** | **Waste Management** | *Specific (long term) RAW inventory* | *WM.1* |
| | **Safety** | *Risks of accidents* | *S.1* |
| | **Environment** | *Greenhouse gas emissions* | *E.1* |
| **Acceptability** | **National security** | *Degree of dependence on supplier(s)* | *NS. 1* |
| | | *Electricity delivery reliability* | *NS. 2* |
| | **Public acceptance** | *Survey of public acceptance* | *PA.1* |
| | **Infrastructure** | *Status of legal framework* | *I.1* |
| | | *Status of state organizations;* | *I.2* |
| | | *Availability of infrastructure to support owner/operator* | *I.3* |
| | | *Government policy* | *I.4* |
| | | *Availability of human resources* | *I.5* |

## 4 Conclusions

The key indicators selection is a very important issue in the process of comparative evaluation of different energy options. They are the base for the comparative evaluations by means of the INPRO KIND assessment methodology. Their selection depends on country specifics and the energy options compared. They should also be selected in respect of possible changes during the long time of operation due to various reasons such as price fluctuations of resources or the development of a newer technology.

Presented in this study selection of the areas of interest and key indicators could be used a base for the comparative evaluation of nuclear and non-nuclear energy options in considering sustainable energy systems development in a small country with limited resources.

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