USER INSTRUCTIONS FOR

KIND-ET (KIND-EVALUATION TOOL)

A multi-attribute value theory based Excel-template for the INPRO project on

Key Indicators for Innovative Nuclear Energy Systems (KIND)

(40 pages, 29 figs., 5 tables, 11 refs.)

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CONTENT

BACKGROUND

This document presents user instructions for KIND-ET (KIND-Evaluation Tool). KIND-ET is a multi-attribute value theory (MAVT) based Excel-template developed for the INPRO collaborative project titled Key Indicators for Innovative Nuclear Energy Systems (KIND) as a guidance tool to assess sustainability of innovations. KIND-ET is based on the MAVT method and a set of the KIND project recommendations.

KIND-ET is a tool adapted for comparative evaluation of the status, prospects, benefits and risks associated with development of nuclear technologies including options for a relatively distant future. With realized architecture and functional capabilities of KIND-ET, this tool may be easily modified by users to take into account their preferences. KIND-ET can help identify merits and demerits of the nuclear technologies being compared under different circumstances and evaluate their overall ranks taking into account NES performance, as well as experts' and decision makers' judgments and preferences.

The characteristic features of the KIND-ET include easy usage, user-friendly interface, automation and visualization capabilities for integrating with convenient tools in order to manage and process the calculation results. KIND-ET provides some flexibility to explore different approaches and techniques in the implementation of MAVT method for the KIND objective. At the same time, KIND-ET observes the characteristic features of the KIND approach and recommendations. The following basic principles and requirements were used to develop the KIND-ET software: problem-orientation and integration; user-friendliness and intuitive obviousness; automation and improvability; self-sufficiency and multi-functionality; openness and extensibility; reliance on Microsoft Office and web-integration.

KIND-ET covers most of the formal stages of the decision support process related to the use of a specific mathematical method: implementation of the MCDA method, performance of uncertainty and sensitivity analysis, and formulation of final conclusions and recommendations. To perform a multi-criteria comparison using the MAVT method, it is required to select a set of performance indicators; identify a structure of the objectives tree; prepare a performance table; determine single-attribute value functions for each indicator; evaluate weighting factors; perform sensitivity analysis; interpret ranking results and formulate recommendations. All the mentioned steps are to be specified in KIND-ET within solution of a certain problem.

The following major assumptions are realized in KIND-ET by default: three-level objectives tree, 15 performance indicators, linear end exponential forms of single-attribute value functions, local and global domains of single-attribute value functions, direct method and hierarchical weighting for weighting factors assessment. Users can at their own discretion specify all steps (a set of indicators used, the structure of the objectives tree, etc.) as well as a goal for each indicator and scales for indicators evaluation.

This user instructions document contains a short description of the MAVT approach adapted for the KIND project; basic information regarding the KIND approach and recommendations; functionalities and capabilities of KIND-ET; directions for usage of KIND- to perform all necessary steps of the NES multi-criteria comparison based on the MAVT method (formation of performance table, specification of single-attribute value functions, weights assessment, sensitivity analysis to weights and single-attribute value functions) as well as some examples demonstrating the implementation of this tool for the NES comparative evaluations.

1. KEY INDICATORS AND COMPARATIVE EVALUATION PROCEDURE

KEY AND SECONDARY INDICATORS AND OBJECTIVES TREE

Within the KIND project, a set of key indicators (KI) and secondary (additional) indicators (SI) is recommended for performing NES comparative evaluation. Each indicator may be evaluated either in scores or in natural units. All indicators may be combined into related areas (economics, waste management, proliferation resistance, environment, safety, maturity of technology, country specifics, etc.). A high-level evaluation might be simplified by focusing on a smaller number of the major objectives which may aggregate individual evaluation areas. It is practically reasonable to consider two or three objectives at the highest level. For example, 'cost', 'benefit' and 'risk' objectives are more commonly used, but 'performance', 'cost' and 'acceptability' objectives will be more appropriate for the KIND approach. Table 1.1 presents a possible list of key and secondary indicators. Experts are free to choose indicator sets, evaluation areas and high-level objectives to be used in a comparative evaluation.

TABLE 1.1. EXAMPLE OF KEY AND SECONDARY INDICATORS

Area	**Type**	**Indicators**	**Abbr.**
Economics	KIs	Levelized energy product or service cost	E.1
		R&D cost	E.2
	SIs	Specific overnight capital cost	SE.1
		Flexibility for non-electrical services and energy products	SE.2
		Load factor	SE.3
Waste management	KIs	Specific radwaste inventory	WM.1
	SIs	Decay heat	SWM.1
Proliferation resistance	KIs	Attractiveness of nuclear material	PR.1
		Attractiveness of technology	PR.2
		Safeguard approach identified	PR.3
	SIs	Link to physical protection	SPR.1
Environment	KIs	The amount of useful energy produced by the system from a unit of mined natural uranium/thorium	ENV.1
	SIs	Evaluation of sufficient supply of identified rare materials for a targeted deployment scale	SENV.1
Safety	KIs	The potential to prevent release	S.1
		Design concept specific safety inherent and passive features and systems	S.2
		Core damage and large early release frequencies	S.3
		Source term	S.4
		Short term and long term accident management	S.5
	SIs	Options to cope with external event impacts, Combinations of external and internal events	SS.1
		Provisions for in-service inspections and replaceability of items	SS.2
		Safety of refueling and SNF handling	SS.3
		Nuclear installation safety in cold state	SS.4
		Material degradation mechanisms and impacts	SS.5
		Link to physical protection regime	SS.6
Maturity of technology	KIs	Design stage	M.1
		Time needed to mature the technology	M.2
		Degree of standardization and licensing adaptability	M.3
	SIs	Degree of validation of basic processes	SM.1
		Share of proven technology	SM.2
		Spin-off potential	SM.3

The objectives tree structure should be elaborated and taken into account throughout a multi-criteria comparative evaluation. It defines procedures of weighting factors assessment and the ranking results interpretation. Such structuring makes it possible to simplify the preparation of the final weighting factors to be used for formation of a multi-attribute value function within the MAVT method as well as provides a clearer explanation of the ranking results.

Selection of the objectives tree structure should be dictated by the simplification of expertise of an organization on the weighting factors assessment. An option based on arranging the indicators in the three-level objectives tree seems to be the most appropriate manner due to a simpler and more apparent procedure of a weighting factors assessment, which may be organized by means of the subject matter experts' survey in different areas. Figure 1.1 illustrates a template for the KIND objectives tree in the form of a three-level hierarchical structure: the orange figures are performance indicators (key and secondary), green figures are evaluation areas, and blue figures are high-level aggregated objectives.

For the ranking results to be interpreted, it is required to calculate scores for the evaluation areas or high-level objectives (within the MAVT method, it is assumed by extraction of individual components of a multi-attribute value function) in accordance with the specified structure of the objectives tree. Based on this decomposition, NES ranking results can have a more clear and meaningful interpretation and more simple procedure of weighting factors preparation. Depending on the interpretation depth and details, this decomposition may be performed at different levels in accordance with the specified structure of the objectives tree.

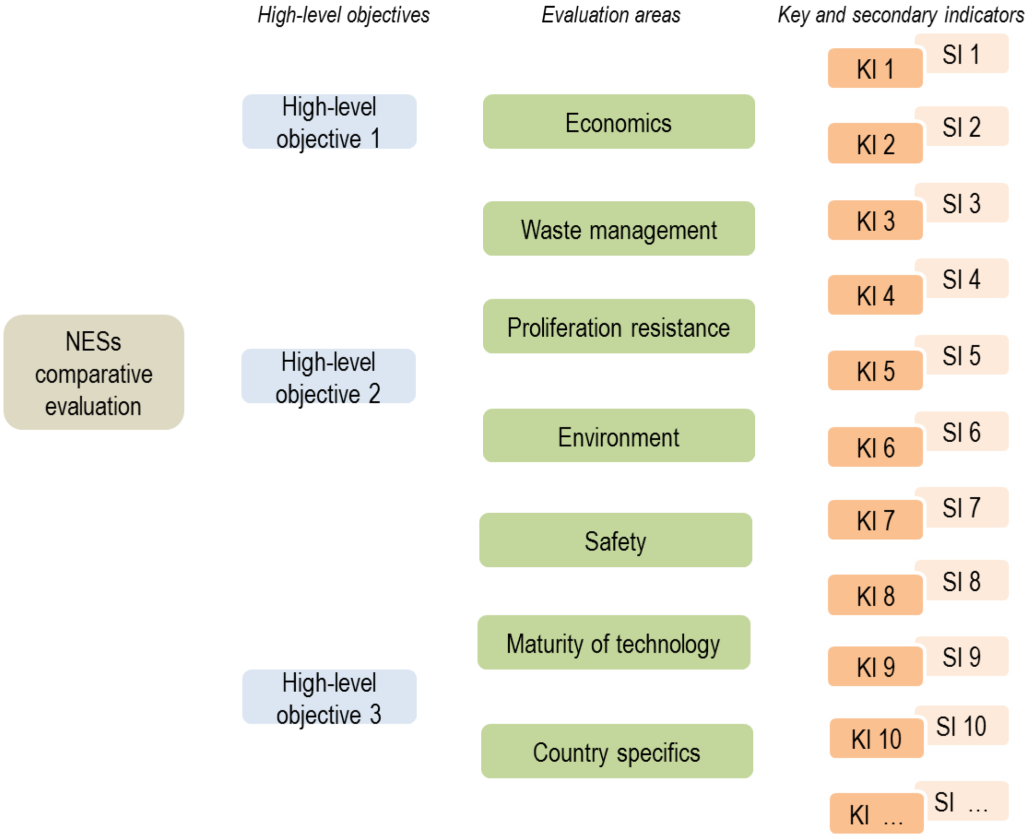


FIG. 1.1. The KIND objectives tree

THE MAVT BASIC ASSUMPTIONS IMPLEMENTED IN KIND-ET

The MAVT method is a quantitative comparison method used to combine different measures of costs, risks and benefits along with expert and decision-maker preferences into an overall score – multi-attribute value function [1-4] (Fig. 1.2).

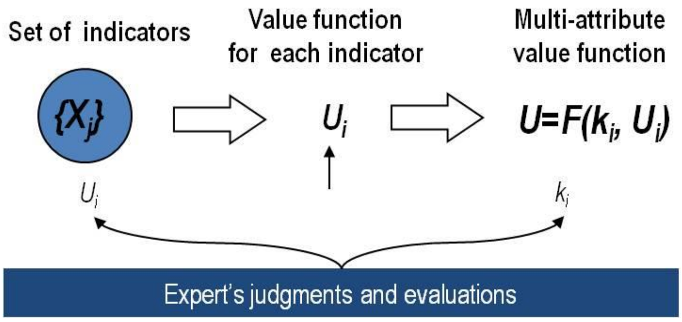


FIG. 1.2. MAVT method

The foundation of the MAVT method is a concept of a single-attribute value function. Single-attribute value functions are used when quantitative information is known about each alternative. Every indicator has a single-attribute value function created for it. These functions transform diverse indicators evaluated in 'natural' scale to one common, dimensionless scale or score (from 0 to 1) known as a single-attribute value function, in accordance with experts' and decision-maker's judgments. These scores are used in further calculations.

These scores are weighted according to their importance. To identify the preferred alternative, experts should multiply each normalized alternative's scores on corresponding weighting factors for all of an alternative's indicators, which reflect the experts' and decision-maker's preferences. The overall scores (multi-attribute value functions) indicate the ranks of the alternatives. The preferred alternative will have the highest overall score.

Multi-attribute and single-attribute value functions

The general form of the multi-attribute value function is:

$$u(x)=\sum_{i=1}^{n}k_i u_i(x_i)+k\sum_{\substack{i=1\\ j\rangle i}}^{n}k_i k_j u_i(x_i)u_j(x_j)+k^2\sum_{\substack{i=1\\ j\rangle i\\ l\rangle j}}^{n}k_i k_j k_l u_i(x_i)u_j(x_j)u_l(x_l)+...$$

$$+k^{n-1}k_1k_2...k_nu_1(x_1)u_2(x_2)...u_n(x_n),\ \text{where}\quad 1+k=\prod_{i=1}^{n}(1+kk_i)$$

The type of multi-attribute value function widely applied in different studies (so called 'additive model of multi-attribute value function') has the following form:

$$u(x)=\sum_{i=1}^{n}k_i u_i(x_i),\ \text{where}\sum_{i=1}^{n}k_i=1$$

In both expressions $u_i(x_i)$ is the single-attribute value function for i indictor that is scaled from 0 to 1, k_i is the weight for i indicator. The independence assumptions that justify the use of the additive model are reasonable for this analysis because of the relationships among the objectives and measures, and the results of the analysis are easier to interpret when the additive model is used. In KIND-ET the additive model is used to aggregate the results of the evaluations.

Different types of single-attribute value functions may be assessed by the experts appointed by decision-making team. These functions could be linear, nonlinear, piecewise continuous or others based on categorical information. The most common types of single-attribute value functions are linear and exponential functions, which have found their wide application in various applied studies (including nuclear engineering), and are presented in Table 1.2. In the KIND-ET tool, these two options are realized.

TABLE 1.2. SINGLE-ATTRIBUTE VALUE FUNCTIONS IN KIND-ET

Type	**Increasing value functions**	**Decreasing value functions**
Linear	$V(x)=\dfrac{x-x^{\min}}{x^{\max}-x^{\min}}$	$V(x)=\dfrac{x^{\max}-x}{x^{\max}-x^{\min}}$
	Attitude to risk: risk neutral trend	
Exponential	$V(x)=\dfrac{1-\exp\left(a\cdot\dfrac{x-x^{\min}}{x^{\max}-x^{\min}}\right)}{1-\exp(a)}$	$V(x)=\dfrac{1-\exp\left(a\cdot\dfrac{x^{\max}-x}{x^{\max}-x^{\min}}\right)}{1-\exp(a)}$
	Attitude to risk: If a>0 – risk proneness trend (convex downward (concave upward) function); If a<0 – risk aversion trend (convex upward (concave downward) function); Exponent power a may be called ‘risk proneness level’.	
$x^{\max}$ and $x^{\min}$ are the minimal and maximal domain values of a single-attribute value function, which is reasonable to select as close to each other as reasonably possible to improve MAVT resolution.		

Taking into account the specificity of the KIND project, a simple (express) method is proposed for assessing single-attribute value function type and its parameter:

(1) It is required to select a scale for assessing performance indicators (a single-attribute value function parameter is different depending on the selected indicator evaluation scale). It may be used for both continuous and scoring scales.

(2) The domain (i.e. end points or range of indicator values) of a single-attribute value function should be selected. Two extreme options are realized in KIND-ET: local (end points are equal to the maximum and minimum indicator values for a considered set of NESs defined in the performance table) and global (end points are determined by default, and include all values from the minimum possible score to the maximum possible score) domains.

(3) It is required to determine the type of a single-attribute value function, i.e. increasing or decreasing. If high values of the indicator correspond to a more attractive NES condition, the single-attribute value function will be increasing, otherwise, it will be decreasing.

(4) For the risk neutrality case, a linear form of a single-attribute function should be used. As a form of single-attribute functions reflects risk attitudes (risk proneness or risk aversion trends), it is recommended to use exponential functions as the most common choice in the MAVT based comparative evaluation.

(5) The risk proneness level (exponent power, a) is determined using the lottery method determining the certainty equivalent in an assumption of a fifty-fifty gamble (Fig. 1.3). Certainty equivalent is the amount of payoff that a decision maker would have to receive to be indifferent between that payoff and a given gamble.

(6) This procedure should be applied to all single-attribute functions attributed to each performance indicator, whereas assessments in different scores can be used for different performance indicators.

(7) After obtaining the result of alternative ranking, it is required to analyze the sensitivity to the single-attribute value function shape by varying the form of functions and risk proneness level (exponent power) within certain limits from the selected basic value.

$$\exp\left(a\cdot\frac{CE}{x^{\max}-x^{\min}}\right)=0.5\cdot\exp\left(a\cdot\frac{BO}{x^{\max}-x^{\min}}\right)+0.5\cdot\exp\left(a\cdot\frac{WO}{x^{\max}-x^{\min}}\right)$$

FIG. 1.3. Certainty equivalence method

Weighting factors evaluation

The representation of preferences among different indicators (weighting factors identification) is the most sensitive issue in the formal application of MCDA methods that require accurateness and reasonableness. The simplest and most natural way to evaluate weighting factors is the direct method, which is to be the most suitable for the KIND objectives (Table 1.3).

Since the KIND objectives tree is a multi-level structure, it is reasonable to implement a hierarchical weighting procedure to evaluate the weighting factors. The main advantage of this approach is that subject-matter experts in a certain area will judge only related indicators weights in their subject area. At the same time, high-level objectives and areas weights are to be obtained based on the input from decision-makers.

For the three-level KIND objectives tree to calculate the final weighting factors for single-attribute value functions, it is required to specify three categories of weights factors (real numbers from 0 to 1): weights for the high-level objectives (for instance, cost, performance, acceptability); weights for each evaluation areas (economics, waste management, proliferation resistance, environment, safety, maturity of technology and country specifics, etc.); and, finally, weights for the lowest level, i.e. the level of key and secondary indicators. At last, the final weighting factors for each indicator will be determined by multiplication of the high-level objectives, evaluation areas, key and secondary indicators weights. Within this procedure the following restrictions should be taken into account (Fig. 1.4 demonstrates an example of the weight assessment procedure)[1].

Restrictions on weights for the high-level objectives (for instance, ‘cost’, ‘performance’, ‘acceptability’) are:

$$\sum_{i=1}^{N_h} w_h^i = 1,$$

where N_h is the number of high-level objectives, w_h^i is a weight for the i high-level objective.

Restrictions on weights for evaluation areas (economics, waste management, proliferation resistance, environment, safety, maturity of technology, country specific, etc.) are:

$$\sum_{j=1}^{N^i} w_a^{i,j} = 1,$$

where N^i is the number of areas within the i-high-level objective, $w_a^{i,j}$ is a weight for the j-evaluation area and the i-high-level objective.

Restrictions on weights at the level of indicators are:

$$\sum_{k=1}^{N^{i,j}} w_{ind}^{i,j,k} = 1 \ ,$$

[1] k_i is replaced with w_i.

where $N^{i,j}$ is the number of indicators within the *i*-high-level objective and the *j*-evaluation area, $w_{ind}^{i,j,k}$ is a weight of the *k*-indicator for the *j*-evaluation area and the *i*-high-level objective. The final weighting factors are determined as multiplication of the abovementioned weights as:

$$W^k = w_h^i \cdot w_a^{i,j} \cdot w_{ind}^{i,j,k} \quad .$$

TABLE 1.3. WEIGHTING FACTORS IDENTIFICATION METHOD IN KIND-ET

Weighting method	Evaluation algorithm	Illustration
Direct method and hierarchical weighting	An expert has to directly specify the weights for each hierarchical level and multiply down to obtain the final lower level weights.	$(w_1, w_2, ..., w_N), \sum_{i=1}^{N} w_i = 1$

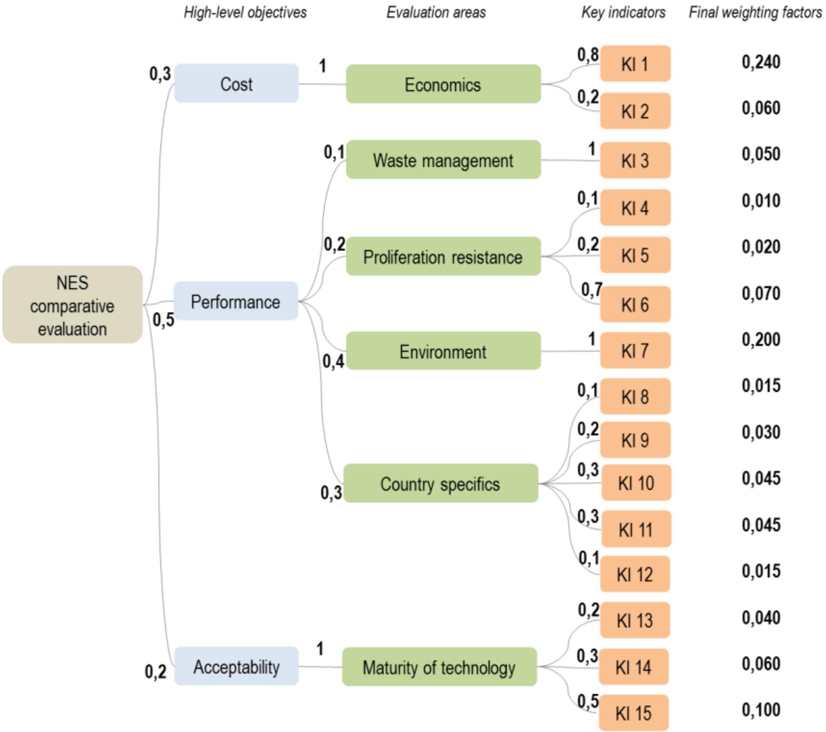


FIG. 1.4. Example of the weighting procedure implementation

Interpretation of results

While it is recommended that the MAVT method be used to support comparative evaluation of NESs including options for a more distant future, the MAVT method is only a simple means. The more important output to support decision makers is the identification (in a clear and understandable manner) of NES features that result in the identified risks and benefits.

To make a representation and explanation of ranking results more understandable, it is recommended to aggregate all performance indicators into a limited number of groups, for example, in accordance with the structure of the objectives tree. Such aggregated characteristics may serve as the high-level objectives (‘cost’, ‘performance’, ‘acceptability’) or evaluation area scores (groups corresponding to the areas of the INPRO methodology).

Experts should select the methods that provide high-quality visualization of results and conclusions. Value paths, radar chart, bar chart, pie chart are the most commonly used samples for representing ranking results and visualizations used for results interpretation.

These examples do not limit any other additional ways in which the results can be represented.

Sensitivity analysis

In the KIND-ET tool, uncertainties are examined through a sensitivity analysis. A sensitivity analysis assumes examination of sensitivity to weights values and single-attribute value function shapes. KIND-ET provides only basic necessary functionalities to perform a sensitivity analysis. Users can apply this tool for an additional analysis by adding new functions or performing serial calculations based on this Excel-template.

A weight sensitivity analysis is a tool for understanding an influence of the assigned weights on the ranking alternatives. A simple weight sensitivity analysis assumes demonstrating the alternatives ranking results for different weighting factors options.

A single-attribute value function sensitivity analysis is a means for assessing the impact of assigned single-attribute value functions on the ranks of alternatives. KIND-ET provides only a simple form of single-attribute value function sensitivity analysis demonstrating the alternatives ranks for different single-attribute value function options.

RECOMMENDATIONS FOR PERFORMING NES COMPARATIVE EVALUATIONS

The general recommendations on selecting MAVT model parameters to be implemented in a NES comparative evaluation procedure within the KIND approach is presented in Table 1.4. These recommendations are aimed at reducing the risks of alternatives' indistinguishability and ranking results' sensitivity to model parameters. These recommendations have been tested in the case studies which have demonstrated their effectiveness [5-8].

Derogations from the recommendations are not crucial and these recommendations by no means limit the possibility of choosing any other model assumptions in conducting a NES comparative evaluation. In each particular case, model parameters should be selected based on comprehensive analysis of the problem.

TABLE 1.4. RECOMMENDATIONS

Small number of NESs being compared	**Large number of NESs being compared**
Number of NESs being compared	
Up to 5	More than 5
Number of used indicators in a comparative evaluation	
Less than 20	
Role of secondary indicators	
SIs may be used for improving the resolution in case of uncertainties within a second iteration focusing more on detailed two-tier comparative evaluation procedure if a 'winner' among alternatives is required.	
Scoring scales	
Wide scoring scale or continuous scale are preferable (e.g. 10-point scoring scale)	Narrow scoring scale is preferable (e.g. 5-point scoring scale)
Objectives tree and weighting factors	
3-level objectives tree, direct method and hierarchical weighting	
Domains of single-attribute value functions	
Local domains for of single-attribute value functions are preferable	Local domains for single-attribute value functions are more preferable, but global domains provide acceptable resolution of NESs
Form of single-attribute value function	
Linear form of single-attribute value functions is acceptable as a first approximation. Risk attitudes may be accounted by using the exponential form of value functions (with identification of risk properness level by means of fifty-fifty lottery).	

2. KIND-ET EXCEL TOOL

KIND-ET FEATURES

The characteristic features of KIND-ET tool include easy usage, user-friendly interface, automation, and visualization capabilities. KIND-ET integrates different convenient options for managing and post-processing the calculation results. Following basic features were implemented in KIND-ET design and development:

Problem-orientedness and integration — KIND-ET is designed as a problem-oriented tool that combines all necessary capabilities into a single application with only one interface and common operational logic in accordance with the KIND approach.

User-friendliness and intuitive obviousness — all decision support stages (input preparation and editing, data display, calculation, automatic analysis and results processing, etc.) are reflected visually on graphical panels — separate Excel worksheets. This allows a high level of information content, easy to adapt and use, fast perception of results, and offers coupling capabilities with other calculation and visualization tools.

Automation and improvability — all operations are carried out automatically to increase the user's productivity in computation modelling. The user only needs to be aware of the problem statement while performing studies. At the same time, the unified rules of data input, calculation control and results processing are implemented.

Self-sufficiency, multifunctionality and validation — all necessary functionalities which provide high reliability of calculations are offered to the user. The algorithms were verified and validated to ensure high accuracy of calculations. KIND-ET was verified on a number of numerical examples by means of comparisons with calculations performed on commercial decision making software. It allowed confirming that this tool provides correct evaluations and may be applied for numerical case studies of the KIND project. Therefore, KIND-ET can be used as a tool for research and educational purposes.

Openness and extensibility — KIND-ET allows easy modification while keeping high user quality by providing the user with abundant opportunities to edit and expand functional capabilities. New approaches may be developed and implemented into KIND-ET in order to keep the front-end level of the tool up-to-date and comply with the advances in the KIND approach development.

MS Office and web-integration — KIND-ET is designed to provide simple possibility of data exchange with Microsoft Office applications and web-integration offering remote access. Microsoft Excel spreadsheets were chosen for KIND-ET implementation because Microsoft Excel contains a broad list of functions that can be useful to advanced users. Apart from this, Microsoft Excel is available on both Windows and Macintosh computers.

FUNCTIONALITIES AND CAPABILITIES

The decision support process goes through the following steps: problem formulation, formulation of alternatives, criteria identification, criteria evaluation, selection and implementation of MCDA method, uncertainty and sensitivity analysis, final conclusions and recommendations.

KIND-ET covers the most formal stages of the decision support process related to usage of a specific mathematical method: implementation of the MCDA method, carrying-out of an uncertainty and sensitivity analysis, formulation of final conclusions and recommendations.

The properly organized evaluation based on the MCDA paradigm studies represent a process not only formally operating with a set of mathematical methods and various analytical tools, but also leading to a comprehensive understanding of the problem and its elaboration. MCDA does not provide a 'right solution'. In this regard, it would be correct to talk about a compromise or a trade-off solution, paying special attention to analysis of the solution stability to the various methods used and their model parameters.

To perform a multi-criteria comparison using the MAVT method, which was chosen as the main method for the KIND approach, it is required to:

(1) Prepare a performance table;
(2) Determine single-attribute value functions for each indicator;
(3) Evaluate weighting factors;
(4) Perform sensitivity analysis;
(5) Interpret ranking results and formulate recommendations.

All the mentioned steps are to be specified in KIND-ET during solution of a certain problem. The following major assumptions are realized in KIND-ET by default in line with the recommendations of KIND approach [10]: Three-level objectives tree, 15 indicators, linear end exponential forms of single-attribute value functions, local and global domains of single-attribute value functions, direct method and hierarchical weighting for weighting factors assessment. Within KIND-ET, users can specify a goal for each indicator and scales for indicators evaluation at their own discretion.

THE KIND APPROACH FOR A NES COMPARATIVE EVALUATION

To perform a multi-criteria comparative evaluation using the KIND-ET tool, the users, at their own discretion, have to:

(1) Specify a set of performance indicators;
(2) Identify a structure of the objectives tree (high-level objectives, evaluation areas, indicators and their hierarchical interrelation) which specifies weighting factors assessment and results representation procedures;
(3) Prepare a performance table;
(4) Determine single-attribute value functions for each indicator;
(5) Evaluate weighting factors;
(6) Perform sensitivity analysis;
(7) Interpret ranking results and formulate recommendations.

Because of flexibility of the KIND-ET tool user has to be careful on the weighting factors assessment and results interpretation stages because the corresponding worksheets require adaptation under the structure of the user specified objectives tree. Comments regarding these stages specification are given in the corresponding sections of the document (‘Weighting factors’ and ‘Ranking results’ worksheets).

KIND-ET FILES PACKAGE

To simplify KIND-ET application, a typical Excel template (xlsx-file) was created, which provides an opportunity to comparatively evaluate 5 NESs by means of 15 indicators. It allows minimizing experts’ efforts to adapt the basic calculation template to a number of considered systems and indicators used. If it is necessary to consider more or less than 5 systems or 15 indicators, a user familiar with the basics of Microsoft Excel can easily expand the number of systems being compared by stretching the corresponding cell areas in each KIND-ET worksheet. Table 2.1 shows the main files in the KIND-ET work package.

TABLE 2.1. KIND-ET FILES PACKAGE

File	Description
Documents: user instruction and verification report	
KIND-ET_UserInstructions.pdf	User instructions
KIND-ET_VerificationReport.pdf	KIND-ET verification report
KIND-ET	
KIND-ET.xlsx	General template
Demo cases	
KIND-ET-DemoCase-5_NES-1 KIND-ET-DemoCase-5_NES-2	Numerical examples: 5 hypothetical NES comparative evaluation
KIND-ET-DemoCase-2_NES-1 KIND-ET-DemoCase-2_NES-2	Numerical examples: 2 hypothetical NES comparative evaluation
KIND-ET-DemoCase-GAINS-v1 KIND-ET-DemoCase-GAINS-v2a KIND-ET-DemoCase-GAINS-v2b KIND-ET-DemoCase-GAINS-v3 KIND-ET-DemoCase-GAINS-v4	Numerical examples: GAINS NES deployment scenarios comparative evaluation

KIND-ET APPLICATION PROCEDURE

For the KIND-ET tool application, it is required to regularly fill in necessary information (indicators values, weighting factors, and single-attribute value functions) of ‘Performance table’, ‘Weighting factors’, ‘Single-attr. value functions’ Excel worksheets containing basic input data in order to perform comparative evaluation in accordance with the MAVT method.

The evaluation results based on input information are displayed in the ‘Ranking results’ worksheet. The sensitivity analysis may be carried out by using the ‘Weights sensitivity’, ‘Value function sensitivity’ worksheets (Fig. 2.1).

FIG. 2.1. The basic Excel worksheets of KIND-ET

To improve information perception on the KIND-ET worksheets, cell-coloring is used: the cells that require inputting figures are marked in light green in the ‘Performance table’, ‘Weighting factors’, ‘Single-attr. value functions’, ‘Weights sensitivity’, ‘Value function sensitivity’ worksheets; the intermediate results of calculations are light blue in the ‘Weighting factors’, ‘Single-attr. value functions’, ‘Weights sensitivity’, ‘Value function sensitivity’ worksheets; the calculation results of multi-attribute value function and its components required for the formulation of recommendations and the ranking results interpretation for the options under consideration are light orange in the ‘Ranking results’, ‘Weights sensitivity’, ‘Value function sensitivity’ worksheets. The example below shows the file structure for 5 NES comparative evaluation.

‘Performance table’ worksheet

The ‘Performance table’ worksheet requires inputting titles and abbreviations of high-level objectives, evaluation areas and indicators, ranges for indicators (minimum and maximum scores within these ranges, all indicators should be assessed) and indicator values for NESs being considered (Fig. 2.2). This worksheet reflects the hierarchically-organized structure of the KIND indicators grouped in evaluation areas and high-level objectives.

The user should also indicate the names of the systems under consideration (by default they are called NES-1, NES-2, NES-3, etc). All titles are automatically used in all of the following worksheets. Indicators values may be evaluated in integer or real numbers.

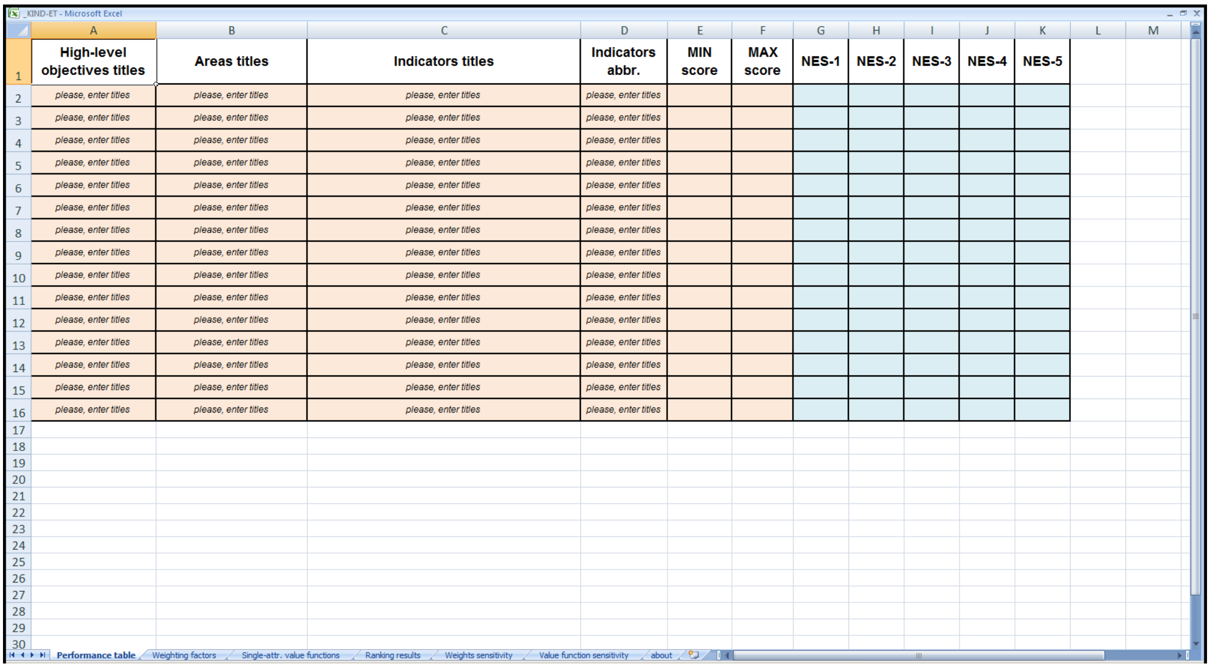


FIG. 2.2. Screenshot of the 'Performance table' worksheet

'Weighting factors' worksheet

The 'Weighting factors' worksheet assesses the final weighting factors for each indicator in accordance with the combined direct and hierarchical weighting methods (Fig. 2.3). The titles of high-level objectives, evaluation areas and indicators are automatically filled based on information indicated in 'Performance table' worksheet. This worksheet also reflects the hierarchically-organized structure of the KIND indicators grouped in evaluation areas and high-level objectives.

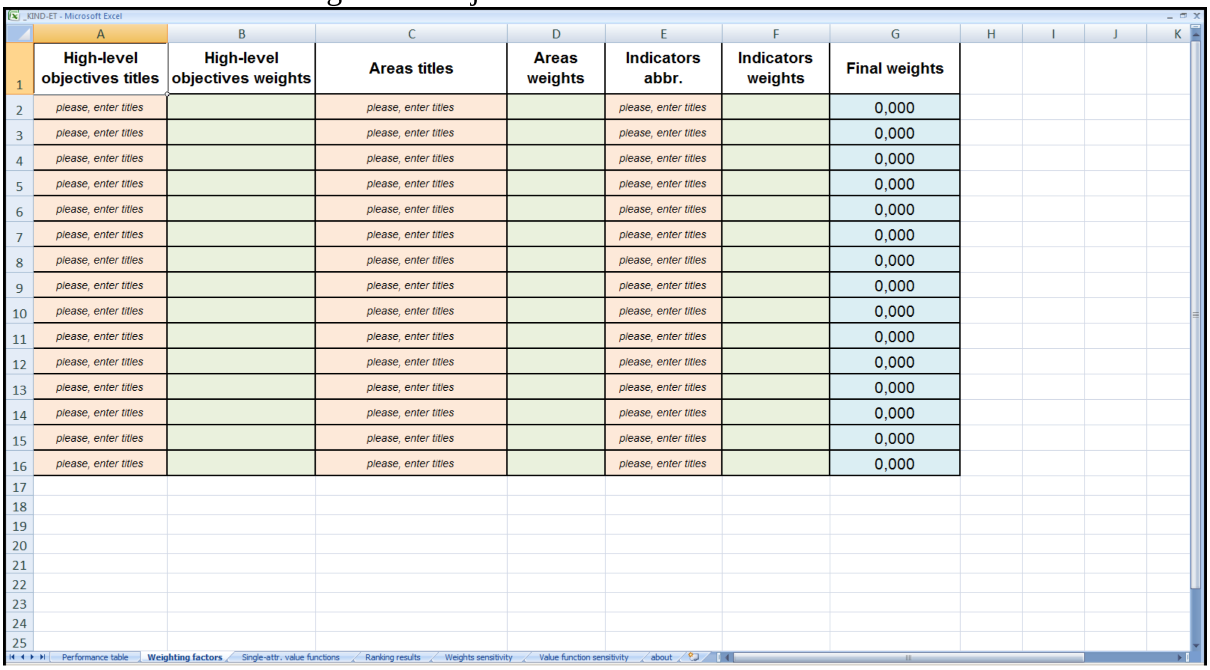
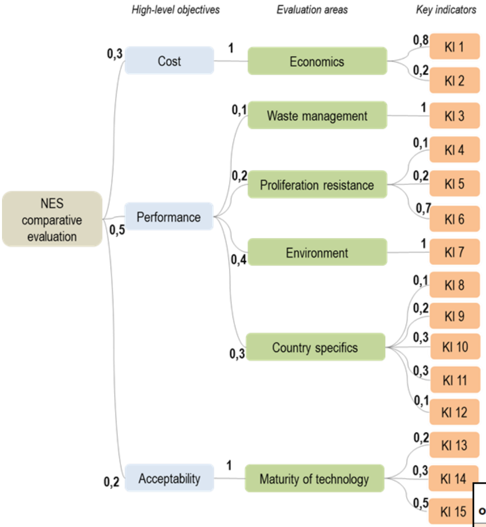


FIG. 2.3. Screenshot of the 'Weighting factors' worksheet

The user has to set the weighting factors (real numbers from 0 to 1) in the light-green cells (the significance of high-level objectives, evaluation areas and individual indicators). The final values of weighting factors are given in the light-blue column 'Final weights'. The tooltips show the input data format requirements. At each branch of the objectives tree, the sum of corresponding weighting factors must be equal to 1.

Figure 2.4 shows an example of filling the 'Weighting factors' worksheet cells which may be considered as a hint to manage with this step during the first KIND-ET application.



High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights
Cost	0,3	Economics	1	E 1	0,8
				E 2	0,2
Performance	0,5	Waste management	0,1	WM 1	1
		Proliferation resistance	0,2	PR 1	0,1
				PR 2	0,2
				PR 3	0,7
		Environment	0,4	ENV 1	1
		Country specifics	0,3	CS 1	0,1
				CS 2	0,2
				CS 3	0,3
				CS 4	0,3
				CS 5	0,1
Acceptability	0,2	Maturity of technology	1	M 1	0,2
				M 2	0,3
				M 3	0,5

High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
Cost	0,3	Economics	1	E 1	0,8	0,240
Cost	0,3	Economics	1	E 2	0,2	0,060
Performance	0,5	Waste management	0,1	WM 1	1	0,050
Performance	0,5	Proliferation resistance	0,2	PR 1	0,1	0,010
Performance	0,5	Proliferation resistance	0,2	PR 2	0,2	0,020
Performance	0,5	Proliferation resistance	0,2	PR 3	0,7	0,070
Performance	0,5	Environment	0,4	ENV 1	1	0,200
Performance	0,5	Country specifics	0,3	CS 1	0,1	0,015
Performance	0,5	Country specifics	0,3	CS 2	0,2	0,030
Performance	0,5	Country specifics	0,3	CS 3	0,3	0,045
Performance	0,5	Country specifics	0,3	CS 4	0,3	0,045
Performance	0,5	Country specifics	0,3	CS 5	0,1	0,015
Acceptability	0,2	Maturity of technology	1	M 1	0,2	0,040
Acceptability	0,2	Maturity of technology	1	M 2	0,3	0,060
Acceptability	0,2	Maturity of technology	1	M 3	0,5	0,100

FIG. 2.4. Example of filling 'Weighting factors' worksheet

'Single-attr. value functions' worksheet

The 'Single-attr. value functions' worksheet calculates the values of single-attribute value functions (Fig. 2.5). The user has to set the goals for each indicator ('min' or 'max' options), the type of single-attribute value function (linear 'lin' or exponential 'exp' forms), the type of domain of single-attribute value function (local or global domains) by selecting them from 'Goal', 'Form' and 'VF domain' columns.

For the exponential form, it is also required to set the exponent powers (risk proneness level) in the 'Exponent power' column. The evaluation results are given in the light-blue columns. By default, the 'min', 'lin', 'local' options are set for all indicators. 'MAX VF domain' and 'MIN VF domain' columns demonstrate the values of the end points for single-attribute value functions for local and global domains cases.

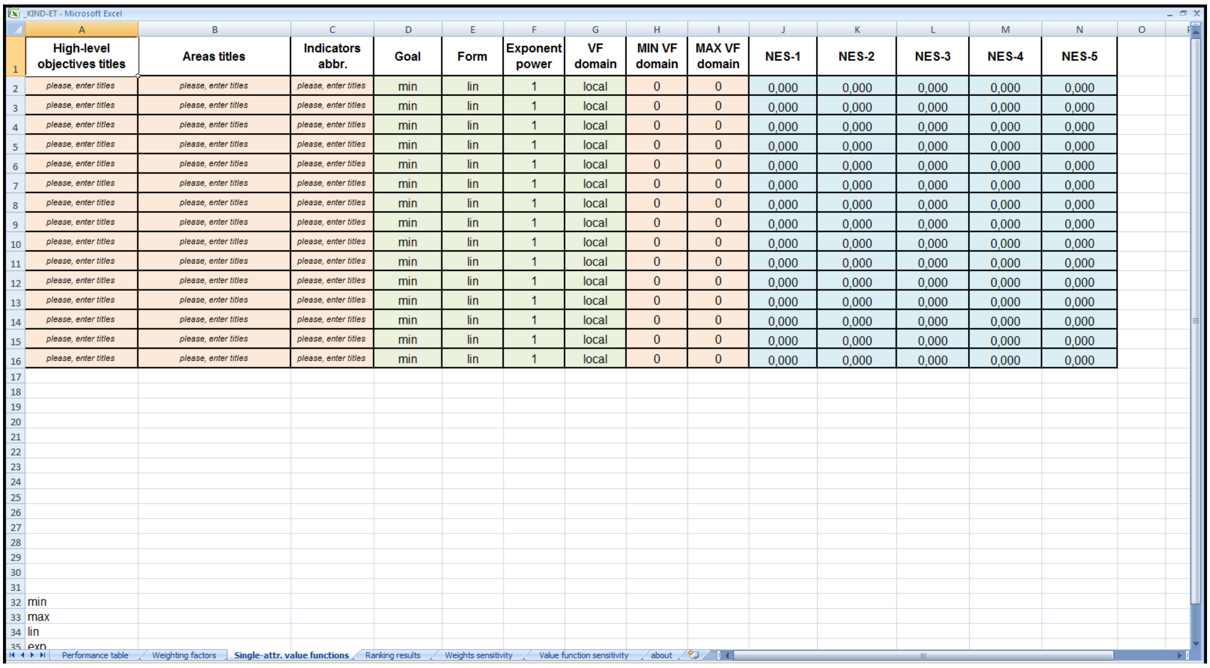


FIG. 2.5. Screenshot of the 'Single-attr. value functions' worksheet

'Ranking results' worksheet

The 'Ranking results' worksheet is the main list for interpreting the calculation results and formulating recommendations for a decision-maker regarding the more appropriate NES option identified within implementation of the decision support process (Fig. 2.6). If an outcome does not satisfy the decision-maker, analysts should return to the previous steps.

One of the possible options for interpretation of the MAVT ranking results is a decomposition of multi-attribute value functions on the individual components (for example in accordance with the structure of the objectives tree). Depending on the depth and level of details, the interpretation needs to be done and this decomposition may be performed in different ways.

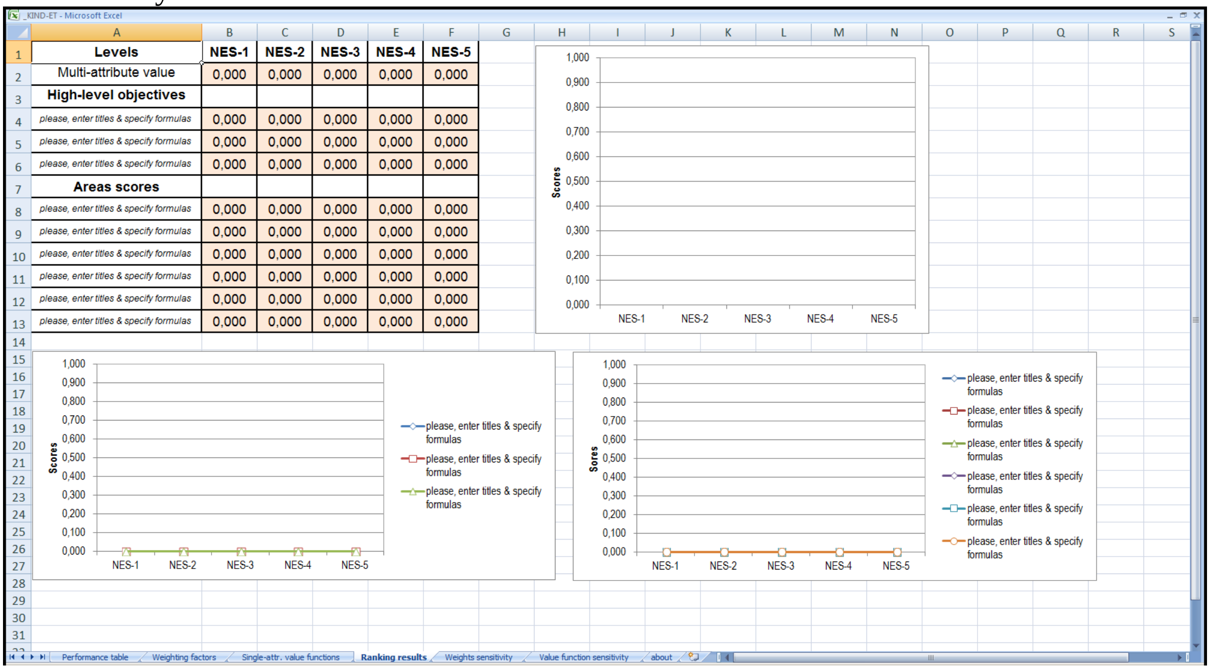


FIG. 2.6. Screenshot of the 'Ranking results' worksheet

The 'Ranking results' worksheet displays information about the scores of multi-attribute value functions and their components (if decision-makers and experts want further explanation of the reasons that have led to the dominance of one alternative over another) for the alternatives considered in tabular and graphical forms. The calculation results are visualized in the bar graph format for multi-attribute value functions and line graph format for the components of the multi-attribute value functions corresponding to the high-level objectives and evaluation area scores. These graphs clearly illustrate the high-level and area performance associated with each NES option providing an opportunity to identify high-level merits and demerits related to the considered alternatives.

A general additive form of the multi-attribute value function is as follows:

$$V(x) = \sum_{k=1}^{N} W^k \cdot V^k(x) \ ,$$

where x is a NES option, W^k and $V^k(x)$ is the final weight and single-attribute value function for k-indicator, correspondingly, and N is the total number of the indicators used.

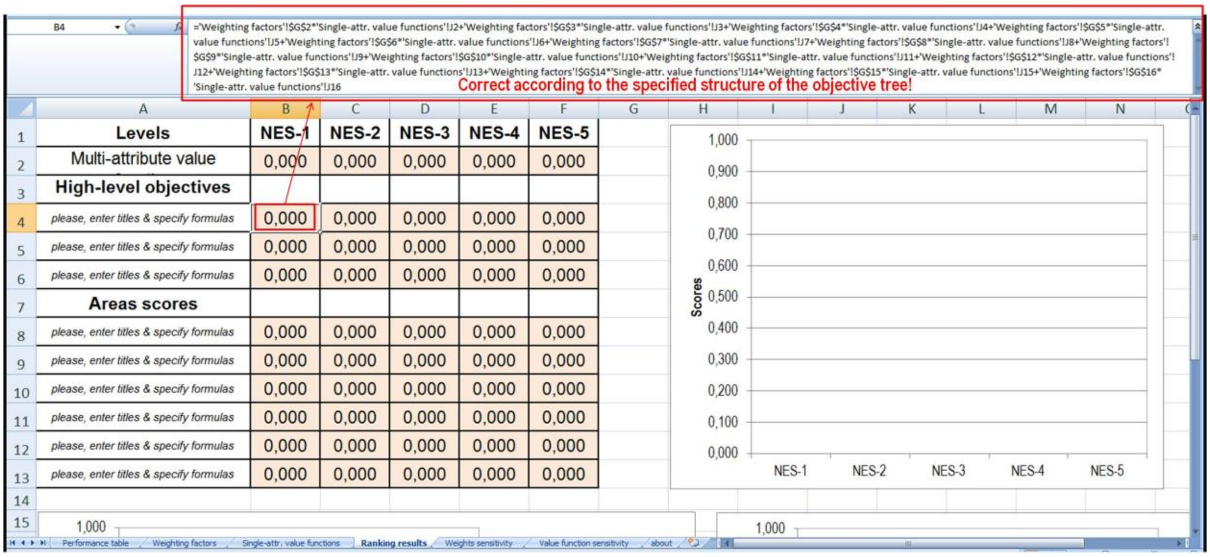
To calculate a component of a multi-attribute value function which is responsible for the representation of a certain aspect score (a high-level objective or evaluation area), it is necessary to sum only those single-attribute value functions which characterize this aspect:

$$\sum_{k=k_1}^{k_2} W^k \cdot V^k(x) \ ,$$

where x is a NES option, W^k and $V^k(x)$ is the final weight and single-attribute value function for k-indicator, k_1 and k_2 are the first and last indicator numbers under a certain aspect, respectively.

Please note: If it is necessary to evaluate components of the multi-attribute value functions by KIND-ET, the user has to specify the formulas for calculation of high-level objectives scores and area scores on the ‘Ranking results’ worksheet (Fig. 2.7(a)).

According to the specified structure of the objectives tree, the user has to create formulas by keeping only those single-attribute value functions which are responsible for the representation of the high-level objectives and evaluation area scores at the corresponding level of the objectives tree. Figure 2.7(b) provides an example of identification of indicator indexes for the indicators to be kept in the formula to evaluate high-level objectives and evaluation area scores.



(a)

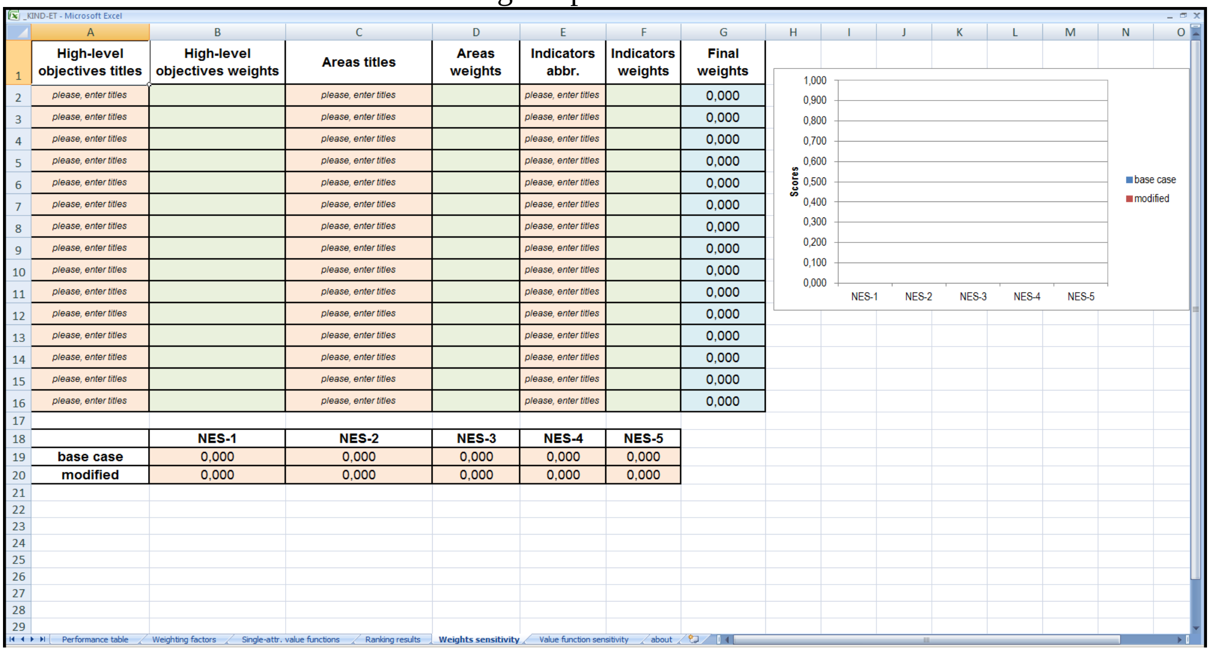
High-level objectives titles	Areas titles	Indicators abbr.	Index in formula	Overall score	High-level objectives scores			Area scores					
					Cost	Performance	Acceptabity	Economis	Waste management	Proliferation resistance	Environment	Country specifics	Maturity of technology
Cost	Economics	E.1	2	v	v			v					
		E.2	3	v	v			v					
Performance	Waste management	WM.1	4	v		v			v				
	Proliferation resistance	PR.1	5	v		v				v			
		PR.2	6	v		v				v			
		PR.3	7	v		v				v			
	Environment	ENV.1	8	v		v					v		
	Country specifics	CS.1	9	v		v						v	
		CS.2	10	v		v						v	
		CS.3	11	v		v						v	
		CS.4	12	v		v						v	
		CS.5	13	v		v						v	
Acceptability	Maturity of technology	M.1	14	v			v						v
		M.2	15	v			v						v
		M.3	16	v			v						v

(b)

FIG. 2.7. Demonstration of evaluation of high-level objectives (a) and area scores (b) at the 'Ranking results' worksheet

'Weights sensitivity' worksheet

The 'Weights sensitivity' worksheet provides a capability to carry out a simple sensitivity analysis of the weighting factors' values (Fig. 2.8). To perform this analysis, the user has to select a set of weighting factors to be changed, redefine their values and analyze how the ranking results will be changed in comparison with the base case weights options specified in the 'Weighting factors' worksheet. The corresponding values of multi-attribute value functions are titled 'base case' and 'modified' in the light-orange colored table at bottom of the worksheet and in the diagram panel.



High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000

	NES-1	NES-2	NES-3	NES-4	NES-5
base case	0,000	0,000	0,000	0,000	0,000
modified	0,000	0,000	0,000	0,000	0,000

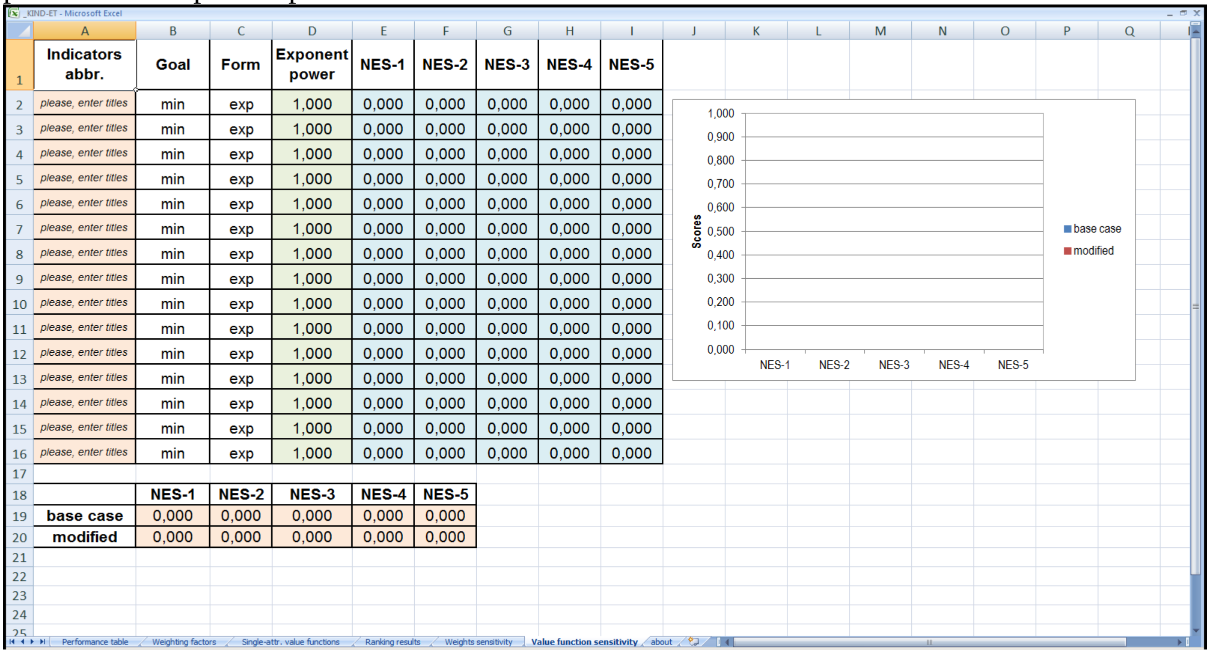
FIG. 2.8. Screenshot of the 'Weights sensitivity' worksheet

'Value function sensitivity' worksheet

The 'Value function sensitivity' worksheet provides a capability to perform a simple sensitivity analysis in regard to the forms of single-attribute value functions (Fig. 2.9). To carry out such analysis, it is required to select a set of indicators which need to be examined, renew parameters of corresponding single-attribute value functions and analyze how the ranking results will be changed in comparison with the base case option.

The corresponding values of multi-attribute value functions are titled 'base case' and 'modified' in the light-orange colored table at the bottom of worksheet and in the diagram panel. The goals are automatically set to be the same as in the 'Single-attr. value functions' worksheet.

Due to the limited functionality of KIND-ET, only the exponential forms of single-attribute value functions are considered which requires identification of only a single parameter – exponent power.



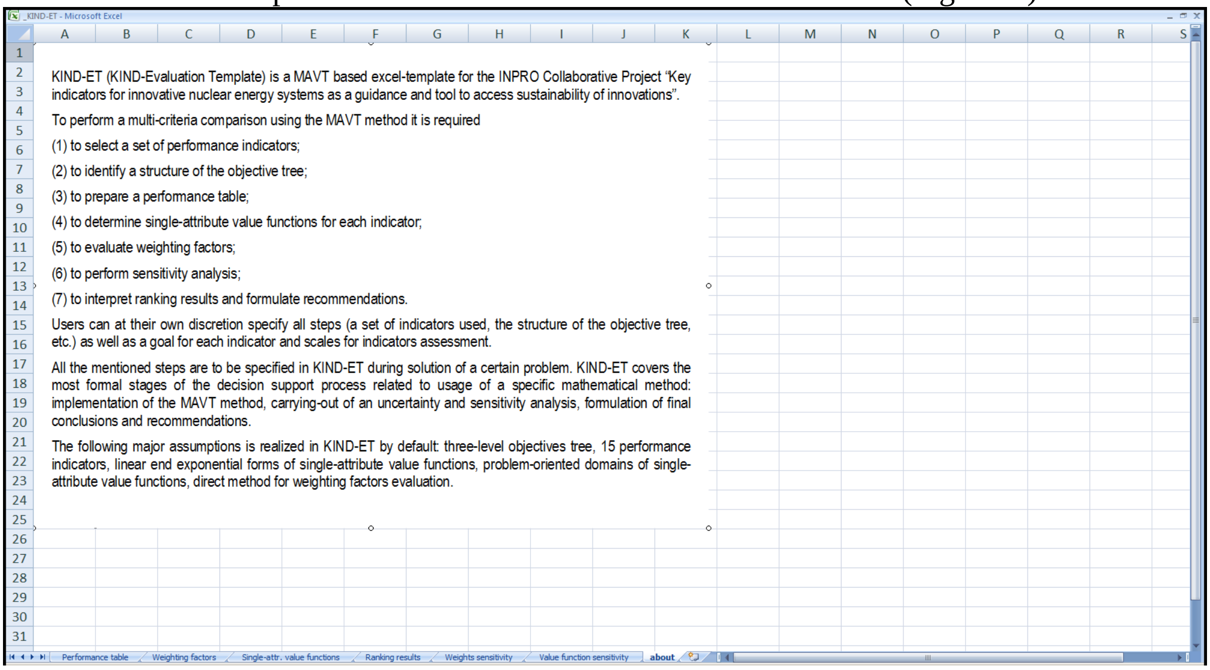
Indicators abbr.	Goal	Form	Exponent power	NES-1	NES-2	NES-3	NES-4	NES-5
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000
please, enter titles	min	exp	1,000	0,000	0,000	0,000	0,000	0,000

	NES-1	NES-2	NES-3	NES-4	NES-5
base case	0,000	0,000	0,000	0,000	0,000
modified	0,000	0,000	0,000	0,000	0,000

FIG. 2.9. *Screenshot of the 'Value function sensitivity' worksheet*

'About' worksheet

The 'About' worksheet contains a brief description of the KIND-ET tool, its basic functionalities and capabilities as well as some additional information (Fig. 2.10).



KIND-ET (KIND-Evaluation Template) is a MAVT based excel-template for the INPRO Collaborative Project "Key indicators for innovative nuclear energy systems as a guidance and tool to access sustainability of innovations".

To perform a multi-criteria comparison using the MAVT method it is required

(1) to select a set of performance indicators;

(2) to identify a structure of the objective tree;

(3) to prepare a performance table;

(4) to determine single-attribute value functions for each indicator;

(5) to evaluate weighting factors;

(6) to perform sensitivity analysis;

(7) to interpret ranking results and formulate recommendations.

Users can at their own discretion specify all steps (a set of indicators used, the structure of the objective tree, etc.) as well as a goal for each indicator and scales for indicators assessment.

All the mentioned steps are to be specified in KIND-ET during solution of a certain problem. KIND-ET covers the most formal stages of the decision support process related to usage of a specific mathematical method: implementation of the MAVT method, carrying-out of an uncertainty and sensitivity analysis, formulation of final conclusions and recommendations.

The following major assumptions is realized in KIND-ET by default: three-level objectives tree, 15 performance indicators, linear end exponential forms of single-attribute value functions, problem-oriented domains of single-attribute value functions, direct method for weighting factors evaluation.

FIG. 2.10. *Screenshot of the 'About' worksheet*

EXTENSION OF FUNCTIONALITIES

KIND-ET provides only basic and necessary functionalities to perform a multi-criteria comparative evaluation of NES options. However, users can apply this tool to an additional analysis by adding new functions or performing serial calculations based on this tool. Some useful patterns for performing additional analysis are shown below. Obviously, a set of additional functionalities should not be limited to just the ones considered in this section.

Users may propose additional options, but verification as to using corresponding options for a specific problem solution should be provided.

'Value paths' and 'radar chart' visualization of performance tables

Visualization of the performance table may be presented in the form of so-called 'value path' and 'radar chart' diagrams.

The 'value paths' diagram shows variations in the values of all KIs for the entire set of NESs and allows estimating quantitatively how much improvement in the value of one KI deteriorates the values of other KIs due to the transition from one NES to another. The procedure of NES multi-criteria comparative evaluation may be formulated by an identification of the closeness of each NES by a set of KIs to the upper limit of graph.

The 'radar chart' diagram (also known as web chart, spider chart, star chart, star plot, cobweb chart, etc.) is a graphical method of displaying multivariate data in the form of a two-dimensional chart of three or more quantitative variables represented on axes starting from the same point. The multi-criteria comparative evaluation of NESs may be formulated by an identification of the closeness of NESs by a set of KIs to the diagram center.

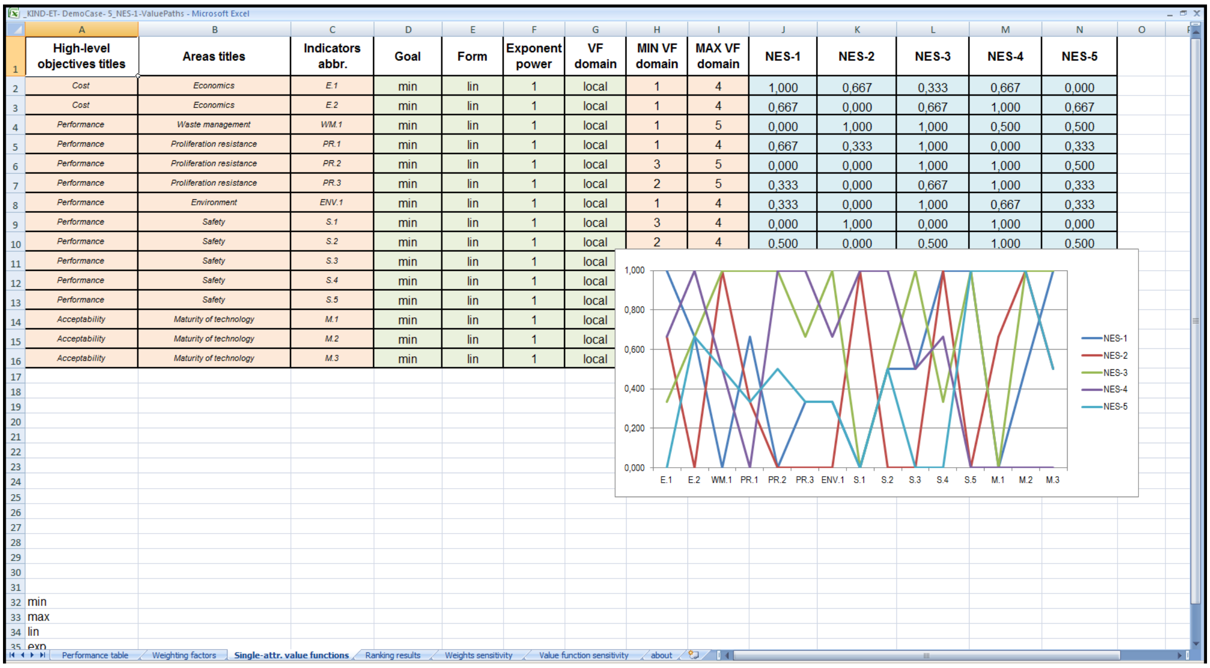
To build the 'value path' diagram in KIND-ET, it is necessary to:

- Open the 'Single-attr. value functions' sheet, to select linear forms (the 'lin' option) of a single-attribute value function for each indicator;
- Correctly identify goals for each indicator and to set these goals in the 'Goal' column;
- Evaluate the values of single-attribute value functions for each indicator and for each NES; and
- Build graphs by selecting the 'linear graphs' options in the Excel control panel.

To build the 'radar chart' diagram in KIND-ET, it is necessary to:

- Open the 'Single-attr. value functions' sheet, to select linear forms (the 'lin' option) of a single-attribute value function for each indicator;
- Correctly identify goals for each indicator and to set reverse goals in the 'Goal' column;
- Evaluate the values of single-attribute value functions for each indicator and for each NES; and
- Build graphs by selecting the 'radar charts' option in the Excel control panel.

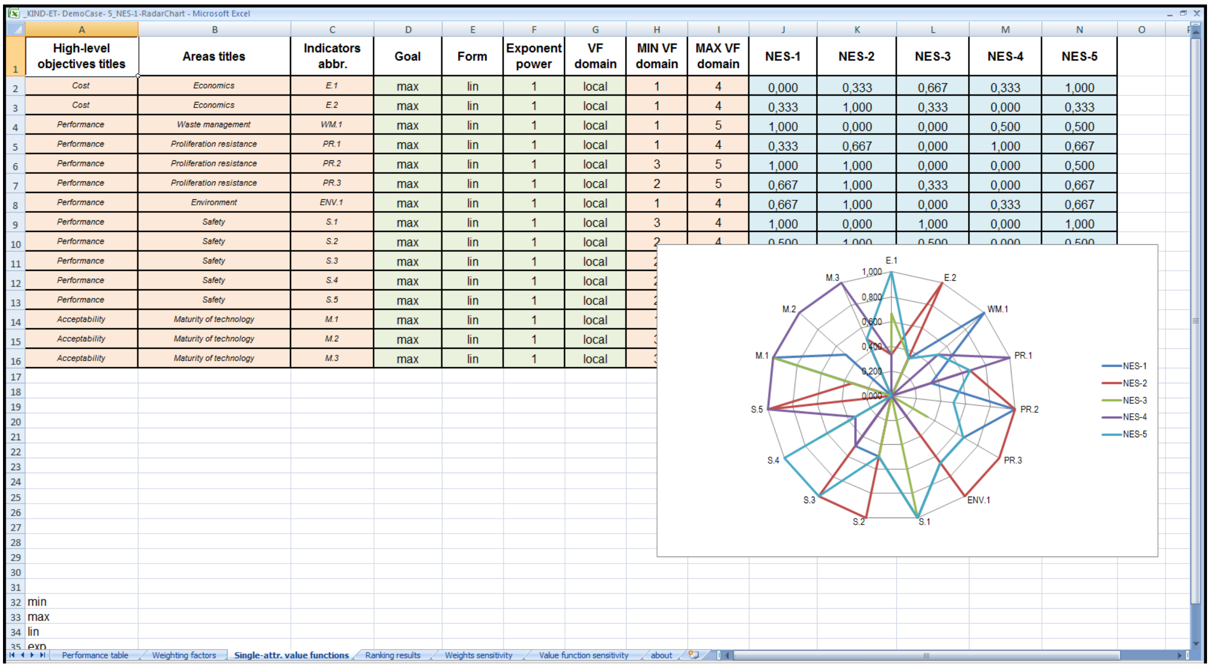
Figure 2.11(a) and (b) show the 'value paths' and 'radar chart' graphs for the cases of 5 hypothetical NES comparative evaluation.



_KIND-ET- DemoCase- 5_NES-1-ValuePaths - Microsoft Excel

High-level objectives titles	Areas titles	Indicators abbr.	Goal	Form	Exponent power	VF domain	MIN VF domain	MAX VF domain	NES-1	NES-2	NES-3	NES-4	NES-5
Cost	Economics	E.1	min	lin	1	local	1	4	1,000	0,667	0,333	0,667	0,000
Cost	Economics	E.2	min	lin	1	local	1	4	0,667	0,000	0,667	1,000	0,667
Performance	Waste management	WM.1	min	lin	1	local	1	5	0,000	1,000	1,000	0,500	0,500
Performance	Proliferation resistance	PR.1	min	lin	1	local	1	4	0,667	0,333	1,000	0,000	0,333
Performance	Proliferation resistance	PR.2	min	lin	1	local	3	5	0,000	0,000	1,000	1,000	0,500
Performance	Proliferation resistance	PR.3	min	lin	1	local	2	5	0,333	0,000	0,667	1,000	0,333
Performance	Environment	ENV.1	min	lin	1	local	1	4	0,333	0,000	1,000	0,667	0,333
Performance	Safety	S.1	min	lin	1	local	3	4	0,000	1,000	0,000	1,000	0,000
Performance	Safety	S.2	min	lin	1	local	2	4	0,500	0,000	0,500	1,000	0,500
Performance	Safety	S.3	min	lin	1	local							
Performance	Safety	S.4	min	lin	1	local							
Performance	Safety	S.5	min	lin	1	local							
Acceptability	Maturity of technology	M.1	min	lin	1	local							
Acceptability	Maturity of technology	M.2	min	lin	1	local							
Acceptability	Maturity of technology	M.3	min	lin	1	local							

(a)



_KIND-ET- DemoCase- 5_NES-1-RadarChart - Microsoft Excel

High-level objectives titles	Areas titles	Indicators abbr.	Goal	Form	Exponent power	VF domain	MIN VF domain	MAX VF domain	NES-1	NES-2	NES-3	NES-4	NES-5
Cost	Economics	E.1	max	lin	1	local	1	4	0,000	0,333	0,667	0,333	1,000
Cost	Economics	E.2	max	lin	1	local	1	4	0,333	1,000	0,333	0,000	0,333
Performance	Waste management	WM.1	max	lin	1	local	1	5	1,000	0,000	0,000	0,500	0,500
Performance	Proliferation resistance	PR.1	max	lin	1	local	1	4	0,333	0,667	0,000	1,000	0,667
Performance	Proliferation resistance	PR.2	max	lin	1	local	3	5	1,000	1,000	0,000	0,000	0,500
Performance	Proliferation resistance	PR.3	max	lin	1	local	2	5	0,667	1,000	0,333	0,000	0,667
Performance	Environment	ENV.1	max	lin	1	local	1	4	0,667	1,000	0,000	0,333	0,667
Performance	Safety	S.1	max	lin	1	local	3	4	1,000	0,000	1,000	0,000	1,000
Performance	Safety	S.2	max	lin	1	local	2	4	0,500	1,000	0,500	0,000	0,500
Performance	Safety	S.3	max	lin	1	local							
Performance	Safety	S.4	max	lin	1	local							
Performance	Safety	S.5	max	lin	1	local							
Acceptability	Maturity of technology	M.1	max	lin	1	local							
Acceptability	Maturity of technology	M.2	max	lin	1	local							
Acceptability	Maturity of technology	M.3	max	lin	1	local							

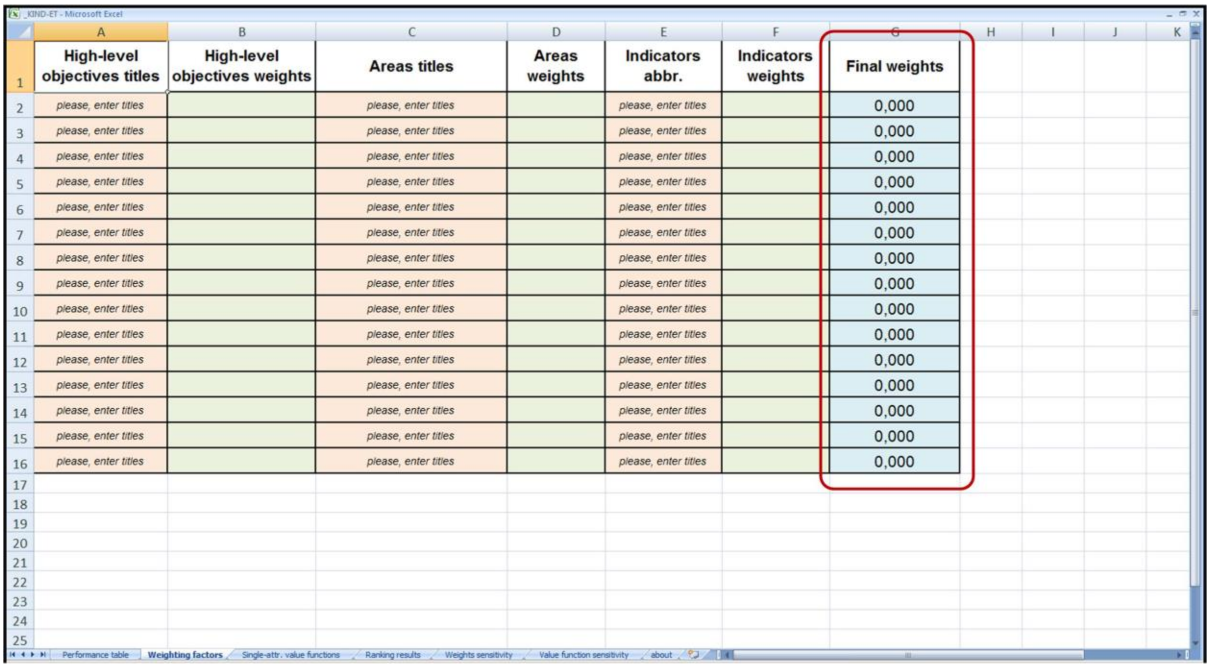
(b)

FIG. 2.11.Visualization of the 'value paths' (a) and 'radar chart' (b) for the demo case of 5 hypothetical NES comparison

Implementation of additional weighting factors identification methods

Any other methods of weighting factors assessment may be used within KIND-ET, such as the rating, ranking, pairwise comparisons, and swing methods. The corresponding weights should be identified by using external tools and afterwards be introduced to the 'Weighting factors' sheet replacing the column containing final weights. Figure 2.12 shows the area on the 'Weighting factors' sheet that requires changing.

It should be noted that to come again to the direct method implemented in the KIND-ET, it is necessary to return to the corresponding formulas in the column containing final weights.



High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000
please, enter titles		please, enter titles		please, enter titles		0,000

FIG. 2.12. Screenshot of the 'Weighting factors' worksheet

Modeling 1-, 2-, 3-level objectives trees

Notwithstanding that in KIND-ET a 3-level objectives tree is assumed by default, it is possible to use this tool for a comparative evaluation based on 1- or 2-level objectives trees. Figure 2.13 demonstrates screenshots of the 'Weighting factors' worksheet for (a) 1-level objectives tree, (b) 2-level objectives tree, and (c) 3-level objectives tree.

If it is necessary to construct a 2-level objectives tree, unity should be placed in all cells of the 'High-level objectives weights' column.

If it is necessary to construct 1-level objectives tree, unity should be placed in all cells of the 'High-level objectives weights' and 'Areas weights' columns.

To check the correctness of identifying the final weighting factors, it is necessary to calculate the sum of the final weights; it must be equal to unity.

High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
	1,000		1,000	E.1	0,053	0,053
	1,000		1,000	E.2	0,053	0,053
	1,000		1,000	WM.1	0,053	0,053
	1,000		1,000	WM.2	0,053	0,053
	1,000		1,000	WM.3	0,053	0,053
	1,000		1,000	PR.1	0,053	0,053
	1,000		1,000	PR.2	0,053	0,053
	1,000		1,000	PR.3	0,053	0,053
	1,000		1,000	PR.4	0,053	0,053
	1,000		1,000	ENV.1	0,053	0,053
	1,000		1,000	S.1	0,053	0,053
	1,000		1,000	S.2	0,053	0,053
	1,000		1,000	S.3	0,053	0,053
	1,000		1,000	S.4	0,053	0,053
	1,000		1,000	S.5	0,053	0,053
	1,000		1,000	M.1	0,053	0,053
	1,000		1,000	M.2	0,053	0,053
	1,000		1,000	M.3	0,053	0,053
	1,000		1,000	M.4	0,053	0,053

(a)

High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
	1,000	Economics	0,167	E.1	0,5	0,083
	1,000	Economics	0,167	E.2	0,5	0,083
	1,000	Waste management	0,167	WM.1	0,333	0,056
	1,000	Waste management	0,167	WM.2	0,333	0,056
	1,000	Waste management	0,167	WM.3	0,333	0,056
	1,000	Proliferation resistance	0,167	PR.1	0,250	0,042
	1,000	Proliferation resistance	0,167	PR.2	0,250	0,042
	1,000	Proliferation resistance	0,167	PR.3	0,250	0,042
	1,000	Proliferation resistance	0,167	PR.4	0,250	0,042
	1,000	Environment	0,167	ENV.1	1	0,167
	1,000	Safety	0,167	S.1	0,2	0,033
	1,000	Safety	0,167	S.2	0,2	0,033
	1,000	Safety	0,167	S.3	0,2	0,033
	1,000	Safety	0,167	S.4	0,2	0,033
	1,000	Safety	0,167	S.5	0,2	0,033
	1,000	Maturity of technology	0,167	M.1	0,25	0,042
	1,000	Maturity of technology	0,167	M.2	0,25	0,042
	1,000	Maturity of technology	0,167	M.3	0,25	0,042
	1,000	Maturity of technology	0,167	M.4	0,25	0,042

(b)

High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
Cost	0,333	Economics	1	E.1	0,5	0,167
Cost	0,333	Economics	1	E.2	0,5	0,167
Performance	0,333	Waste management	0,25	WM.1	0,333	0,028
Performance	0,333	Waste management	0,25	WM.2	0,333	0,028
Performance	0,333	Waste management	0,25	WM.3	0,333	0,028
Performance	0,333	Proliferation resistance	0,25	PR.1	0,250	0,021
Performance	0,333	Proliferation resistance	0,25	PR.2	0,250	0,021
Performance	0,333	Proliferation resistance	0,25	PR.3	0,250	0,021
Performance	0,333	Proliferation resistance	0,25	PR.4	0,250	0,021
Performance	0,333	Environment	0,25	ENV.1	1	0,083
Performance	0,333	Safety	0,25	S.1	0,2	0,017
Performance	0,333	Safety	0,25	S.2	0,2	0,017
Performance	0,333	Safety	0,25	S.3	0,2	0,017
Performance	0,333	Safety	0,25	S.4	0,2	0,017
Performance	0,333	Safety	0,25	S.5	0,2	0,017
Acceptability	0,333	Maturity of technology	1	M.1	0,25	0,083
Acceptability	0,333	Maturity of technology	1	M.2	0,25	0,083
Acceptability	0,333	Maturity of technology	1	M.3	0,25	0,083
Acceptability	0,333	Maturity of technology	1	M.4	0,25	0,083

(c)

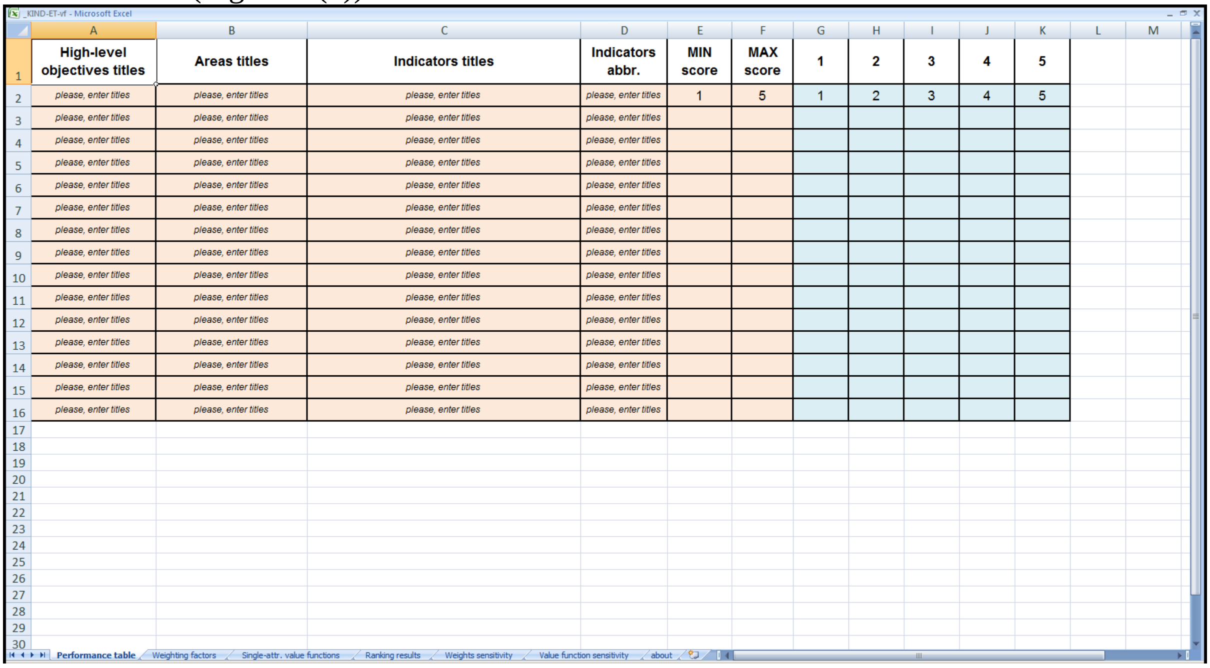
FIG. 2.13. Screenshots of the 'Weighting factors' worksheet for 1-level objectives tree (a), 2-level objectives tree (b) and 3-level objectives tree (c).

Visualization of the single attribute value function shape

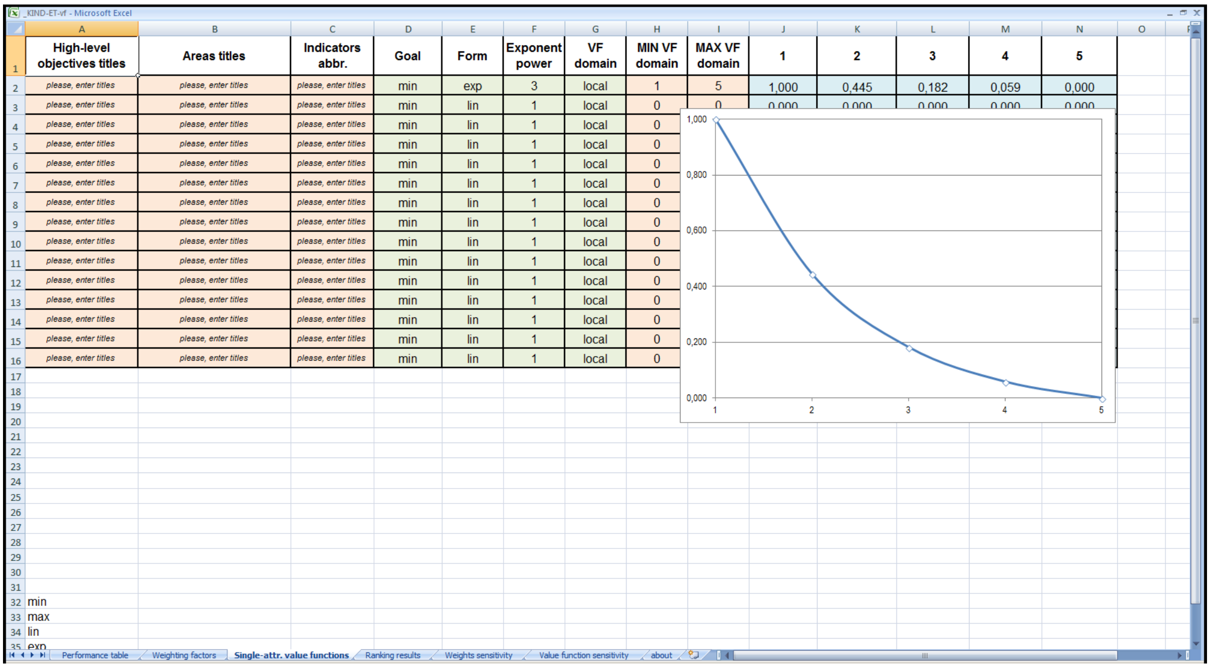
KIND-ET may be used to visualize a single-attribute value function shape. Such graphical information may be included in the final report on a certain case study especially when nonlinear single-attribute value functions are used reflecting different risk attitudes in regard to indicators.

To build a graph of a single-attribute value function, it is necessary to set indicator values at the 'Performance table' worksheet for which this single-attribute value function should be calculated (Fig. 2.14(a)), to select a type of the single-attribute value function at the

'Single-attr. value functions' worksheet, and finally to build a graph of the single-attribute value function (Fig. 2.14(b)).



(a)



(b)

FIG. 2.14. Screenshots of the KIND-ET worksheets with necessary information for visualizing a single-attribute value function

'Linear weights' approach for weights sensitivity analysis

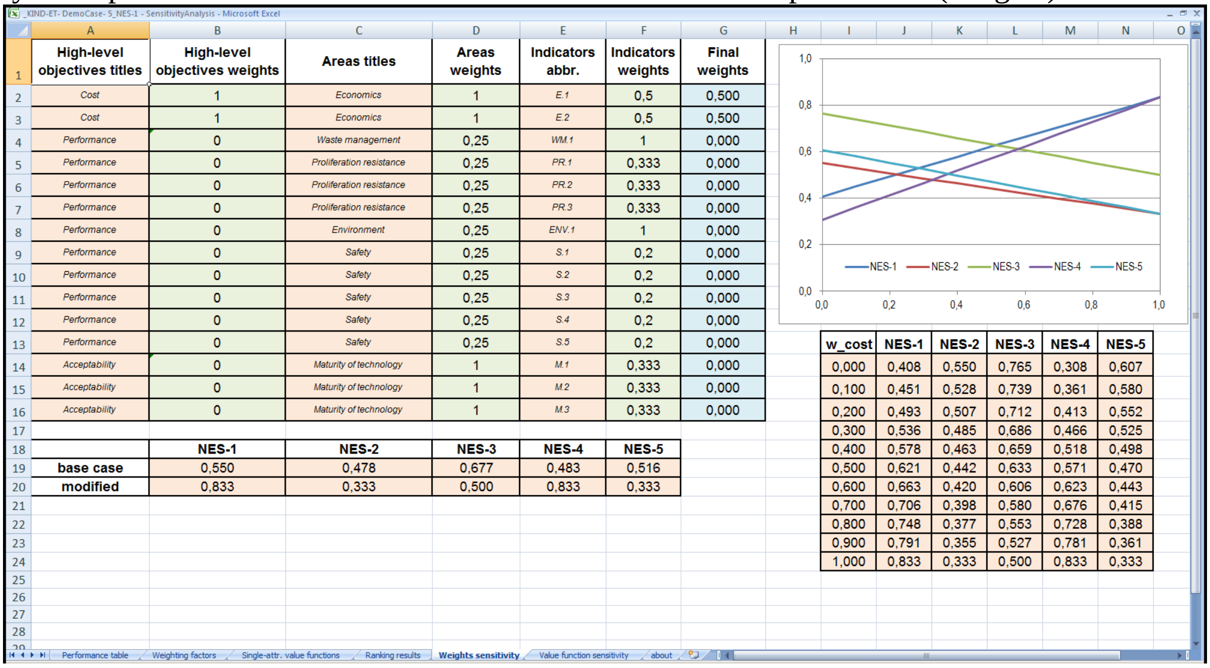
A more detailed analysis demonstrating the alternatives ranks sensitivity to the possible values of weighting factors may be presented using the 'linear weight' approach. This analysis may be carried out for the weighting factors on each level of the objectives tree: the high-level aggregated objectives, an evaluation area level, and an individual indicator level.

In the framework of the 'linear weight' approach, the expert can choose an aspect for a weight sensitivity analysis and analyze how the ranking alternatives will change with a weighting factor changing from 0 to 1 (other weights are automatically changed proportionally holding the weight sum equal to unity, Fig. 2.15):

$$w_j = w_j^0 \cdot \frac{1-w_i}{1-w_i^0}\text{, where } \{w_j^0\} \text{ and } \{w_j\} - \text{initial and modified weights}.$$

Corresponding graphs show the overall scores (values of multi-attribute value functions) for each alternative as a function of the corresponding weighting factor value. Based on this information, the ranks of alternatives may be identified for different weighting factor values as well as the weighting factor areas may be obtained providing the same ranking result.

To implement the KIND-ET tool for realization of the ‘linear weights’ approach in a weights sensitivity analysis, it is required to perform a repeated simulation of the studied system specified in KIND-ET for different values of variable parameters (weights).



High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
Cost	1	Economics	1	E.1	0,5	0,500
Cost	1	Economics	1	E.2	0,5	0,500
Performance	0	Waste management	0,25	WM.1	1	0,000
Performance	0	Proliferation resistance	0,25	PR.1	0,333	0,000
Performance	0	Proliferation resistance	0,25	PR.2	0,333	0,000
Performance	0	Proliferation resistance	0,25	PR.3	0,333	0,000
Performance	0	Environment	0,25	ENV.1	1	0,000
Performance	0	Safety	0,25	S.1	0,2	0,000
Performance	0	Safety	0,25	S.2	0,2	0,000
Performance	0	Safety	0,25	S.3	0,2	0,000
Performance	0	Safety	0,25	S.4	0,2	0,000
Performance	0	Safety	0,25	S.5	0,2	0,000
Acceptability	0	Maturity of technology	1	M.1	0,333	0,000
Acceptability	0	Maturity of technology	1	M.2	0,333	0,000
Acceptability	0	Maturity of technology	1	M.3	0,333	0,000

	NES-1	NES-2	NES-3	NES-4	NES-5
base case	0,550	0,478	0,677	0,483	0,516
modified	0,833	0,333	0,500	0,833	0,333

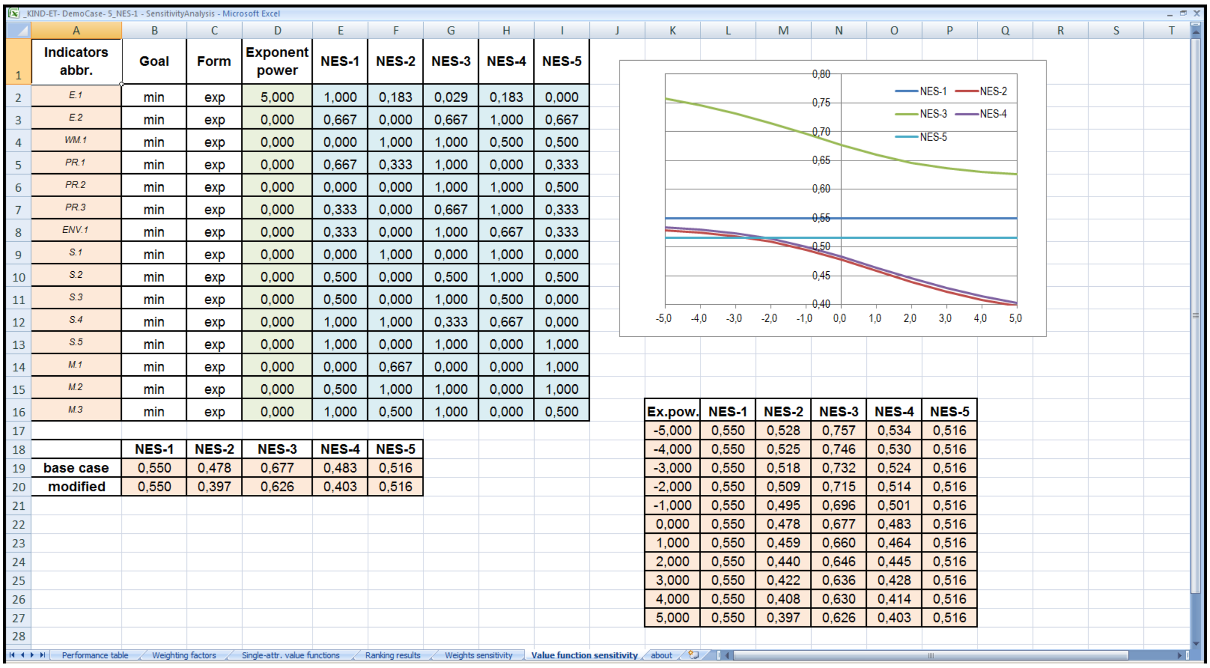
w_cost	NES-1	NES-2	NES-3	NES-4	NES-5
0,000	0,408	0,550	0,765	0,308	0,607
0,100	0,451	0,528	0,739	0,361	0,580
0,200	0,493	0,507	0,712	0,413	0,552
0,300	0,536	0,485	0,686	0,466	0,525
0,400	0,578	0,463	0,659	0,518	0,498
0,500	0,621	0,442	0,633	0,571	0,470
0,600	0,663	0,420	0,606	0,623	0,443
0,700	0,706	0,398	0,580	0,676	0,415
0,800	0,748	0,377	0,553	0,728	0,388
0,900	0,791	0,355	0,527	0,781	0,361
1,000	0,833	0,333	0,500	0,833	0,333

FIG. 2.15. Screenshot of the ‘Weights sensitivity’ worksheet with the realization of the ‘linear weights’ approach

Parametric value function sensitivity analysis

A parametric analysis examines an impact of variation in a single model parameter on the ranking results: if the induced variation does not change the ranking results, these results are considered robust.

Within KIND-ET, a parametric value function sensitivity analysis may be carried out in the following way. The exponent power (risk proneness level) of a certain single-attribute value function is varied within a given range and NES overall scores are saved in a separate table for further building a graph of NES overall scores as a function of the given exponent power. Based on this graph, it is possible to observe rank reversing as an impact on change in risk attitudes with regard to a certain indicator (Fig. 2.16).



Indicators abbr.	Goal	Form	Exponent power	NES-1	NES-2	NES-3	NES-4	NES-5
E.1	min	exp	5,000	1,000	0,183	0,029	0,183	0,000
E.2	min	exp	0,000	0,667	0,000	0,667	1,000	0,667
WM.1	min	exp	0,000	0,000	1,000	1,000	0,500	0,500
PR.1	min	exp	0,000	0,667	0,333	1,000	0,000	0,333
PR.2	min	exp	0,000	0,000	0,000	1,000	1,000	0,500
PR.3	min	exp	0,000	0,333	0,000	0,667	1,000	0,333
ENV.1	min	exp	0,000	0,333	0,000	1,000	0,667	0,333
S.1	min	exp	0,000	0,000	1,000	0,000	1,000	0,000
S.2	min	exp	0,000	0,500	0,000	0,500	1,000	0,500
S.3	min	exp	0,000	0,500	0,000	1,000	0,500	0,000
S.4	min	exp	0,000	1,000	1,000	0,333	0,667	0,000
S.5	min	exp	0,000	1,000	0,000	1,000	0,000	1,000
M.1	min	exp	0,000	0,000	0,667	0,000	0,000	1,000
M.2	min	exp	0,000	0,500	1,000	1,000	0,000	1,000
M.3	min	exp	0,000	1,000	0,500	1,000	0,000	0,500

	NES-1	NES-2	NES-3	NES-4	NES-5
base case	0,550	0,478	0,677	0,483	0,516
modified	0,550	0,397	0,626	0,403	0,516

Ex.pow.	NES-1	NES-2	NES-3	NES-4	NES-5
-5,000	0,550	0,528	0,757	0,534	0,516
-4,000	0,550	0,525	0,746	0,530	0,516
-3,000	0,550	0,518	0,732	0,524	0,516
-2,000	0,550	0,509	0,715	0,514	0,516
-1,000	0,550	0,495	0,696	0,501	0,516
0,000	0,550	0,478	0,677	0,483	0,516
1,000	0,550	0,459	0,660	0,464	0,516
2,000	0,550	0,440	0,646	0,445	0,516
3,000	0,550	0,422	0,636	0,428	0,516
4,000	0,550	0,408	0,630	0,414	0,516
5,000	0,550	0,397	0,626	0,403	0,516

FIG. 2.16. Screenshot of the 'Value function sensitivity' worksheet with the realization of parametric value function sensitivity analysis

VALIDATION AND VERIFICATION

Initially KIND-ET was developed in Microsoft Office Excel 2007 and has been tested in the following versions for Windows: Excel 2002 (Microsoft Office XP), Excel 2003 (Microsoft Office 2003), Excel 2007 (Microsoft Office 2007), Excel 2010 (Microsoft Office 2010), Excel 2013 (Microsoft Office 2013) and Excel 2014 (Microsoft Office 2014).

To verify the KIND-ET tool, a series of verification calculations were performed using some software tools for decision support as well as the software developed within the KIND project [10] that helped to ensure correct operation and workability of the Excel-template to solve the problems. The results of verification of KIND-ET are presented in the verification report [11].

This verification report contains a description of model assumptions and initial data for demo-cases (numerical case studies) as well as calculation results obtained both in original studies carried out within the KIND project and performed under KIND-ET. In case of necessity, relevant calculations may be reproduced by any other software tools to justify presented evaluations. To enlarge the scope of KIND-ET verification, a set of demo-cases may be expanded that is reasonable in justification of KIND-ET applications for other tasks. The performed verifications confirm that the KIND-ET tool provides correct evaluations and can be used for numerical case studies within the KIND project.

3. DEMO CASES

The KIND approach may be applied both to nuclear technologies and NES deployment scenario comparative evaluation. KIND-ET may be tailored for these types of comparative evaluation studies as well. In this regard, it is especially important to provide demonstration of the KIND-ET application for different groups of numerical studies.

This section presents such examples of KIND-ET application to three groups of different demo-cases prepared as part of the KIND project:

– Five hypothetical NES comparative evaluation, i.e. demonstration of a two-tier NES comparative evaluation procedure (Major assumptions: a 3-level objectives tree, 15 key and 15 secondary indicators, linear decreasing single-attribute value functions);
– Two hypothetical NES comparative evaluation, i.e. demonstration of two NES comparative evaluation specifics using different scoring scales and domains of single-attribute value functions (Major assumptions: a 3-level objectives tree, 19 key indicators, linear increasing single-attribute value functions);
– GAINS scenarios comparative evaluation, i.e. demonstration of the KIND approach application for NES deployment scenarios comparative evaluation (major assumptions: a 1-level objectives tree, 11 NES scenarios, 9 key indicators, linear decreasing single-attribute value functions).

These demo-cases are based on different assumptions regarding the number of used indicators, structure of the objectives tree, different scoring scales for indicators evaluation and different single-attribute value function shapes. All demo cases illustrate the basic MCDA steps that must be completed to perform NES comparative evaluation: formation of a performance table, assessment of weighting factors and other model parameters, carrying out evaluations and sensitivity analysis, and interpretation of the evaluation results. These numerical demo-cases were well documented and described in the KIND project materials. In this regard, only short description of the considered demo-cases is given below.

This section provides just screenshots of the all KIND-ET case study worksheets (‘Performance table’, ‘Weighting factors’, ‘Single-attr. value functions’, ‘Ranking results’, ‘Weights sensitivity’, ‘Value function sensitivity’) for the elaborated groups of demo-cases with minimum additional comments and discussions. Corresponding Excel files are distributed within the KIND-ET files package and may be run, analyzed and modified by the interested users.

A more detailed consideration of these studies can be found in Refs [5-8, 10] and in the KIND-ET verification report [11], which also contains descriptions of model assumptions and initial data for demo-cases as well as calculation results obtained both in original studies carried out within the KIND project and by KIND-ET.

The presented examples demonstrate the basic steps to be completed by KIND-ET for the NES multi-criteria comparative evaluation within the KIND approach and represent a possible template for the calculation results presentation and interpretation that may be implemented in comparing real systems.

KIND-ET was verified on these numerical examples which were elaborated within the KIND project. The calculations carried out in these studies were performed by means of commercial decision making software or specialized computational codes. The verification performed confirms that the KIND-ET tool provides correct evaluations and can be used for numerical case studies within the KIND project.

FIVE HYPOTHETICAL NES COMPARATIVE EVALUATION

A comparative evaluation of five hypothetical NESs demonstrates a two-tier comparative evaluation procedure. A two-tier evaluation procedure assumes that secondary indicators can be used at the final selection stage to eliminate the indistinguishability of alternatives which was not resolved by key indicators. Within the study for illustrative purposes, it was assumed that a set of unnamed 15 key and 15 secondary indicators are given (all indicators should be minimized). Fifteen key and 15 secondary indicators were used within the first and second tier of comparative evaluation procedure, respectively. These performance indicators were grouped in six evaluation areas and three high-level objectives. The performance table was formed randomly (Figs 3.1 and 3.2).

The following model parameters were selected in line with the KIND recommendations: linear decreasing single-attribute value functions with local domains were applied with the end points defined from the performance table; 5- and 10- point scoring scales for indicators' evaluation were used within the first and second tier of comparative evaluation procedure, respectively. The only assumption that was made to assess weight values is that at each level of the objectives tree, significance or importance of all high-level objectives, the evaluation areas and indicators appear identical.

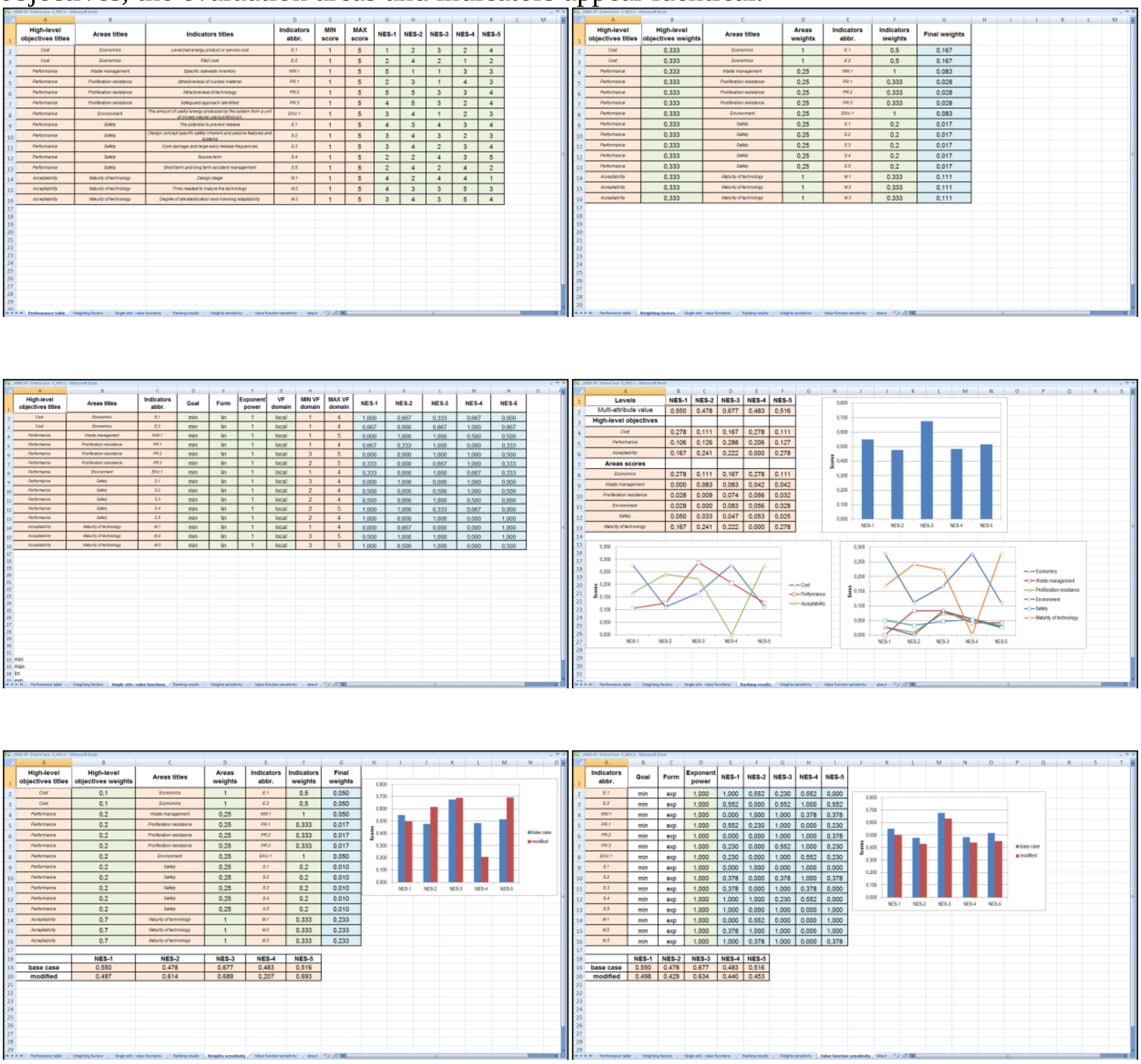


FIG. 3.1. Screenshots of the case study worksheets: The first tier of two-tier comparative evaluation procedure

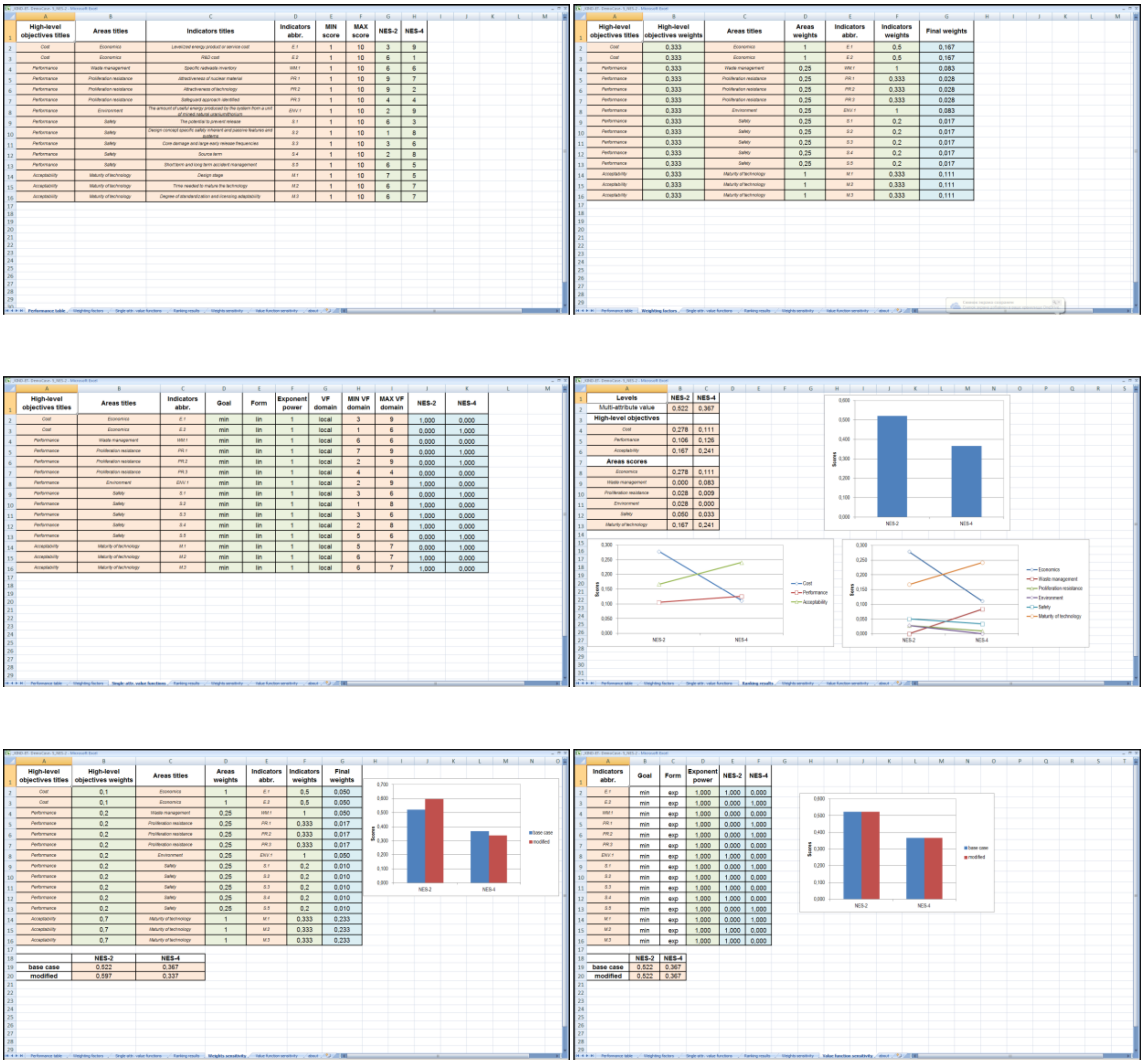


FIG. 3.2. Screenshots of the case study worksheets: The second tier of two-tier comparative evaluation procedure

TWO HYPOTHETICAL NES COMPARATIVE EVALUATION

A comparative evaluation of two hypothetical NESs demonstrates two NES comparative evaluation specifics using different scoring scales and domains of single-attribute value function. A comparative evaluation of two hypothetical NESs was performed in accordance with the following assumptions: 19 unspecified key indicators were involved in the comparative evaluation procedure, which were grouped into six evaluation areas and three high-level objectives. Each indicator was assessed in 2-point scoring scales. Linear increasing functions defined on the local domains were chosen as single-attribute value functions for the base case option. The only assumption that was made to assess weight values is that at each level of the objectives tree, significance or importance of all high-level objectives, the areas of evaluation and indicators appear identical (Figs 3.3 and 3.4).

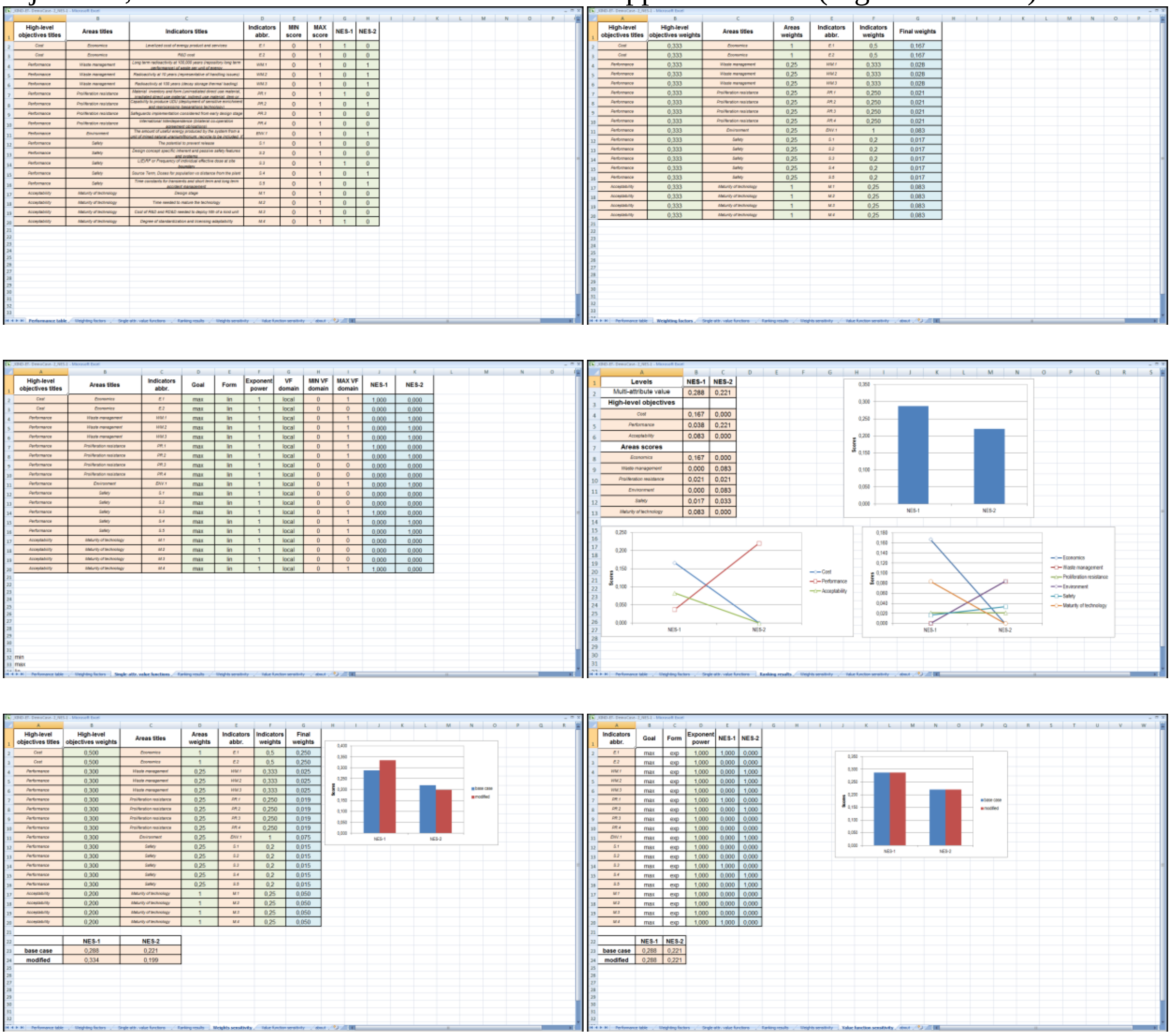


FIG. 3.3. Screenshots of the case study worksheets: Two NES comparative evaluation using 2-point scoring scale

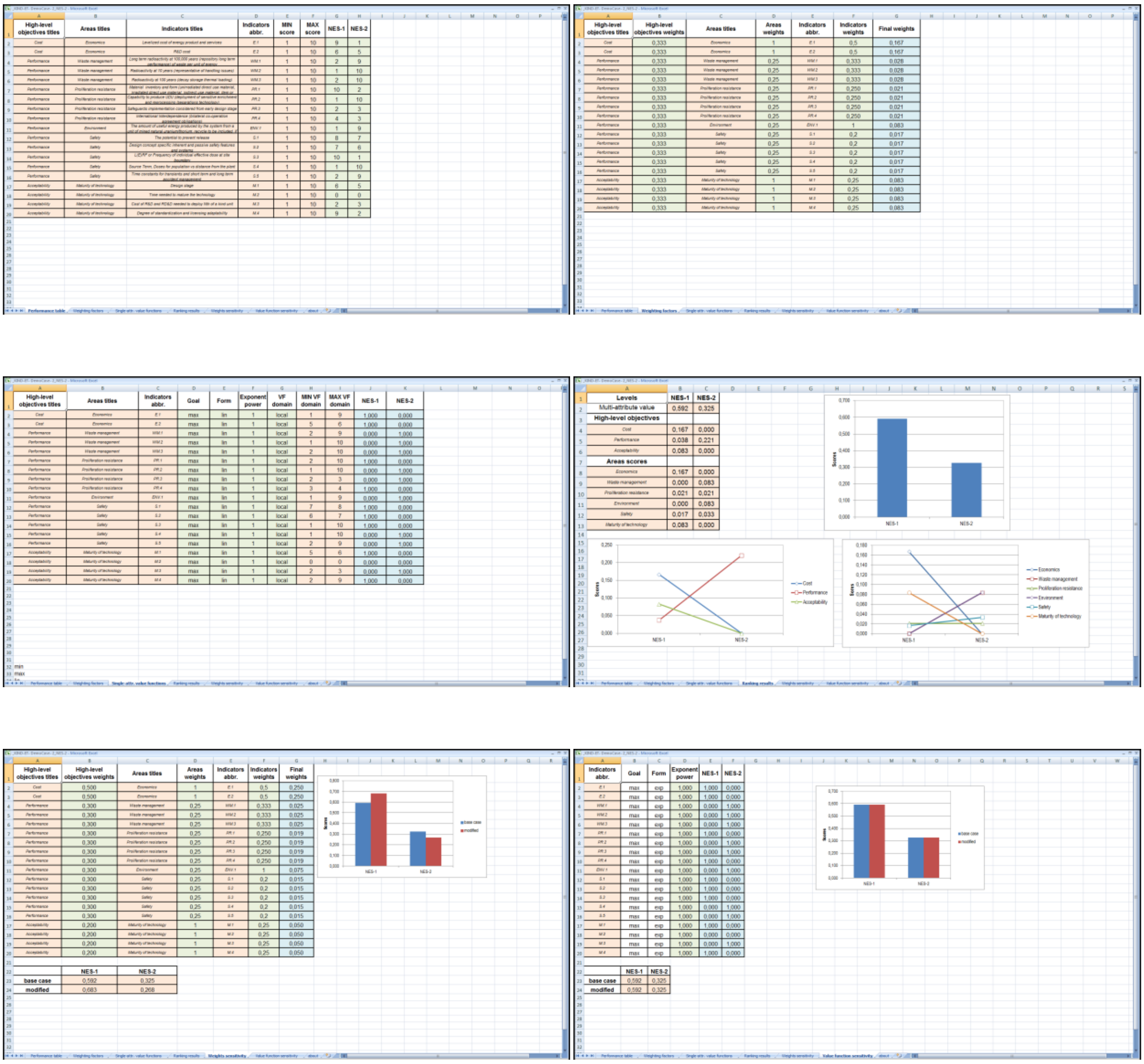


FIG. 3.4. Screenshots of the case study worksheets: Two NES comparative evaluation using 10-point scoring scale

GAINS SCENARIOS COMPARATIVE EVALUATION

A case study on application of some well-known MCDA methods for comparative evaluation of the NES deployment scenarios analyzed in the framework of the INPRO collaborative project on Global Architecture of Innovative Nuclear Energy Systems Based on Thermal and Fast Reactors Including a Closed Fuel Cycle (GAINS) was carried out to examine applicability of the KIND approach to NES deployment scenarios. Among more than 55 NES evolution scenarios considered in the GAINS project, 11 scenarios were selected for the study. A set of 9 key indicators (all indicators should be minimized) defined in GAINS was used. Five weighting options were considered reflecting possible experts' preferences regarding desirable goals that NES evolution scenarios should achieve: equal significance of all key indicators (variant #1); expert preferences based on the questionnaires distributed at the INPRO meetings (variant #2a and variant #2b); preference to investments minimization (variant #3); preference to wastes minimization (variant #4). Linear increasing functions defined on the local domains were chosen as single-attribute value functions for the base case option. Indicators were not aggregated (a single-level structure of the objectives tree is assumed) (Figs 3.5–3.9).

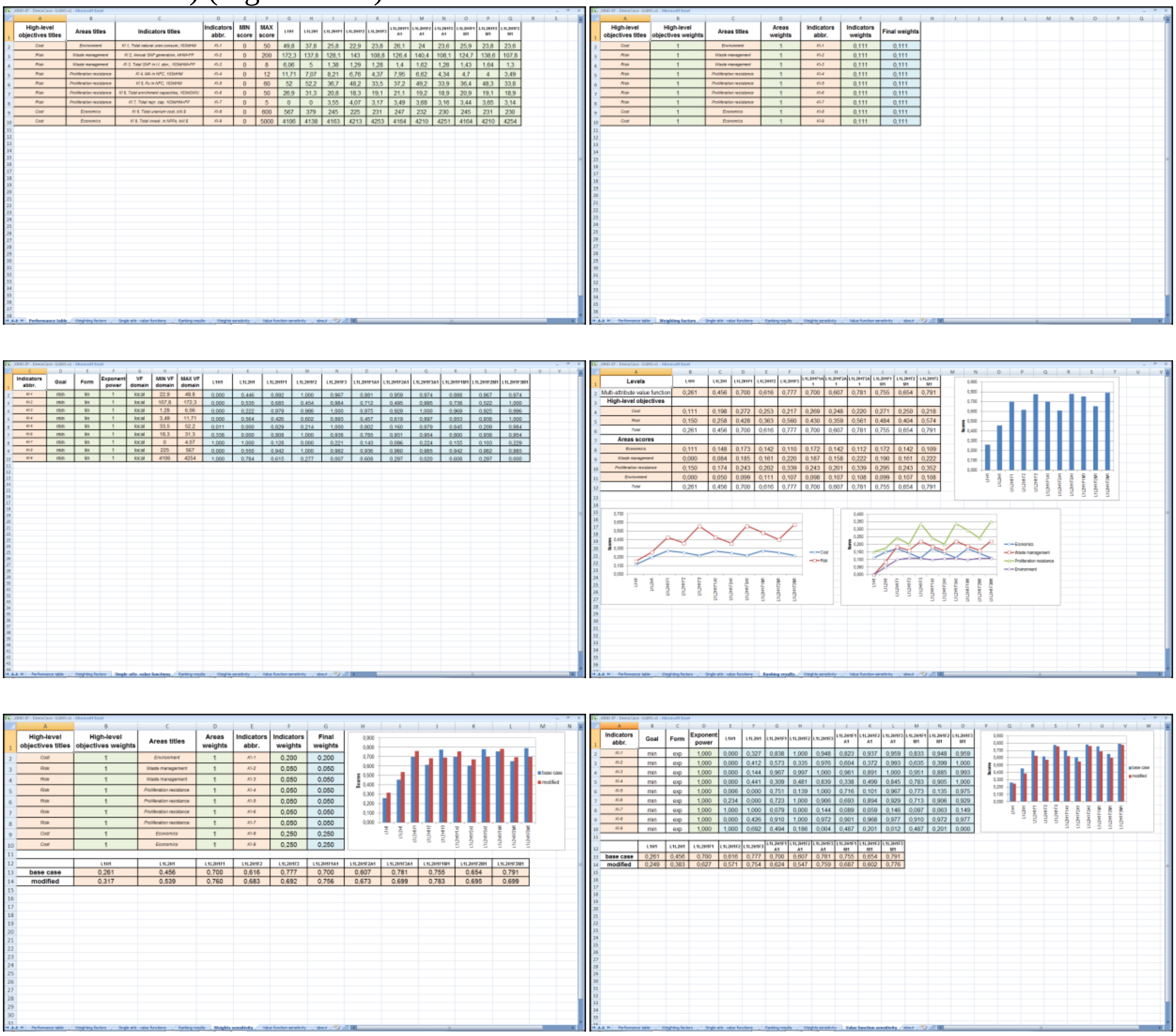


FIG. 3.5. Screenshot of the case study worksheets: GAINS scenarios comparative evaluation, weights option – variant #1

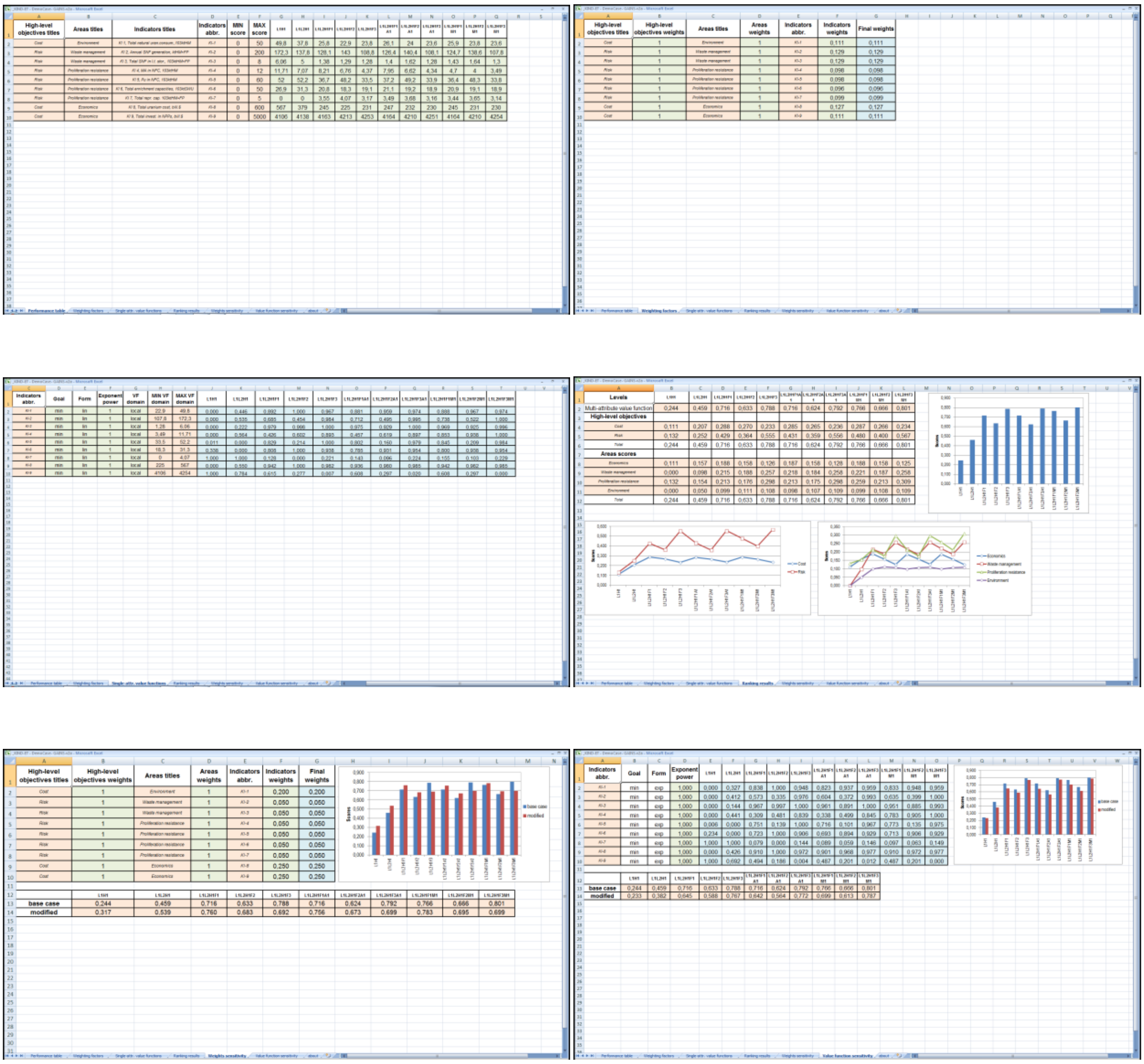


FIG. 3.6. Screenshots of the case study worksheets: GAINS scenarios comparative evaluation, weights option – variant #2a

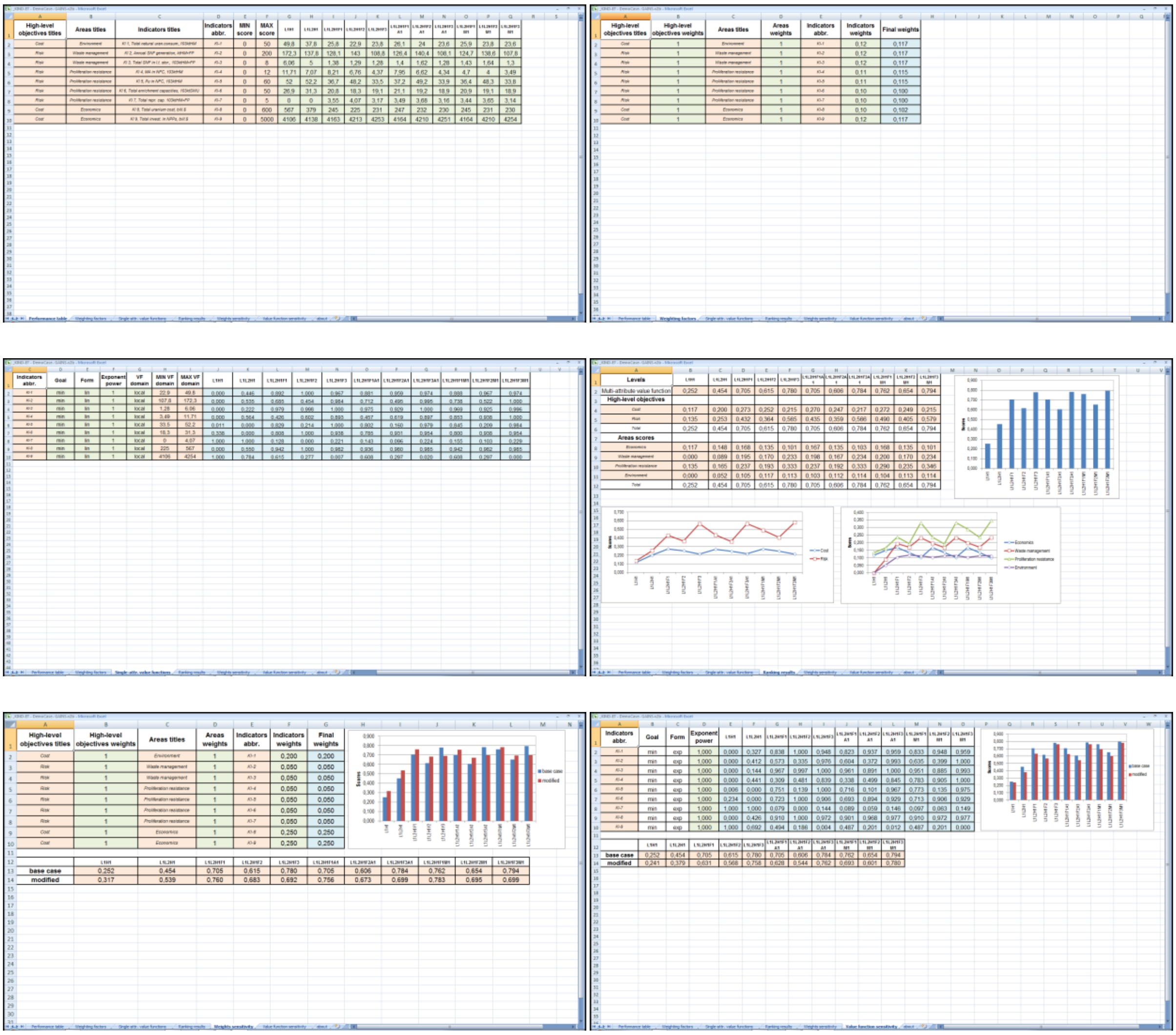


FIG. 3.7. Screenshots of the case study worksheets: GAINS scenarios comparative evaluation, weights option – variant #2b

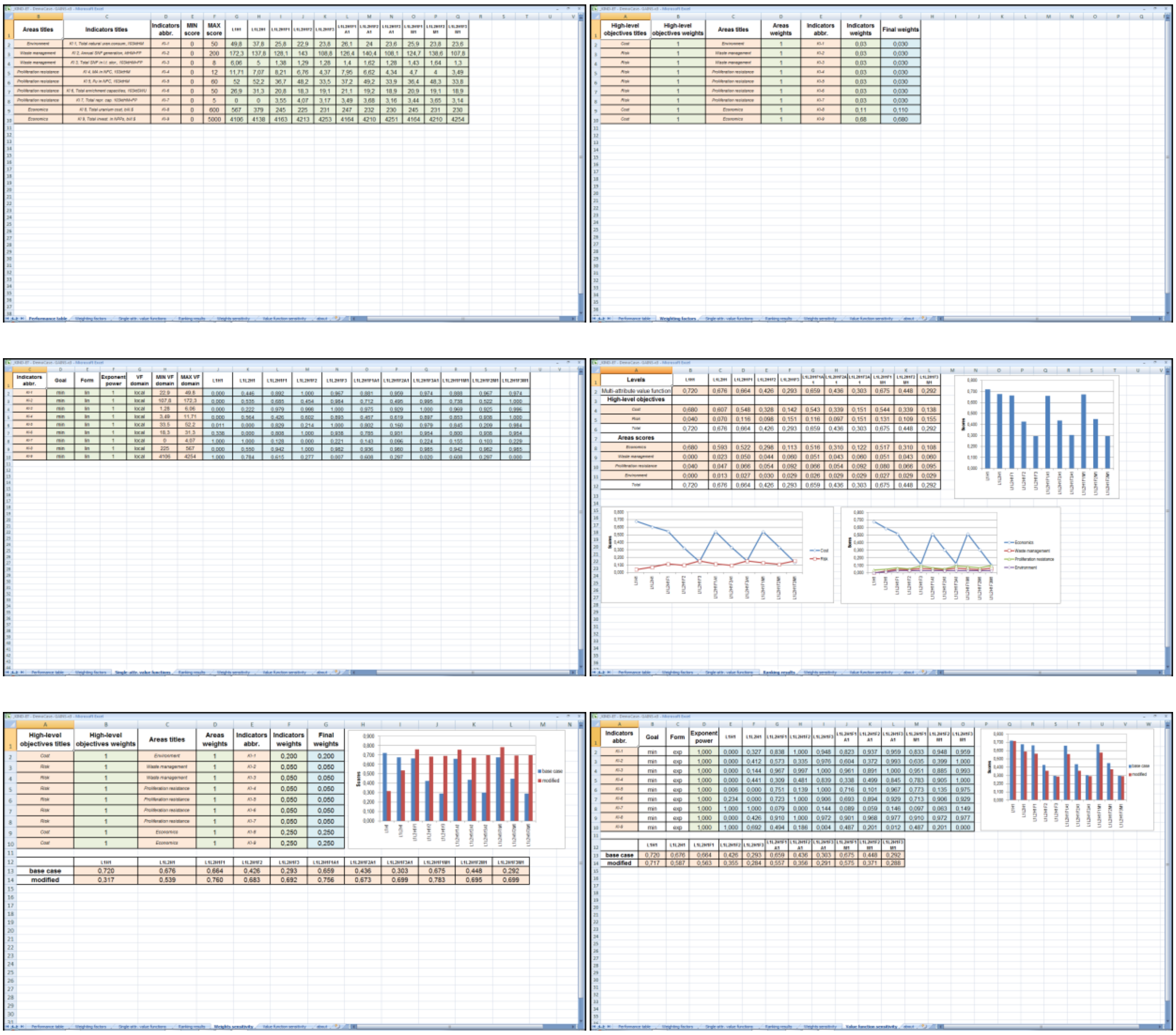


FIG. 3.8. Screenshots of the case study worksheets: GAINS scenarios comparative evaluation, weights option – variant #3

FIG. 3.9. Screenshots of the case study worksheets: GAINS scenarios comparative evaluation, weights option – variant #4

SUMMARY

The KIND-ET tool is an Excel-template adapted to provide necessary capability of comparative evaluation of the status, prospects, benefits and risks associated with development of nuclear technologies including options for a more distant future. With realized architecture and functional capabilities of the KIND-ET, this tool may easily be modified by users to take into account their preferences.

The MAVT method is quite flexible; it allows implementation of different approaches for comparing and differentiating alternatives as well as interpreting the ranking results. KIND-ET provides some flexibility to perform different options related to the MAVT method implementation for the KIND objective, at the same time keeping characteristic features of the KIND approach and elaborated recommendations. In this regard, KIND-ET is capable to provide identification of different circumstances regarding the merits and demerits of NESs being compared, and evaluate their overall scores and ranks taking into account NES performance, experts and decision makers' judgments and preferences.

These user instructions and the presented examples demonstrate the basic steps to be completed by KIND-ET for the NES multi-criteria comparative evaluation within the KIND approach and represent a possible template for the calculation results presentation and interpretation that may be implemented in comparing real systems.

REFERENCES

[1] Fishburn, P.C. (1967). *Methods of estimating additive utilities*. Management Science, Vol. 13, No. 7.

[2] Keeney, R. and Raiffa, H. (1976). *Decisions with multiple objectives: preferences and value trade-offs.* Wiley: New York.

[3] Von Winterfeldt, D. and W. Edwards (1986). *Decision Analysis and Behavioral Research*. Cambridge University Press: Cambridge.

[4] Kuznetsov, V.; Fesenko, G.; Schwenk-Ferrero, A.; Andrianov, A.; Kuptsov, I. *Innovative Nuclear Energy Systems: State-of-the Art Survey on Evaluation and Aggregation Judgment Measures Applied to Performance Comparison*. Energies 2015, 8, 3679-3719.

[5] *"Comparative evaluation of GAINS deployment scenarios based on the KIND methodology*" report for the INPRO collaborative project on Key Indicators for Innovative Nuclear Energy Systems (KIND), 2014.

[6] "*Comparative assessment of hypothetical innovative nuclear energy systems based on the KIND methodology*" report for the INPRO collaborative project on Key Indicators for Innovative Nuclear Energy Systems (KIND), 2014.

[7] Kuznetsov, V.; Fesenko, G.; Andrianov, A.; Kuptsov, I. *INPRO activities on development of advanced tools to support judgment aggregation for comparative evaluation of nuclear energy systems*. Sci. Technol. Nuclear Install. 2015, 2015.

[8] Kuznetsov V., Fesenko G., Andrianov A. *INPRO collaborative project on key indicators for innovative nuclear energy systems (KIND)*. Innovative Designs and Technologies of Nuclear Power: Abstracts of IV International Scientific and Technical Conference (September 27–30, 2016, Moscow). Moscow, JSC "NIKIET" Publ., 292 p.

[9] Microsoft Excel, http://office.microsoft.com/en-001/excel/

[10] *"Key indicators for innovative nuclear energy systems as a guidance and tool to assess sustainability of innovations"* draft report for the INPRO collaborative project on Key Indicators for Innovative Nuclear Energy Systems (KIND), 2017.

[11] *KIND-ET verification report.* Report for the INPRO collaborative project on Key Indicators for Innovative Nuclear Energy Systems (KIND), 2017.

ABBREVIATIONS AND ACRONYMS

IAEA	International Atomic Energy Agency
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
NES	Nuclear Energy System
KI	Key Indicator
KIND	The INPRO collaborative project on Key Indicators for Innovative Nuclear Energy Systems.
KIND-ET	KIND-Evaluation Tool
MAVT	Multi-Attribute Value Theory
MCDA	Multi-Criteria Decision Analysis
SI	Secondary Indicator

ABOUT KIND-ET

KIND-ET (KIND-Evaluation Tool) is a MAVT based Excel-template developed for the INPRO Collaborative Project on Key indicators for Innovative Nuclear Energy Systems (KIND) as a guidance and support tool to assess sustainability of innovations.

To perform a multi-criteria comparison using the MAVT method, it is required to:

(1) Select a set of performance indicators;
(2) Identify a structure of the objectives tree;
(3) Prepare a performance table;
(4) Determine single-attribute value functions for each indicator;
(5) Evaluate weighting factors;
(6) Perform sensitivity analysis; and
(7) Interpret ranking results and formulate recommendations.

Users can at their own discretion specify all steps (a set of indicators used, the structure of the objectives tree, etc.) as well as a goal for each indicator and scales for indicators evaluation.

All the mentioned steps are to be specified in KIND-ET during solution of a certain problem. KIND-ET covers the most formal stages of the decision support process related to usage of a specific mathematical method: implementation of the MAVT method, carrying-out of an uncertainty and sensitivity analysis and formulation of final conclusions and recommendations.

The following major assumptions are realized in KIND-ET by default: three-level objectives tree, 15 performance indicators, linear end exponential forms of single-attribute value functions, problem-oriented domains of single-attribute value functions and direct method for weighting factors evaluation.