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Application of Economic Risk Measures for a Comparative Evaluation of Less and More Mature Nuclear Reactor Technologies

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Less mature nuclear reactor technologies are characterized by a greater uncertainty due to insufficient detailed design information, operational data, cost information, etc., but the expected performance characteristics of less mature options are usually more attractive in comparison with more mature ones. The greater uncertainty is, the higher economic risks associated with the project realization will be. Within a comparative evaluation of less and more mature nuclear reactor technologies, it is necessary to apply economic risk measures to balance judgments regarding the economic performance of less and more mature options. Assessments of any risk metrics involve calculating different characteristics of probability distributions of associated economic performance indicators and applying the Monte-Carlo method. This paper considers the applicability of statistical risk measures for different economic performance indicators within a trial case study on a comparative evaluation of less and more mature unspecified LWRs. The presented case study demonstrates the main trends associated with the incorporation of economic risk metrics into a comparative evaluation of less and more mature nuclear reactor technologies.

Keywords: Levelized cost, Net present value, Value-At-Risk, Technology readiness

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1. Introduction

Less developed reactor technologies are characterized by a higher degree of uncertainty in basic technical and economic parameters as compared to more mature options due to the lack of detailed information on the design, operational data, costs, etc., but the expected performance of such systems tends to be more attractive as compared with more mature options. It is evident that the greater the uncertainty is, the higher the economic risks associated with the relevant project are.

In this regard, during a comparative evaluation of the competitiveness and performance of reactor technologies of different degrees of maturity, it is necessary to consider the economic risks for balancing judgments about the economic indicators and expected performance of the options under consideration. The economic risk theory is a reliable basis for judgments about the potential costs, benefits and risks, when more or less mature reactor technologies are compared to inform decision-makers who are responsible for issues related to the deployment of new technologies, which requires a clear understanding of the risks involved.

It should be noted that, despite the urgency of the issues associated with assessments of the economic risks inherent in the design, operation and decommissioning of nuclear technologies and their components in the framework of major international methodological efforts focused on assessments and comparative analysis of nuclear energy system options and components thereof, these issues have not received due attention [1–5]. At the same time, consideration of the relevant aspects can change the view on the compared options. For example, one of the arguments in favor of small and medium sized reactors is that the deployment of nuclear energy systems on their basis may reduce the risks associated with the loss of capital investments [6]. A correct assessment of the economic risks inherent in the deployment of new reactor technologies could lead to the conclusion of a feasible preliminary reduction of the associated uncertainties (including the necessity of additional R&D) before their implementation [7].

Assessments of risk indicators (such as Value at Risk, expected shortfalls, 'tail' Value at Risk, etc.) involve calculations of the characteristics of probability distributions of economic performance indicators (net present value, present value, internal rate of return, discounted payback period, etc.) and require a systematic application of statistical approaches based on the Monte Carlo methods.

This paper, using a comparative analysis of two hypothetical light water reactor technologies (less and more mature options) as an example, presents the results of an evaluation of several indicators of economic risks for different economic performance measures in order to demonstrate the applicability of relevant concepts for a comparative evaluation of nuclear technologies. It also reveals contradictions between the economic performance indicators and risks to be taken into account when considering issues related to the selection of the most attractive deployment option [8–10].

2. Methodology

2.1 Criteria for comparison of alternatives in case of risk and uncertainty

In assessing the efficiency of projects in the energy sector in the context of liberalization of energy markets, where economic entities have high autonomy in decision-making and are seeking to maximize profits, it has become a common practice to use principles and criteria that are different from those used in the centralized economy, where the primary efficiency criterion was the one of minimum overall discounted costs [11–12]. In this context, the cash flow theory is used as the basic one for selecting the projects, where the net present value, present value, internal rate of return, discounted payback period are the basic decision-making economic performance indicators (Table 1) [13–14].

Based on these indicators, it is possible to perform a

Table 1. Economic performance indicators

Indicator	Calculation Formula
Net Present Value (NPV)	$NPV = \sum_{t=T_1}^{T_2} \frac{D_t}{(1+d)^t} - \sum_{t=0}^{T_2} \frac{R_t}{(1+d)^t}$
Present Value (PV)	$PV = \sum_{t=0}^{T_2} \frac{R_t}{(1+d)^t}$
Internal Rate of Return (IRR)	The interest rate at which the NPV is equal to 0.
Discounted Payback Period (DPP)	The period of time required for the revenue generated by the investment, taking into account the discount, to cover the investment cost.
Levelized Cost (LC)	$LC = \sum_{t=0}^{T_2} \frac{R_t}{(1+d)^t} \Big/ \sum_{t=T_1}^{T_2} \frac{W_t}{(1+d)^t}$

* Where D_t is the operating income at the time t; R_t is the operating costs at the time t; W_t is the current power generation; d is the rate of discount; T_1 is the construction period (years); T_2 is the project lifetime (years); t is the discrete time.

multi-criteria assessment of the economic performance of energy system options and components thereof. Depending on the specific task, a particular set of performance indicators can be used. For example, in the case of investor orientation, the main indicator is the net present value (NPV). In the case of proprietary orientation the main economic efficiency indicator of a NPP project is usually the present values (PV). In general, it is necessary to take into account the entire spectrum of performance indicators that reflect different aspects of the project.

Since risk is a category associated with the uncertainty, probabilistic methods are widely used in assessments of risk indicators. The undefined parameters of the project implementation conditions as well as the uncertainty in technical and economic characteristics of a project determine the resulting uncertainty in the above-mentioned economic performance measures, for each of which statistical risk factors can be evaluated. The criteria that can be used for decision-support under risk describe alternatives and take into account the peculiarities of relevant statistical distributions, thus defining the applicable scope of the criteria. Listed below are the most commonly used criteria (risk factors) for comparison of alternatives under risk and uncertainty [15–16].

- The Mathematical Expectation (ME) criterion suggests that the options should be evaluated by the expectation value (this indicator can be viewed as a measure of economic performance).
- The Most Probable (MP) value criterion suggests that the option assessed by this criterion should have the highest probability (this figure can be considered as another measure of economic performance).
- The Value at Risk (VaR) criterion is an estimate expressed in monetary terms of losses that do not exceed the expected loss with a given probability equal to the confidence level α. Therefore, in 1-α cases, the loss will exceed the VaR value. Thus, it can be affirmed with probability α that the losses will not exceed the VaR units.
- The Expected Shortfalls (ES) criterion estimates the distribution "tail" intercepted by a given limit: it represents the expectation of the distribution "tail" which characterizes the losses.
- The Tail Value at Risk (tVaR) is used for assessing the capital deficiency risks and is equal to the ES indicator, for which the VaR value is taken as the boundary.

There are other measures of risk, which on par with the above-mentioned criteria can be used for comparing alternatives in the case of risk and uncertainty.

All the considered indicators that can be used in

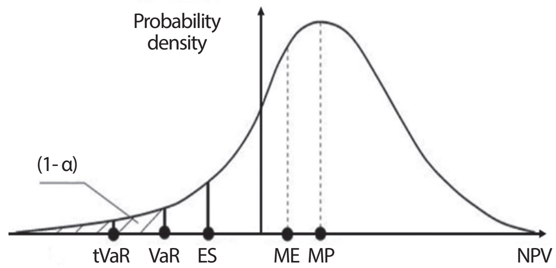

Fig. 1. Relative position of different risk measures.

decision-making under risk conditions characterize the alternatives in their own way, being guided by certain features and distribution characteristics. This determines the scope of the criteria. By way of illustration, a distribution with left-sided asymmetry was specially chosen, since it is more typical for such models. Sources of income are usually limited to revenues from core activities. At the same time, the list of pure risks envisaging only losses is always much more extensive. These include both relatively light or moderate risks and large or even catastrophic risks. Therefore, the distribution of financial performance of activities is almost always more stretched to the side of losses. Fig.1, for the typical NPV probability distribution, shows the arrangement of different risk criteria (negative values denote a loss, positive values denote a profit). It is noted that the consideration is limited only by the uncertainty in technical and economic parameters of the system, technical and economic parameters, excluding major catastrophic risks, which even more stretch the distribution into the loss area. Briefly, the conclusions regarding the applied criteria are as follows:

- There are no marginal values of outcomes in the area of losses, as a rule. That is, it is almost impossible to assess the maximum possible total loss. Therefore, the criterion of marginal values can not be applied.
- With left-hand asymmetry, the most MP criterion is more optimistic than the ME criterion. The ME criterion is a probability-weighted average value; therefore, it allows for a significant probability that the actual result will be lower than the criterion value (usually the area below density plot, located to the left of ME, is quite large).
- By setting larger values of the confidence level α in the VaR criterion, it is possible to estimate the loss amount that can be calculated with the required confidence or the loss amount of loss that may have to be covered at its sole cost and expense. Nevertheless, there will always be a (1-α)-percent probability of very heavy losses that were not taken into account in the VaR criterion.
- The ES criterion is the expected loss value. Therefore, if one is interested in the average loss amount in a situation where, instead of profit, the project will show a negative result, this indicator fits very well for this. However, there is a chance of an even greater loss exceeding the criterion value.
- The most conservative of the considered criteria is tVaR. If this criterion is used as a guide for calculating the reserve of own funds, it is possible to ensure a sufficiently high stability level both in the face of normal risks and in the conditions of catastrophic events.

Statistical methods are widely used for quantifying risk indicators. One of the most popular recent approaches to analyzing uncertainties is the use of statistical methods which involve setting uncertainties as random variables with the known distribution (Monte Carlo methods) [17]. This methodology is implemented based on the following algorithm: it is necessary to define a set of input parameters that affect the resulting functional uncertainty, form sets of initial input data by randomly selecting input parameters, calculate the functional of interest, statistically process the calculation results and estimate statistical characteristics of the distributed resulting functional.

2.2 Specification of a trial model

Two hypothetical light water reactor technologies (assuming that one is less and the other is more mature) is considered in order to demonstrate an assessment of economic risk factors for various economic performance indicators

Table 2. Initial data

Parameter	More mature technology	Less mature technology
External conditions		
Price of electricity (cent/kWh)	8	
Discount rate (%)	7	
Income tax rate (%)	0	
System characteristics		
Installed electric power (MW(e))	1200	
Operation period (years)	60	
Construction period (years)	6–8	4–9
Overnight capital costs ($/kW(e))	5000–6000	4000–7000
Fixed operation and maintenance costs (mln. USD per year)	30–40	20–50
Burn-up (MW (th) d/kg U)	45–50	50–55
Efficiency (%/100)	0.33–0.34	0.34–0.35
Load factor (%/100)	0.8–0.85	0.85–0.9
Nuclear fuel cost ($ per kg U)	600–700	500–900

and applicability of relevant economic concepts for a comparative analysis of nuclear technologies as well as arising contradictions between the expected economic performance and risk indicators.

The initial data are the external conditions (price of electricity, nuclear fuel price, discount rate, profits tax rate) which were selected to be similar for both technological options to provide the comparable conditions for analyzing, technical and economical parameters of the unit (installed electric power, load factor, construction period, overnight capital cost, fixed operation and maintenance costs, fuel burn-up, efficiency, etc.). The basic set of initial data is presented in Table 2. It is assumed that all the parameters are uniformly distributed within the specified limits.

Based on the data in Table 2, calculations are made of annual capital costs, fuel costs and operating costs, which make it possible to assess the performance indicators of the project for the construction of NPPs on the basis of the corresponding reactor technology. In estimating the probable values of economic performance indicators by the Monte Carlo method with different sets of input parameters to provide statistical significance of the results, 10,000 options are generated. The confidence level α for VaR calculations is chosen to be equal to 95%.

To perform evaluations presented in the paper, it was used a relevant risk assessment software tool proposed and tested by the authors.

3. Discussion and results

Fig. 2 shows the uncertainty tube and average cumulative NPV on the project life cycle in millions of dollars for the considered two technology options. Traditionally, these two sections are distinguished: the flow of accumulated capital investment in the construction of facilities for a given period and the cumulative net present value in the facility operation area from the beginning of operation until

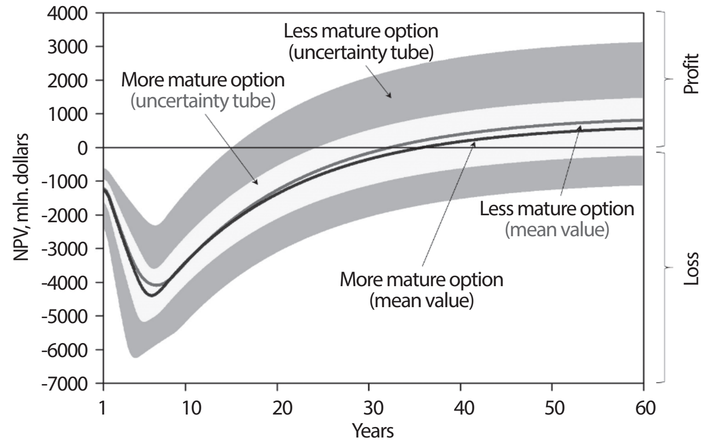

Fig. 2. Uncertainty tube and average NPV.

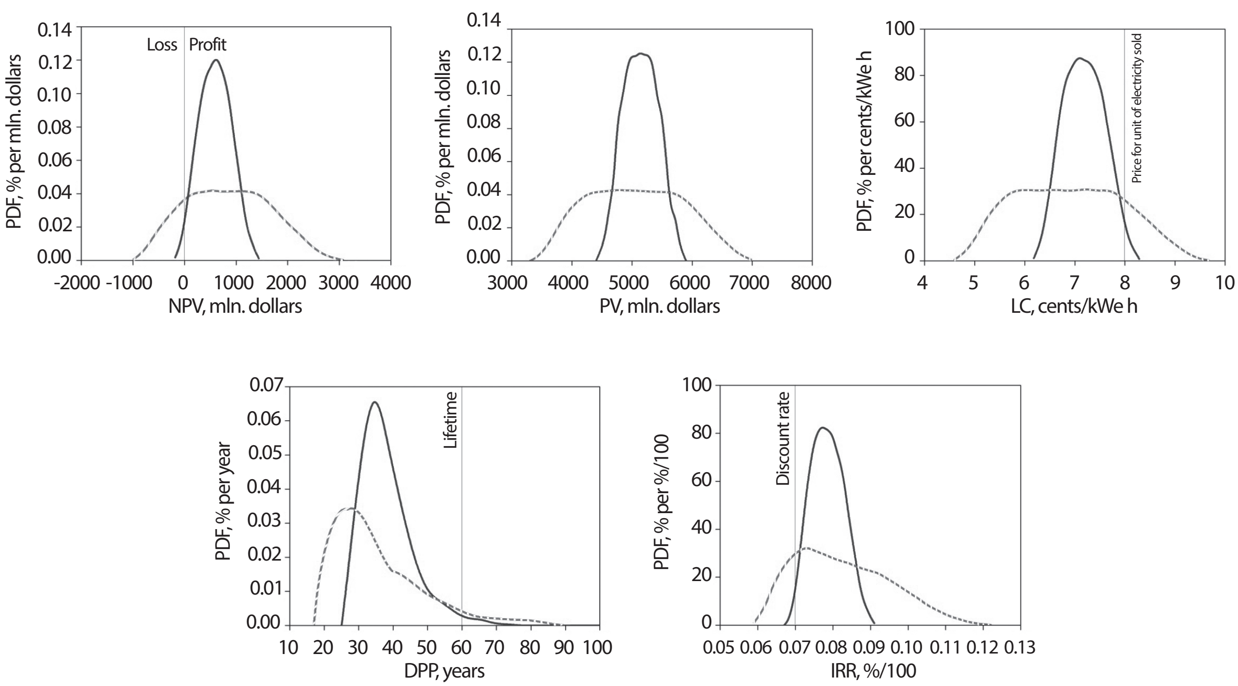

Fig. 3. Probability distributions of economic performance indicators: dotted line – less mature technology, solid line – more mature technology.

the end of the life cycle.

The expected (average) cumulative net present values in 2060 will amount to 596 and 840 million USD for more and less mature technologies, respectively. The upper and lower boundaries of the uncertainty tube amount -210, 1472 and -1473, 3153 million USD for more and less mature technologies, respectively. As we can see, the expected (average) NPV is higher for less mature technologies but, at the same time, the range of possible values of this indicator is wider, which leads to higher values of the risk indicators.

Probability density distributions of economic performance measures presented in Table 1 for 2060 are shown

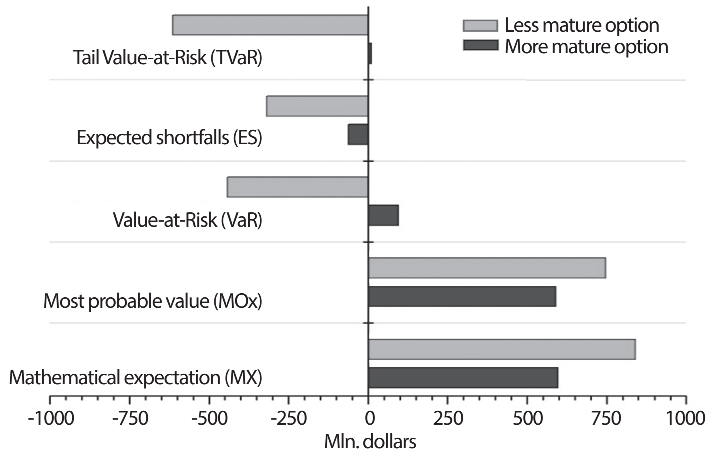

Fig. 4. Values of economic risk measures.

in Fig. 3. This figure also shows boundary values for different performance measures at which the project becomes unprofitable.

The Discounted Payback Period (DPP) is defined as the point of intersection of the accumulated flow with the horizontal axis, where the NPV is equal to zero. Since the investor begins to receive the income from the project only at times greater than the payback period, it is clear that the payback period should be much shorter than the life cycle duration.

The Internal Rate of Return (IRR) of the project is the interest rate at which the NPV is zero. It is believed that the higher the IRR and the greater the difference between its value and a predetermined discount rate, the more attractive the project is.

The levelized costs (LC) must be less than the specified price of electricity; in this case, the project can be considered profitable.

If the investor is a proprietor, the main economic performance indicators are the present values (PV) which must be minimized.

Based on the data of statistical distributions and taking into account the project break-even requirements, it is possible to define the values of risk indicators. For example, the values of the considered expected economic performance and risk indicators for NPVs are shown in Fig. 4 for both technological options.

These results suggest that, despite the fact that the expected economic performance (for the ME and MP indicators) for a less mature technology is more attractive as compared to a more mature one; all the considered economic risk indicators (tVaR, ES, VaR) for a less mature technology are considerably higher (in absolute value) than the corresponding values for a more mature option due to a higher degree of uncertainty in their main technical and economic parameters.

For example, the expected NPV for a less mature option is 1.4 times higher than the corresponding values of a more mature one; however, all the risk indicators are higher in a less mature option: 4.6, 5.2 and 61.4 times for the VaR, ES and tVaR, respectively. Of note, the VaR and tVaR are positive for more mature options, which indicates that a more mature option can yield a profit to be counted on with a given confidence level even in adverse conditions while a less mature option with the same confidence level will incur losses to be covered at one's own expense. These results demonstrate that taking into account the indicators of economic risks can change the attractiveness perception with regard to less mature reactor technologies: the expected improvement in performance may be incomparable with the increasing risks associated with the deployment of new technologies.

It is obvious that the presented analysis cannot form a basis for actual decision-making due to its demonstrative qualitative nature and limited scope of the study. The selection of the most appropriate economic performance measures and risk indicators also remains an open question, which in each case should be solved taking into account the specifics of the situation, the availability of necessary data for assessing associated uncertainties. These items should be taken into account if it becomes necessary to use this approach to generating real risk-based decisions with regard to finding the most appropriate well-balanced technological option to be deployed in terms of different costs, benefits and risks [18 – 20].

To increase the validity of the analysis results and their confidence level, it is necessary to organize an examination with the involvement of proponents and opponents of different technical concepts in order to develop a common set of indicators of economic performance and risks for assessments and specify all scenarios and model assumptions as well as uncertainties. To select the ultimate decision, it may be useful to resort to formal multi-criteria decision support methods (including those taking into account uncertainties), which are widely used in different subject areas for aggregating conflicting indicators (in this case, economic performance measures and risk indicators) with due account for the judgments and preferences of experts and decision-makers. Such an examination can make it possible to perform an objective assessment, based on a quantitative analysis of costs, benefits and risks associated with each of technological options, contributing to the search for and justification of the most balanced one among them.

4. Conclusion

The application of economic risk indicators to a comparative evaluation of reactor technologies is useful for communication with decision-makers who are not familiar with the technical specifications and performance measures of reactor technologies but aware of the economic risk concepts. The terminology based on economic risk indicators can be effectively used for interpreting the ranking results within multi-criteria comparative evaluations of more and less mature reactor technologies. The presented hypothetical example showed the main trends related to the incorporation of uncertainty in assessing less and more mature reactor technologies.

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