IAEA
International Atomic Energy Agency

Analysis Support for Enhanced Nuclear Energy Sustainability

IAEA/INPRO service to Member States

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NENP/ INPRO

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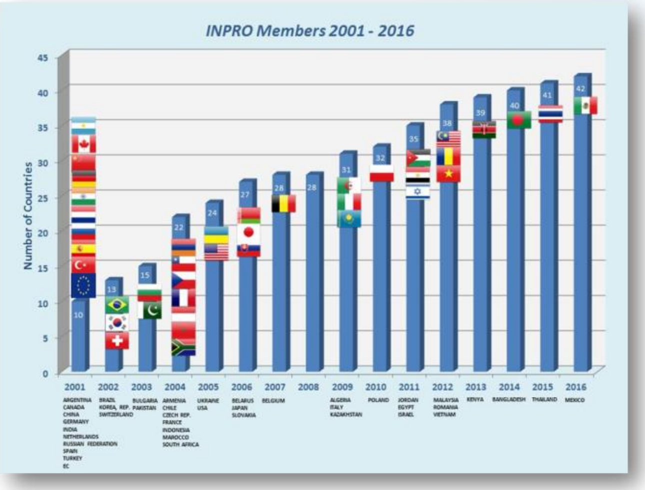
Introduction:



- The International Project for Innovative Nuclear Reactors and Fuel Cycles (INPRO) supports Member States in their long-term planning for development of *sustainable nuclear energy systems*.
- INPRO's main activities focus on four themes: Global scenarios, Innovations, Sustainability assessment and strategies, and Dialogue and outreach. INPRO activities take place through close cooperation of the IAEA's Member States – INPRO members (42 member countries and international organizations).
- Global scenarios: Using scientific and technical analysis tools, INPRO develops global and regional nuclear energy scenarios to investigate specifically how collaboration/trade among different States and organizations can facilitate the transition to globally sustainable nuclear energy systems.

Developing nuclear energy strategies

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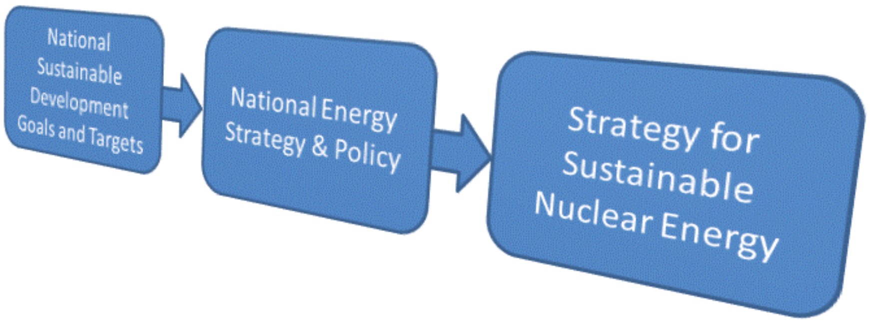
- The IAEA implements elaborate programmes for supporting its Member States for conducting national energy studies to identify the potential role for various energy technologies, including nuclear power, in meeting their future energy needs.



- Nuclear energy system is a part of the overall energy system of a country. The potential role of nuclear energy has to be evaluated by considering all the options for delivering required energy services to the society and economy in a safe, clean and affordable manner
- National decision on nuclear energy should, therefore, be evaluated in the context of a bigger picture for the development of a country which is firmly tied with the international environment
- Once nuclear energy has been identified as a desirable component of a country's future energy mix, it would be necessary to perform an evaluation of the entire nuclear energy system (NES) to raise the awareness of all the issues associated with the *sustainable* development and deployment of nuclear energy, before making any national decision

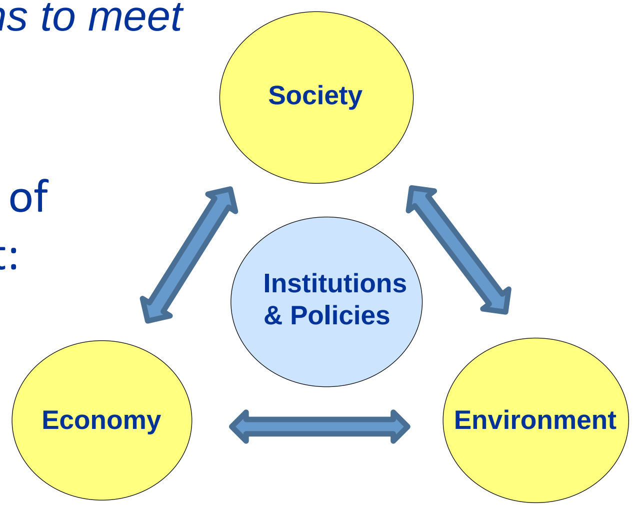
Sustainability of a nuclear energy system

Definition of sustainable development according to the report of the Brundtland Commission ("Our Common Future", Oxford University Press, Oxford (1987)

"Sustainable Development is the capacity to meet the needs of the present without compromising the ability of future generations to meet their own needs,"

Three dimensions/pillars of sustainable development:

- Social
- Economical
- Environmental



More recent developments:

2012 the Rio+20 conference on sustainable development

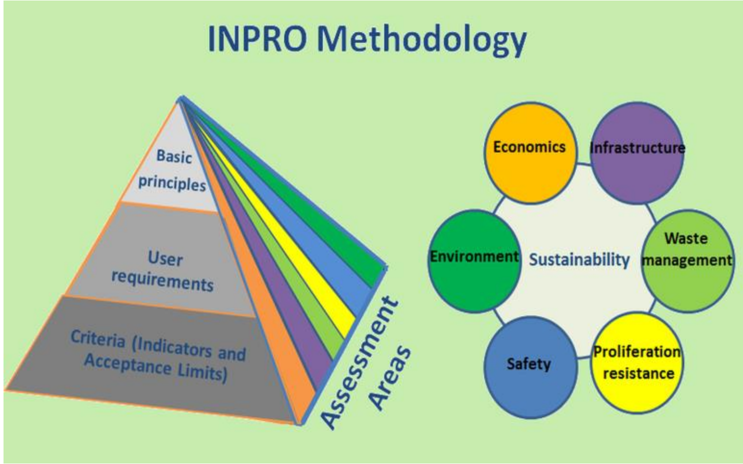
2015 High level Political Forum on sustainable development

Universal, integrated and transformative 2030 Agenda for Sustainable Development, along with a set of 17 Sustainable Development Goals (SDGs) and 169 associated targets

2016 Climate Change Conference (Conference of the Parties -COP 22)

Nuclear Energy potential: Affordable and clean energy (SDG 7) and Climate change mitigation (SDG 13)

INPRO Methodology for NES sustainability Assessment



Basic Principles: goal for development of a sustainable NES

User Requirements: what should be done by designer, operator, industry and/or State to meet the goal defined in the Basic Principle

Criteria:
Assessor's metric to check whether a User Requirement is being met

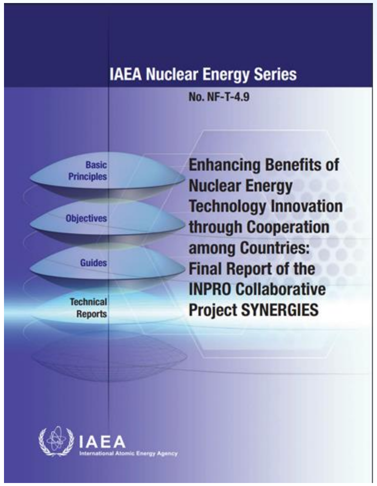
Concept and assessment tool for (basic) NES sustainability:

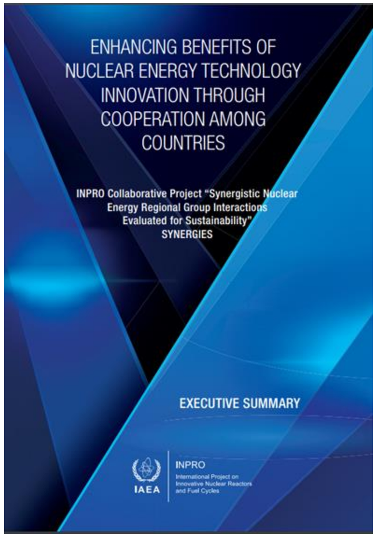
- **Is what we have or what we target sustainable?**
- **What are the gaps?**

- Developed by qualified experts – representatives of the IAEA Member States – INPRO Members
- Provides a basis for all other INPRO projects/ activities
- Consistent with the UN concept of sustainable development,
- 7 Basic Principles, 30 User requirements and more than one hundred criteria in the assessment areas of Economics, Safety, Infrastructure, Environment, Proliferation Resistance and Waste Management, each consisting of an indicator and an acceptance limit
- INPRO methodology is primarily a tool to identify gaps in sustainability of a particular NES (facilitating finding a pathway to eliminate them)
- INPRO Methodology defines the basic concept of NES sustainability and includes provisions for further sustainability enhancements (introduces the notion of Key Indicators (KIs) by which substantial enhancements of sustainability in particular assessment areas could be evaluated and quantified)

Options to enhance nuclear energy sustainability

The INPRO collaborative project "Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability" (SYNERGIES) has developed a concept of "Options for enhanced nuclear energy sustainability"





- ➢ Enhanced sustainability may be achieved through:
- innovations in technologies and/or changes in policies, as well as
- through enhanced cooperation among countries, including the technology holder and technology user countries and internationally recognized bodies responsible for defining sustainable energy policy on a global scale

INPRO Area “Global Scenarios”

- INPRO “Global scenarios” Task has been conducting nuclear energy evolution scenario modelling to understand major issues of nuclear energy system sustainability.
- Several collaborative projects have been implemented with active participation of Member States. They brought out main challenges for development of sustainable nuclear energy systems.
  - ✓Global Architecture of Innovative Nuclear Energy Systems **(GAINS)** developed an analytical framework to model NES evolution scenarios involving cooperation/trade among countries
  - ✓Synergetic Nuclear Energy Regional Group Interactions Evaluated for Sustainability **(SYNERGIES)** amended and applied this framework to national/regional case studies
  - ✓Key Indicators for Innovative Nuclear Energy System Development **(KIND)** developed an approach for comparative evaluation of NES/scenario options based on multi-criteria decision analysis
  - ✓Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems” **(ROADMAPS)** has developed a structured approach for mapping the course toward globally sustainable NESs to be achieved through both, technology innovations and international cooperation. ROADMAPS integrated the outputs of the SYNERGIES, GAINS and KIND collaborative projects
  - ✓Comparative Evaluation of Nuclear Energy System Options **(CENESO)** is implementing the lessons learned from the KIND project outputs and to extend the KIND approach and the case studies on comparative evaluation of NES options/scenarios of interest to CENESO participants

INPRO area "Global scenarios"

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Collaborative Projects → Methods, Tools and Publications → Services to MSs: ASENES

GAINS- Global Architecture of Innovative Nuclear Energy Systems;

SYNERGIES - Synergetic Nuclear Energy Regional Group Interactions Evaluated for Sustainability;

KIND/CENESO- Key Indicators for Innovative Nuclear Energy System Development/ Comparative evaluation of nuclear energy system options

ROADMAPS- Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems

Some of the most important outputs of the projects are methods and software tools

ASENES- Analysis Support for Enhanced Nuclear Energy Sustainability

ASENES Service: INPRO toolkit

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INPRO ASENES tools can be used for integrated analysis of the performance and sustainability of national NES and deployment scenario options:

- **Nuclear Economics Support Tool (NEST)**: to assess the levelized unit electricity cost (LUEC) (including all fuel cycle components) for NPPs with different nuclear reactors and fuel cycles, including sensitivity analysis to various factors;

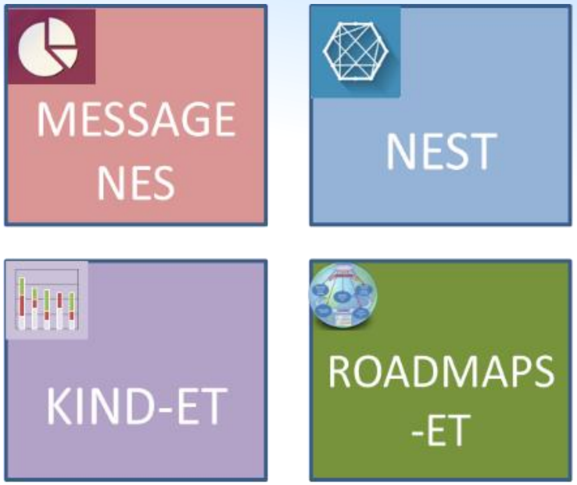
- **The MESSAGE-NES energy planning tool considering the specifics of nuclear technology**: to carry out scenario and material flow analyses, as well as to optimize NES structure taking into account the resource and infrastructural constraints and restrictions;

- **The excel tool KIND-ET and its CENESO extensions**: to perform multi-criteria comparative evaluations and ranking of NES or deployment scenario options, including relevant sensitivity/uncertainty analyses with respect to key factors important for decision making;

- **The excel tool ROADMAPS-ET**: to develop and present technology and infrastructure deployment roadmaps towards enhanced nuclear energy sustainability, including tracking progress against key milestones.

Benefits of ASENES use

- Nuclear energy system evolution scenario modelling could help better understand the key issues of, and find plausible solutions for, enhancing nuclear energy sustainability.
- Analysis of specific cooperation options could be performed to find out how specific cooperation with other countries could save national resources and efforts toward sustainable development of nuclear energy.
- Comparative evaluation of nuclear energy system options based on problem structuring and the state-of-the art judgement aggregation/uncertainty analysis methods could be used to support the multi-criteria selection of a preferred energy system through a substantive dialogue with decision makers.
- Road mapping activities would help represent the status, prospects, benefits and risks associated with a variety of options for the national energy system configuration and evolution scenario.

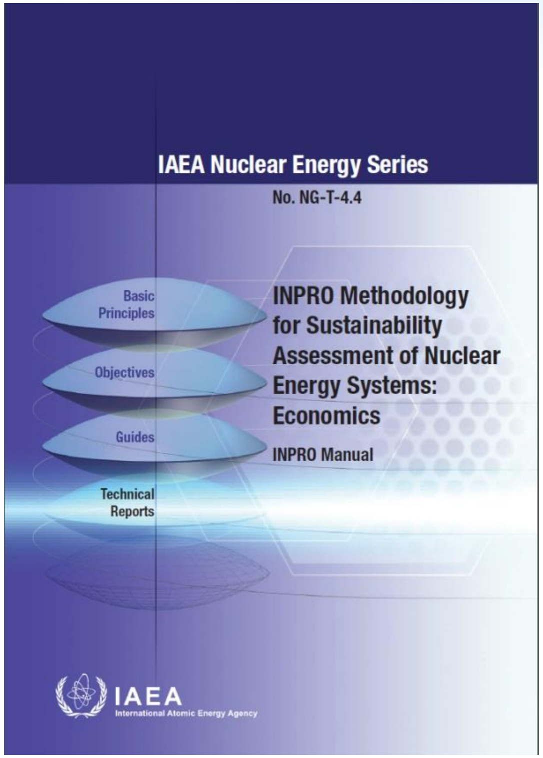


Nuclear Economics Support Tool (NEST)

- INPRO economic assessment and scenario analysis are supported by the Nuclear Economics Support Tool (NEST).

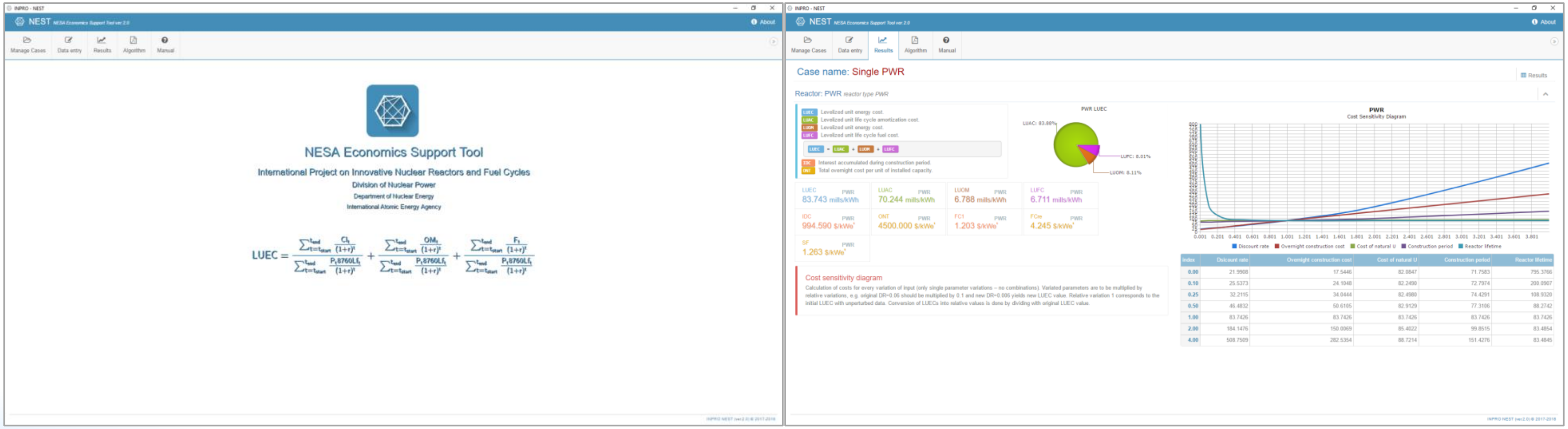
- NEST comprises several models and options to calculate economic parameters; it converts basic technical and economic inputs into standard functions used in economics (levelized unit energy cost, net present value, internal rate of return, etc.).

- NEST provides a preliminarily analysis of economic performance of different reactor technologies in the absence of infrastructural and resource factors taken in account.



NEST applications

- Performing evaluation of LUEC and its components for nuclear power plants and non-nuclear power plants according to LUEC calculation models implemented in NEST and technical/economic data specified by the users.
- Performing sensitivity/uncertainty analysis for LUEC or its components with respect to technical and economic data, including:
  - Selection of the most effective (optimal) technical parameters to minimize LUEC or its components, based on direct search methods for the optimization problem solution.



NEST navigation panel and panel for presentation of results

NESA economics support tool (NEST)

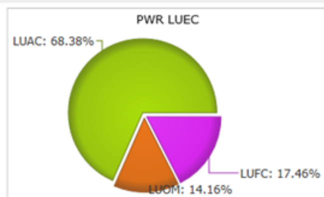
- Collaboration has been established between IAEA INPRO and the GIF Economic Methodology Working Group (EMWG), which included the performance of benchmarks between the G4-ECONS (the GIF model) and the NEST tools. Excellent agreement between the models was found where both codes performed the same types of calculations Ref: *MOORE, M., KORINNY, A., SHROPSHIRE, D., SADHANKAR, R., Benchmarking of Nuclear Economics Tools, Annals of Nuclear Energy, 103, Elsevier (2017).*

Reactor type PWR

LUEC Levelized unit energy cost.
LUAC Levelized unit life cycle amortization cost.
LUOM Levelized unit energy cost.
LUFC Levelized unit life cycle fuel cost.

LUEC = LUAC + LUOM + LUFC

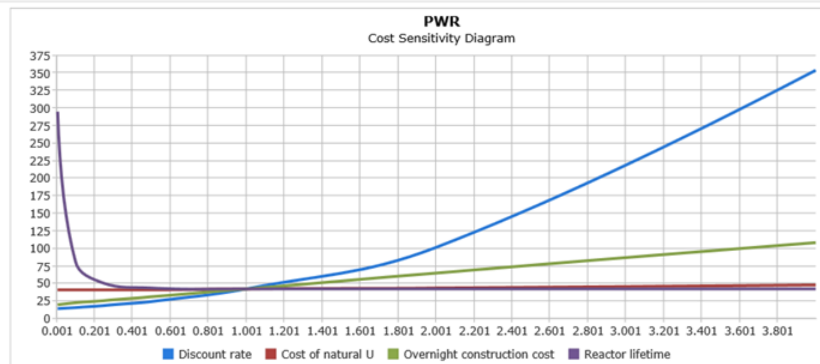
IDC Interest accumulated during construction period.
ONT Total overnight cost per unit of installed capacity.



LUEC PWR 42.232 mills/kWh	LUAC PWR 28.879 mills/kWh	LUOM PWR 5.980 mills/kWh	LUFC PWR 7.372 mills/kWh
IDC PWR 811.151 $/kWe	ONT PWR 1507.000 $/kWe	FC1 PWR 1.364 $/kWe	FCre PWR 4.661 $/kWe
SF PWR 1.347 $/kWe			

Cost sensitivity diagram

Calculation of costs for every variation of input (only single parameter variations – no combinations). Variated parameters are to be multiplied by relative variations, e.g. original DR=0.06 should be multiplied by 0.1 and new DR=0.006 yields new LUEC value. Relative variation 1 corresponds to the initial LUEC with unperturbed data. Conversion of LUECs into relative values is done by dividing with original UEC value.



index	Discount rate	Cost of natural U	Overnight construction cost	Reactor lifetime
0.00	14.3547	40.3737	20.3120	293.9048
0.10	15.6962	40.5578	22.4842	81.8156
0.25	18.3759	40.8368	25.7754	49.9645
0.50	24.5108	41.3017	31.2608	43.3668
1.00	42.2316	42.2316	42.2316	42.2316
2.00	100.3801	44.0913	64.1730	42.1939
4.00	353.2019	47.8107	108.0560	42.1938

Analytical framework for nuclear energy evolution scenario evaluation regarding sustainability

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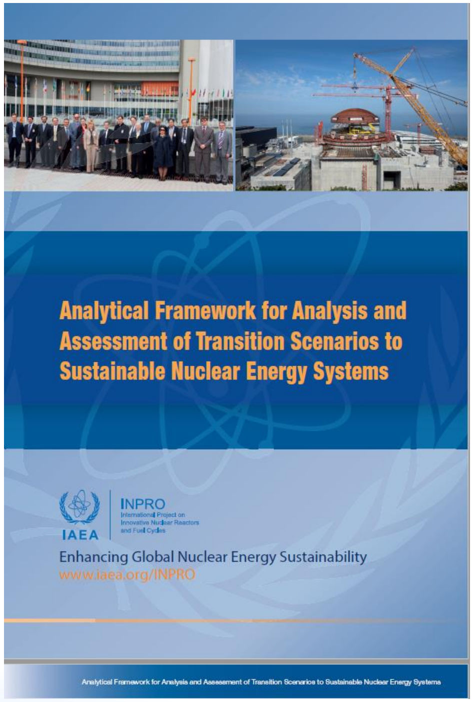
- **The NPRO collaborative project “Global Architecture of Innovative Nuclear Energy Systems Based on Thermal and Fast Reactors Including a Closed Fuel Cycle” (GAINS)** has developed an Analytical framework for nuclear energy evolution scenario evaluation regarding sustainability

- The evaluation is based on a set of scenario-specific Key Indicators in the areas of mass flows and radioactivity of resources and wastes, demands for the fuel cycle front-end and back-end fuel cycle services and economics

- It allows to consider targeted NES options with sustainability enhanced against that defined by the INPRO methodology

Analytical framework for nuclear energy evolution scenario evaluation regarding sustainability:

- **How we get from what we have today to our targeted sustainable future?**
- **First application of the Key Indicator approach allowing to compare NES evolution scenarios**



Analytical framework: elements

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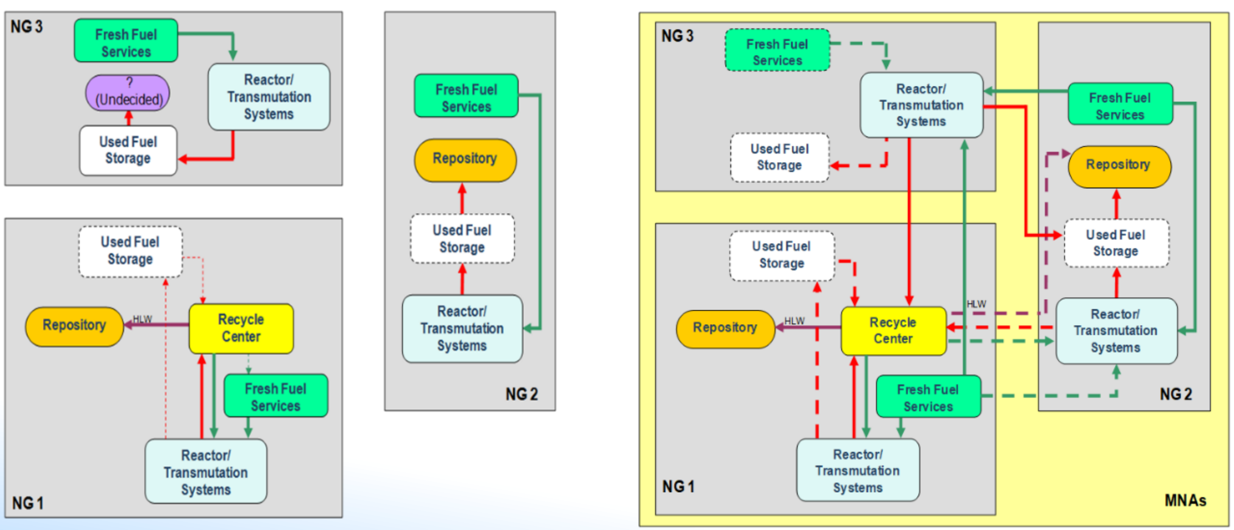
The most significant elements of this framework that might be applied within an integrated analysis of the performance and sustainability of national NES deployment scenarios are as follows:

- metrics and tools for assessing material flows and key performance indicators associated with NES deployment scenarios;
- an internationally verified database with characteristics of existing and advanced nuclear reactors and relevant NFCs needed for a detailed material flow analysis;
- homogeneous and heterogeneous world models comprising groups of non-personified non-geographical countries with different policies regarding the nuclear fuel cycle back-end.



Metrics (Key Indicators and Evaluation Parameters) for scenario analysis

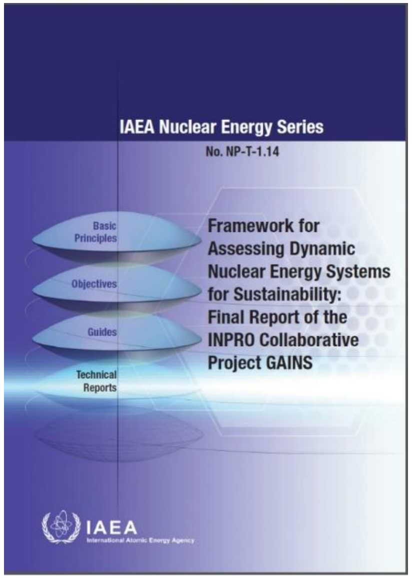
The idea is that a Key Indicator (KI) would have a distinctive capability for capturing the essence of a given area, and that the KIs would provide a means to establish targets in a specific area to be reached via improving technical or infrastructural characteristics of the NES.

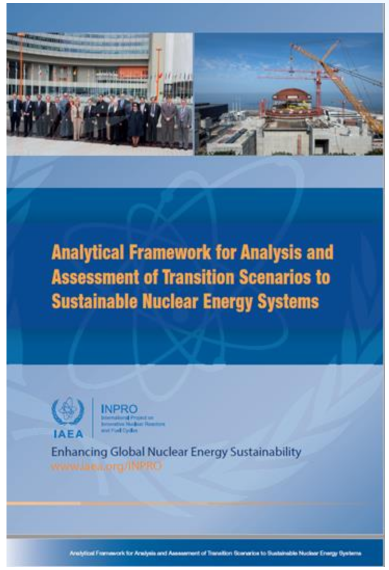
Selection of KIs

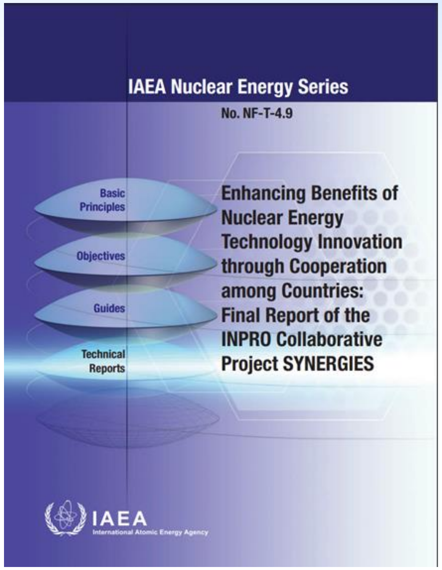
- Ten KIs were identified by screening of ~ 100 indicators of the INPRO methodology
- These KIs present nuclear power production by reactor types, resources, discharged fuel, radioactive waste, fuel cycle services, costs and investment in a global NES

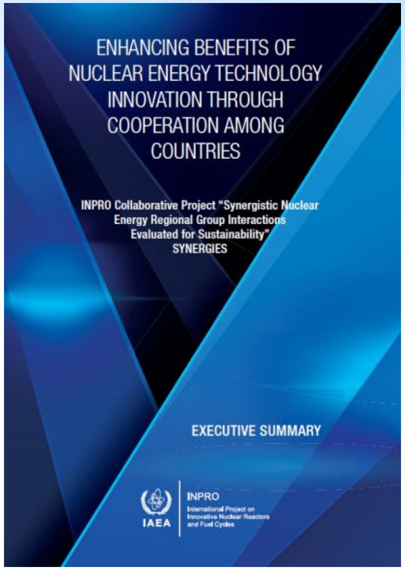
No.	Key indicators and Evaluation Parameters	INPRO assessment areas					
	Color coding indicative of relative uncertainty level in estimating specific quantitative values for future NES (can vary based on a particular scenario): Low / Medium-low / Medium-high / High	Resource Sustainability	Waste Management and Environmental Stressors	Safety	Proliferation Resistance and Physical Protection	Economics	Infrastructure
Power Production							
KI-1	Nuclear power production capacity by reactor type						**X**
EP-1.1	(a) Commissioning and (b) decommissioning rates		X				X
Nuclear Material Resources							
KI-2	Average net energy produced per unit mass of natural uranium	**X**	X				
EP-2.1	Cumulative demand of natural nuclear material, i.e. (a) natural uranium and (b) thorium	X	X				
KI-3	Direct use material inventories per unit energy generated (Cumulative absolute quantities can be shown as EP-3.1)	X			**X**		X
Discharged Fuel[3]							
KI-4	Discharged fuel inventories per unit energy generated (Cumulative absolute quantities can be shown as EP-4.1)		**X**				**X**
Radioactive Waste and Minor Actinides							
KI-5	Radioactive waste inventories per unit energy generated[4] (Cumulative absolute quantities can be shown as EP-5.3)		**X**				X
EP-5.1	(a) radiotoxicity and (b) decay heat of waste, including discharged fuel destined for disposal		X				X
EP-5.2	Minor actinide inventories per unit energy generated		X				X
Fuel Cycle Services							
KI-6	(a) Uranium enrichment and (b) fuel reprocessing capacity, both normalized per unit of nuclear power production capacity				**X**		**X**
KI-7	Annual quantities of fuel and waste material transported between groups		X		X		**X**
EP-7.1	Category of nuclear material transported between groups				**X**		
System Safety							
KI-8	Annual collective risk per unit energy generation			**X**			
Costs and Investment							
KI-9	Levellized unit of electricity cost (LUEC)					**X**	
EP-9.1	Overnight cost for Nth-of-a-kind reactor unit: (a) total and (b) specific (per unit capacity)					X	
KI-10	Estimated R&D investment in Nth-of-a-kind deployment					**X**	X
EP-10.1	Additional functions or benefits[5]					X	

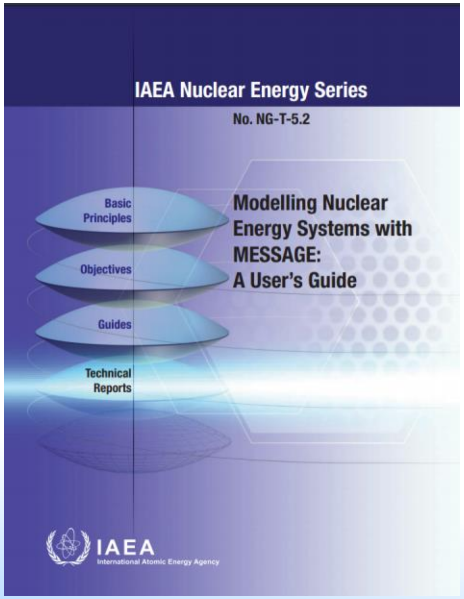
Analytical framework: documents

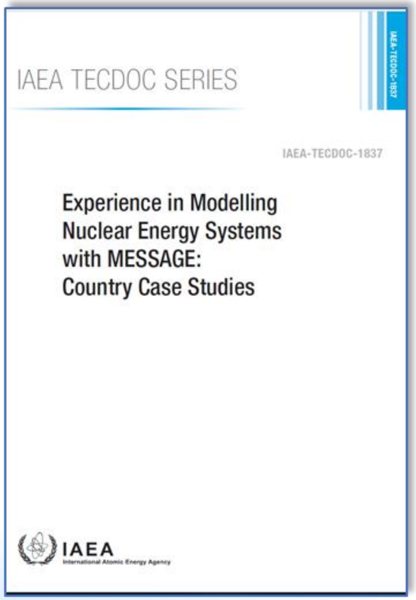








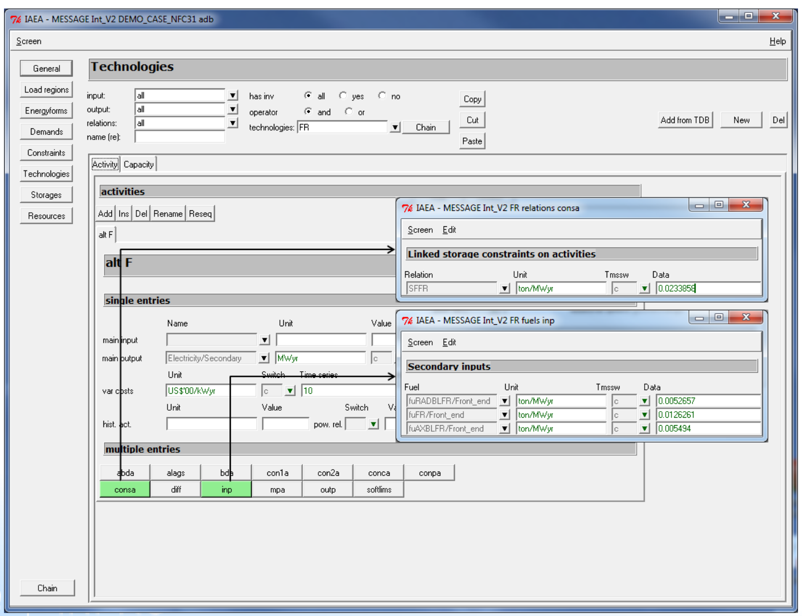


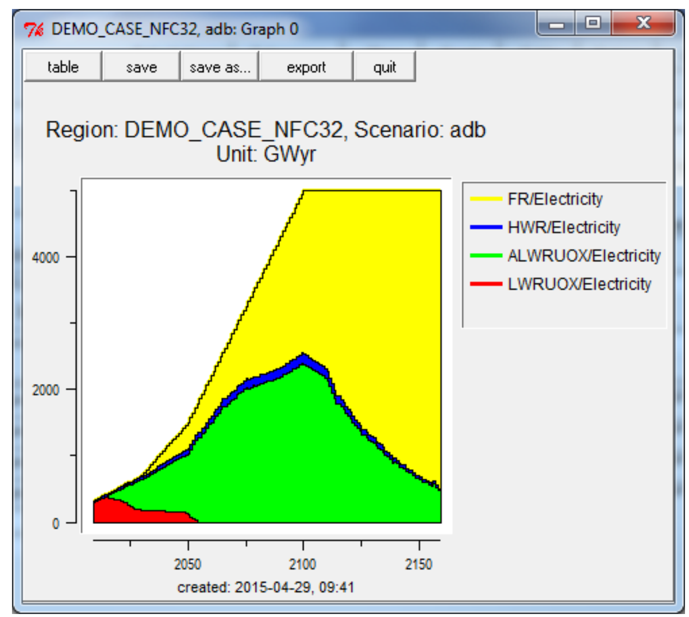


MESSAGE-NES tool

- MESSAGE-NES is an adapted and enhanced version of MESSAGE that is the main IAEA tool for supporting nuclear power planning studies (scenario and material flow analyses).

- MESSAGE-NES provides a convenient platform for modelling complex NESs and developing alternative scenarios of the system dynamic evolution, including material flow analyses and evaluations of trade-offs between the various NES sustainability aspects.

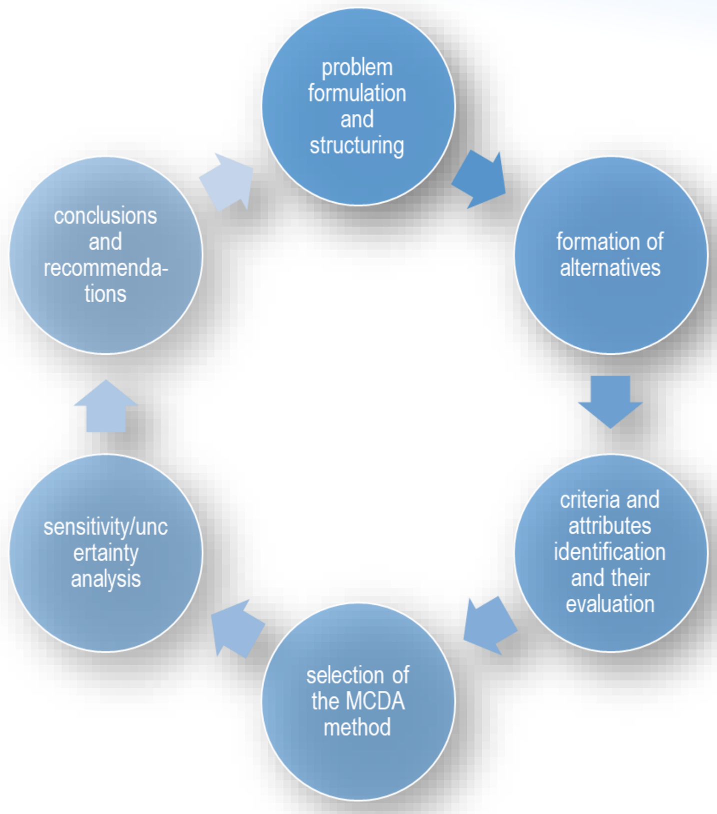




Screenshots from the MESSAGE-NES input and output panels

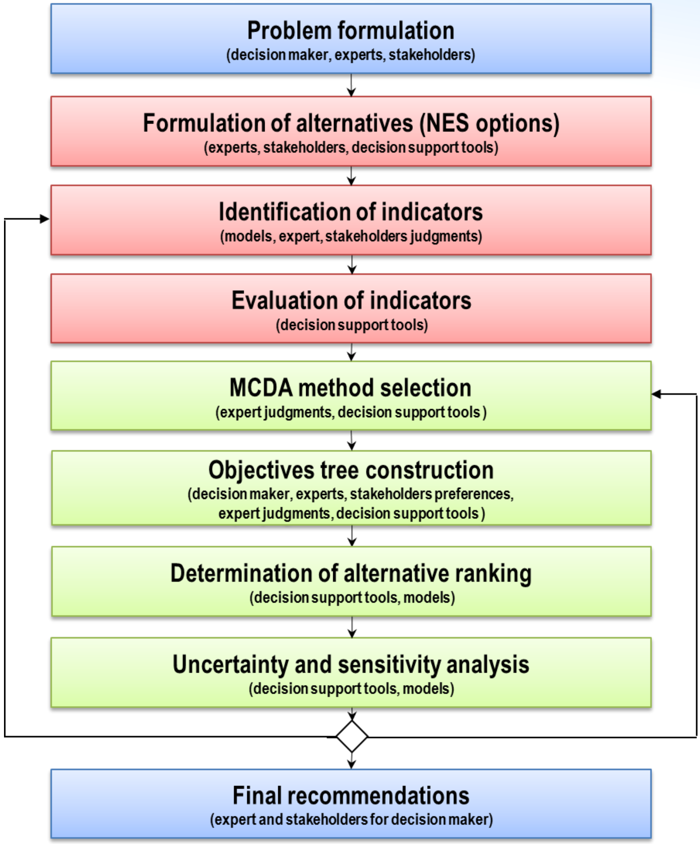
Comparative evaluation of NES or scenario options

- In order to identify the most promising NES/scenario options, a multi-criteria comparative evaluation and ranking can be carried out at the technology or scenario level.
- Comparative evaluation of options under consideration involves weighing up the merits and demerits of various alternatives against the key criteria within the Multi-Criteria Decision Analysis (MCDA) framework.
- The MCDA-based comparative evaluation provides grounds to conclude regarding merits and demerits associated with the compared options, which can be important for supporting the decision-making process.



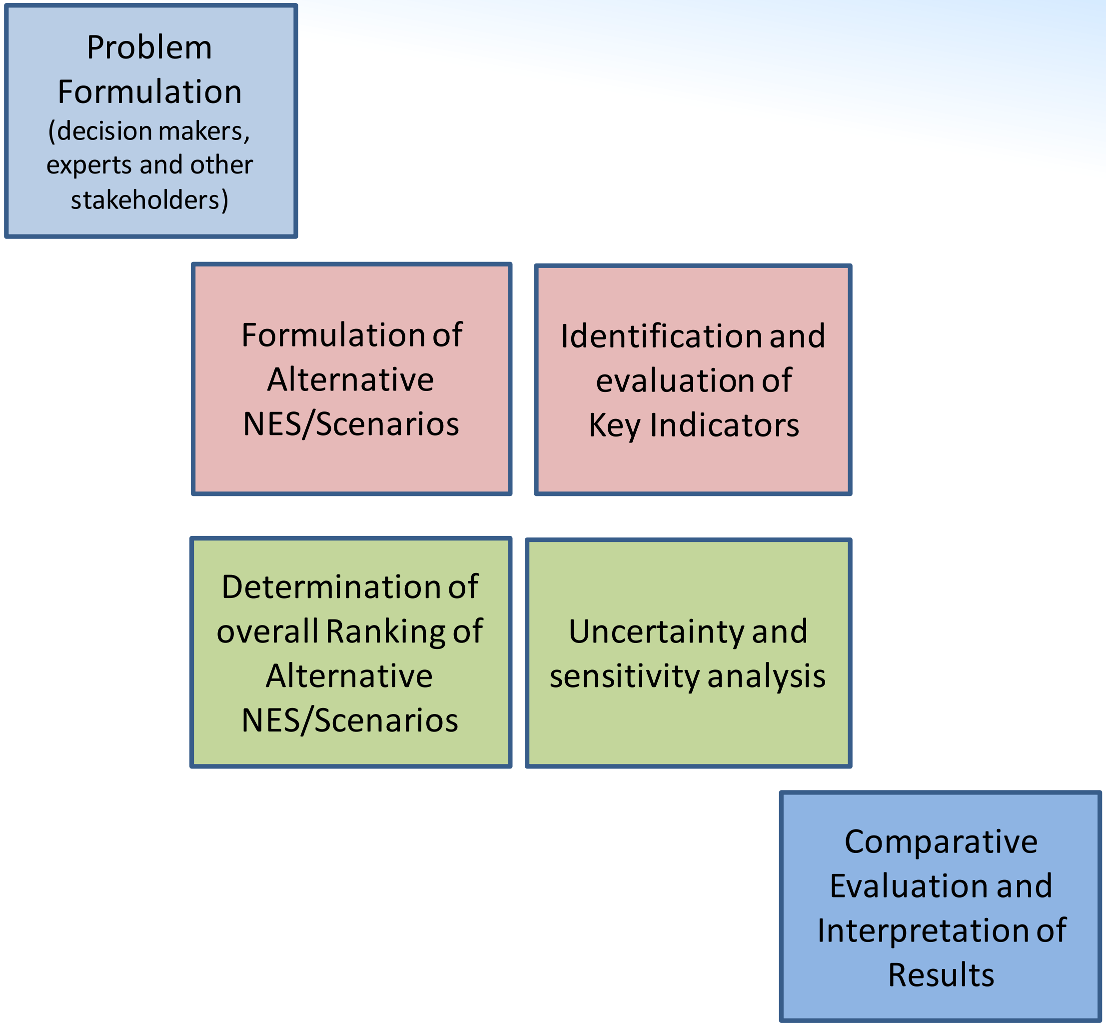
Scope of the INPRO comparative evaluation approach

- The INPRO comparative evaluation approach is an iterative procedure using the top-down and bottom-up perspectives.
- This approach, as a decision support process, begins with the identification of the decision-maker's problem and a group of subject-matter experts and stakeholders and further iteratively goes through the specific steps shown in the figure.
- INPRO provides recommendations and tools for a full cycle of the MCDA application to comparative evaluations of NES options and deployment scenarios.

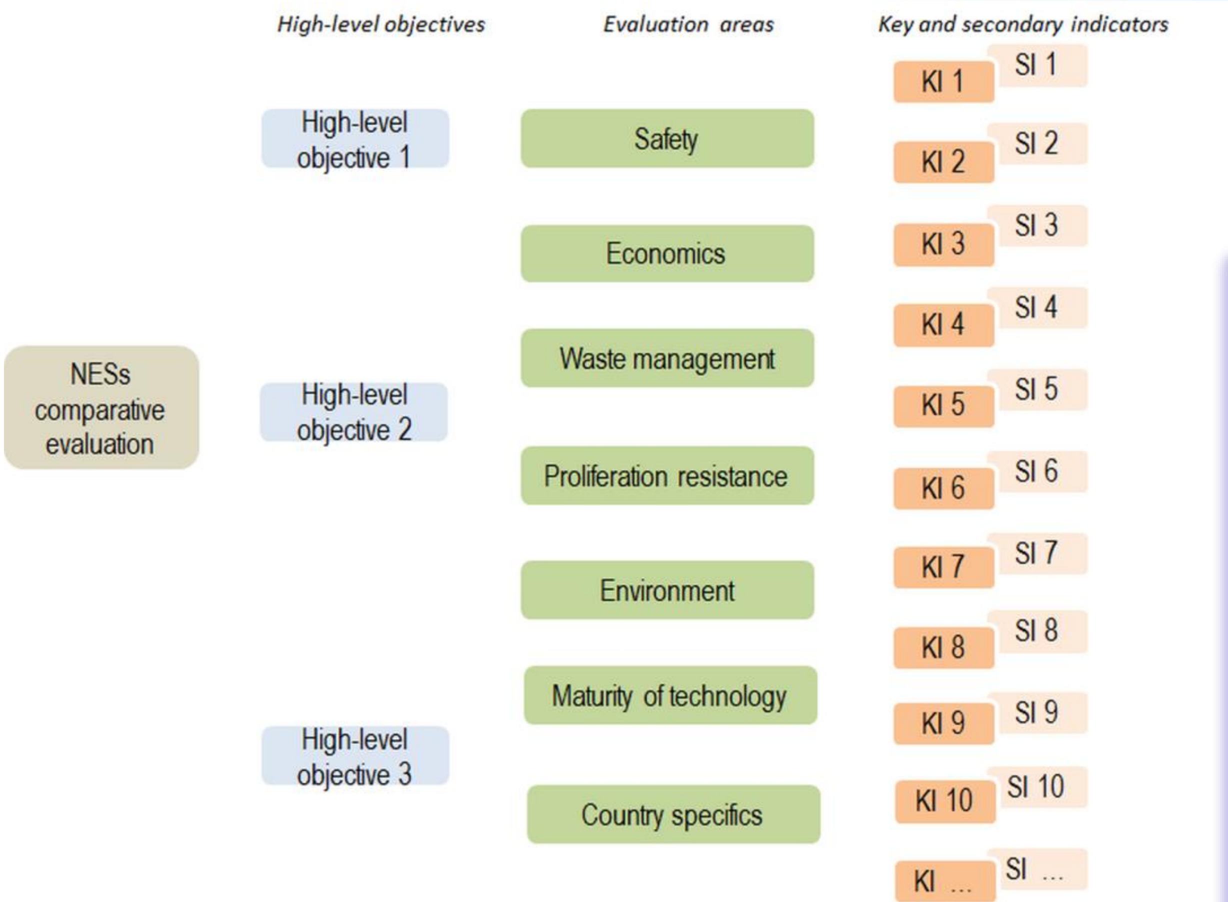


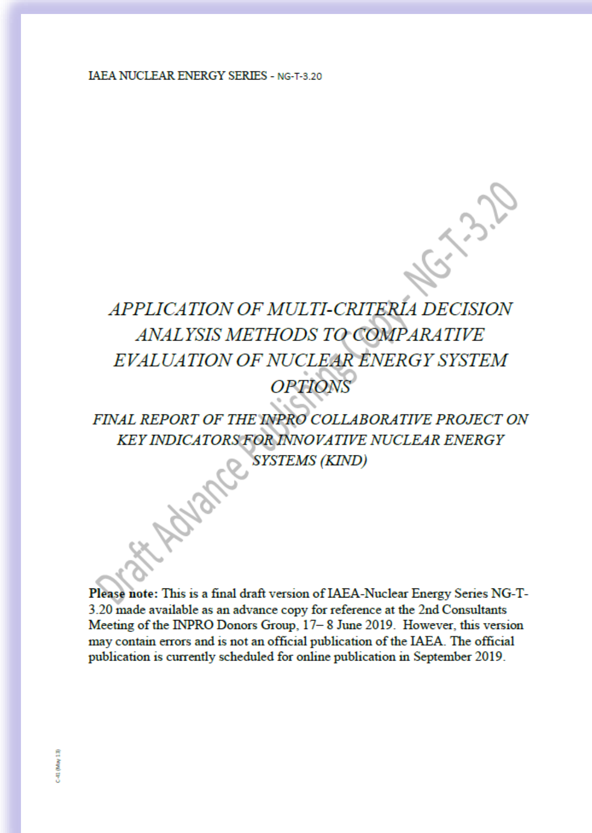
Approach for comparative evaluation of NES/ scenario options

- From the start-up, interaction among decision makers, experts and other main stakeholders is very important
- Formulation of alternatives is to identify the technology options and the factors or driving forces that influence the system evolution
- Key indicators are selected, *inter alia*, based on their measurability and the availability of data and analytical tools for their calculation
- *Comparative evaluation is complementary to regulatory assessments; it supports the selection of an NES that is preferable for a particular user out of those NESs that otherwise meet or are assumed to meet all of the regulatory and other mandatory criteria*
- Key indicators are calculated for each of the alternative scenarios, and a suitable methodology is applied for calculating the overall rank of each scenario by aggregation of the key indicators using experts' judgement and decision makers' preferences



The objectives tree





IAEA NUCLEAR ENERGY SERIES - NG-T-3.20

APPLICATION OF MULTI-CRITERIA DECISION ANALYSIS METHODS TO COMPARATIVE EVALUATION OF NUCLEAR ENERGY SYSTEM OPTIONS

FINAL REPORT OF THE INPRO COLLABORATIVE PROJECT ON KEY INDICATORS FOR INNOVATIVE NUCLEAR ENERGY SYSTEMS (KIND)

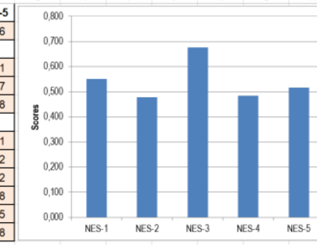
Please note: This is a final draft version of IAEA-Nuclear Energy Series NG-T-3.20 made available as an advance copy for reference at the 2nd Consultants Meeting of the INPRO Donors Group, 17– 8 June 2019. However, this version may contain errors and is not an official publication of the IAEA. The official publication is currently scheduled for online publication in September 2019.

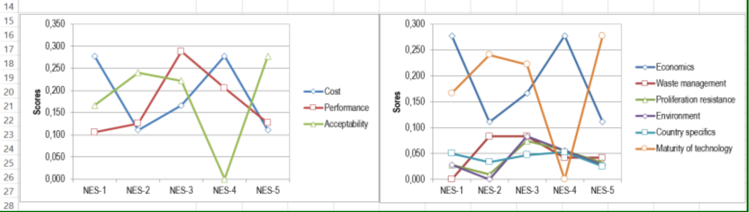
KIND-ET tool and extensions

- INPRO developed a decision support tool, **KIND Evaluation Tool (KIND-ET)**, which is a multi-attribute value theory (MAVT)-based Excel-template intended to perform multi-criteria comparative evaluations and ranking of NES/scenario options.
- The KIND-ET characteristic features include an easy-to-handle, user-friendly interface, automation and visualization capabilities.
- The following **KIND-ET extensions** assist experts in performing sensitivity/uncertainty analyses and enhance the quality of represented results:
  - ***Domination Identifier*** identifies non-dominated and dominated options from a set of considered options;
  - ***Overall Score Spread Builder*** evaluates overall score spreads caused by uncertainties in weighting factors and the objectives tree structure;
  - ***Ranks Mapping Tool*** highlights the first-rank options for different combinations of high-level objective weights.
  - ***Uncertainty Propagator*** evaluates uncertainties in options' overall scores due to uncertainties in single-attribute value function forms and key indicators.

High-level objectives titles	Areas titles	Indicators titles	Indicators abbr.	MIN score	MAX score	NES-1	NES-2	NES-3	NES-4	NES-5
Cost	*Economics*	*Levelized energy product or service cost*	*E.1*	1	5	1	2	3	2	4
Cost	*Economics*	*R&D cost*	*E.2*	1	5	2	4	2	1	2
Performance	*Waste management*	*Specific radwaste inventory*	*WM.1*	1	5	5	1	1	3	3
Performance	*Proliferation resistance*	*Attractiveness of nuclear material*	*PR.1*	1	5	2	3	1	4	3
Performance	*Proliferation resistance*	*Attractiveness of technology*	*PR.2*	1	5	5	5	3	3	4
Performance	*Proliferation resistance*	*Safeguard approach identified*	*PR.3*	1	5	4	5	3	2	4
Performance	*Environment*	*The amount of useful energy produced by the system from a unit of mined natural uranium/thorium*	*ENV.1*	1	5	3	4	1	2	3
Performance	*Country specifics*	*The potential to prevent release*	*S.1*	1	5	4	3	4	3	4
Performance	*Country specifics*	*Design concept specific safety inherent and passive features and systems*	*S.2*	1	5	3	4	3	2	3
Performance	*Country specifics*	*Core damage and large early release frequencies*	*S.3*	1	5	3	4	2	3	4
Performance	*Country specifics*	*Source term*	*S.4*	1	5	2	2	4	3	5
Performance	*Country specifics*	*Short term and long term accident management*	*S.5*	1	5	2	4	2	4	2
Acceptability	*Maturity of technology*	*Design stage*	*M.1*	1	5	4	2	4	4	1
Acceptability	*Maturity of technology*	*Time needed to mature the technology*	*M.2*	1	5	4	3	3	5	3
Acceptability	*Maturity of technology*	*Degree of standardization and licensing adaptability*	*M.3*	1	5	3	4	3	5	4

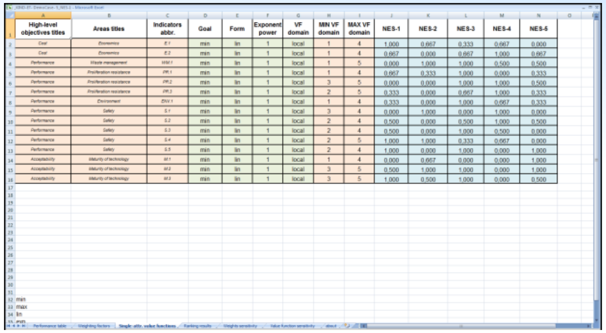
Levels	NES-1	NES-2	NES-3	NES-4	NES-5
Multi-attribute value function	0,550	0,478	0,677	0,483	0,516
High-level objectives scores					
Cost	0,278	0,111	0,167	0,278	0,111
Performance	0,106	0,126	0,288	0,206	0,127
Acceptability	0,167	0,241	0,222	0,000	0,278
Areas scores					
Economics	0,278	0,111	0,167	0,278	0,111
Waste management	0,000	0,083	0,083	0,042	0,042
Proliferation resistance	0,028	0,009	0,074	0,056	0,032
Environment	0,028	0,000	0,083	0,056	0,028
Country specifics	0,050	0,033	0,047	0,053	0,025
Maturity of technology	0,167	0,241	0,222	0,000	0,278

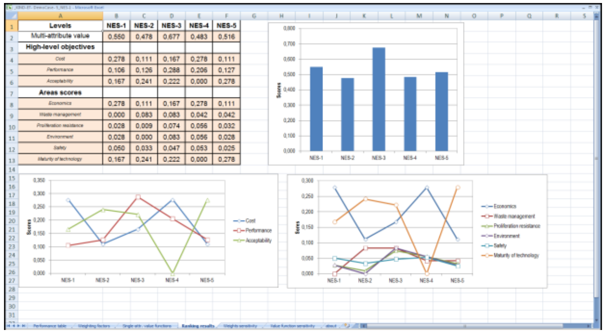


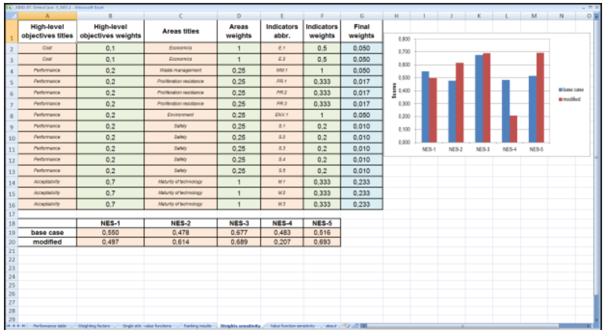


KIND-ET tool to support NES/scenario comparative evaluations

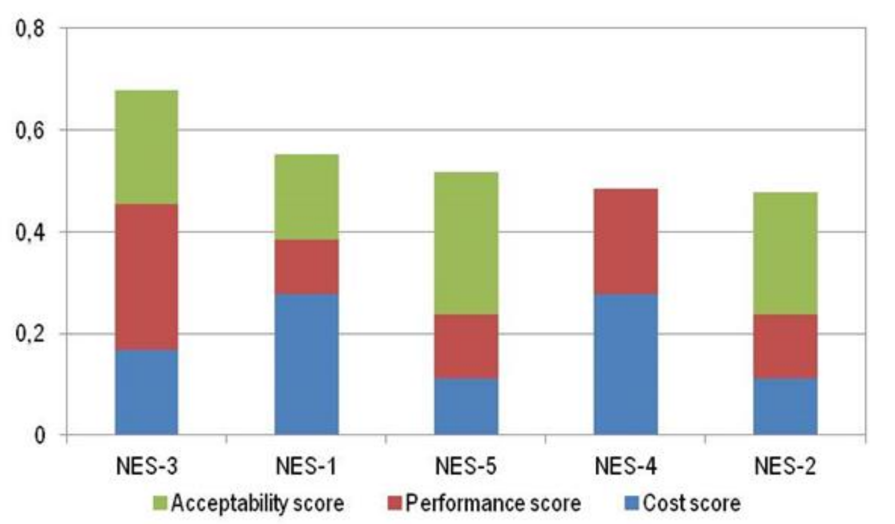
- To perform a multi-criteria comparative evaluation using the KIND-ET tool, users have to:
  - At their own discretion, specify a set of key indicators for NES/scenario comparative evaluation;
  - Identify a structure of the objectives tree (high-level objectives, evaluation areas, indicators and their hierarchical interrelation);
  - Prepare a performance table;
  - Determine single-attribute value functions for each indicator;
  - Evaluate weighting factors;
  - Perform sensitivity analysis;
  - Interpret ranking results and formulate recommendations.







KIND-ET: Presentation of results (example)

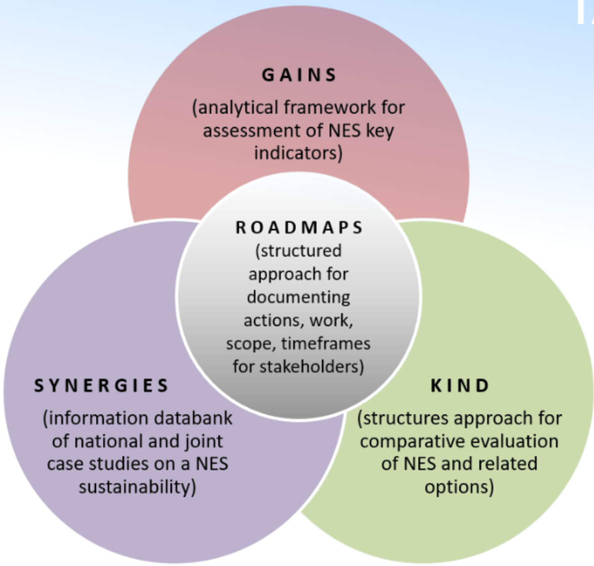


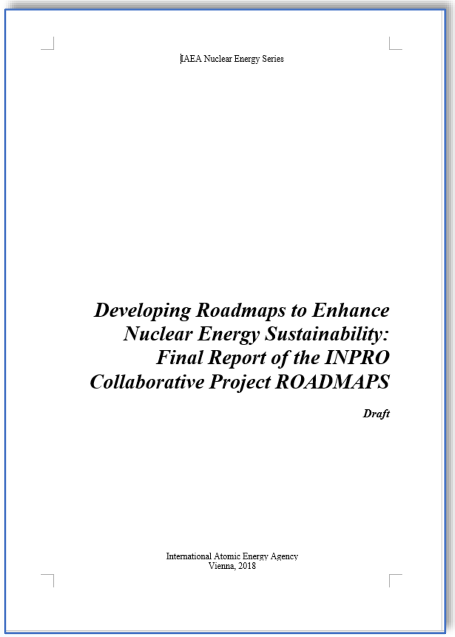
	Cost score	Performance score	Acceptability score	Total score
NES-1	0.278	0.106	0.167	0.55
NES-2	0.111	0.126	0.241	0.478
NES-3	0.167	0.288	0.222	0.677
NES-4	0.278	0.206	0	0.483
NES-5	0.111	0.127	0.278	0.516

Road mapping towards enhanced nuclear energy sustainability

The INPRO collaborative project “Roadmaps for a transition to globally sustainable nuclear energy systems” (ROADMAPS) has developed:

- ➢ The *roadmap template* representing a structured approach for achieving globally sustainable nuclear energy, providing models for international cooperation and framework for documenting actions, scope of work, and timeframes for specific collaborative efforts by particular stakeholders;
- ➢ An approach for bottom-up integration of national roadmaps to derive a regional or a global projection of a pathway towards enhanced nuclear energy sustainability;
- ➢ The ROADMAPS Excel Tool (ROADMAPS-ET) supporting practical application of the above mentioned approaches and the analysis/visualization of the results of such applications;
- ➢ Examples of a trial application of the roadmap template and the integration approach in a series of case studies performed by project participants;





IAEA Nuclear Energy Series

Developing Roadmaps to Enhance Nuclear Energy Sustainability: Final Report of the INPRO Collaborative Project ROADMAPS

Draft

International Atomic Energy Agency
Vienna, 2018

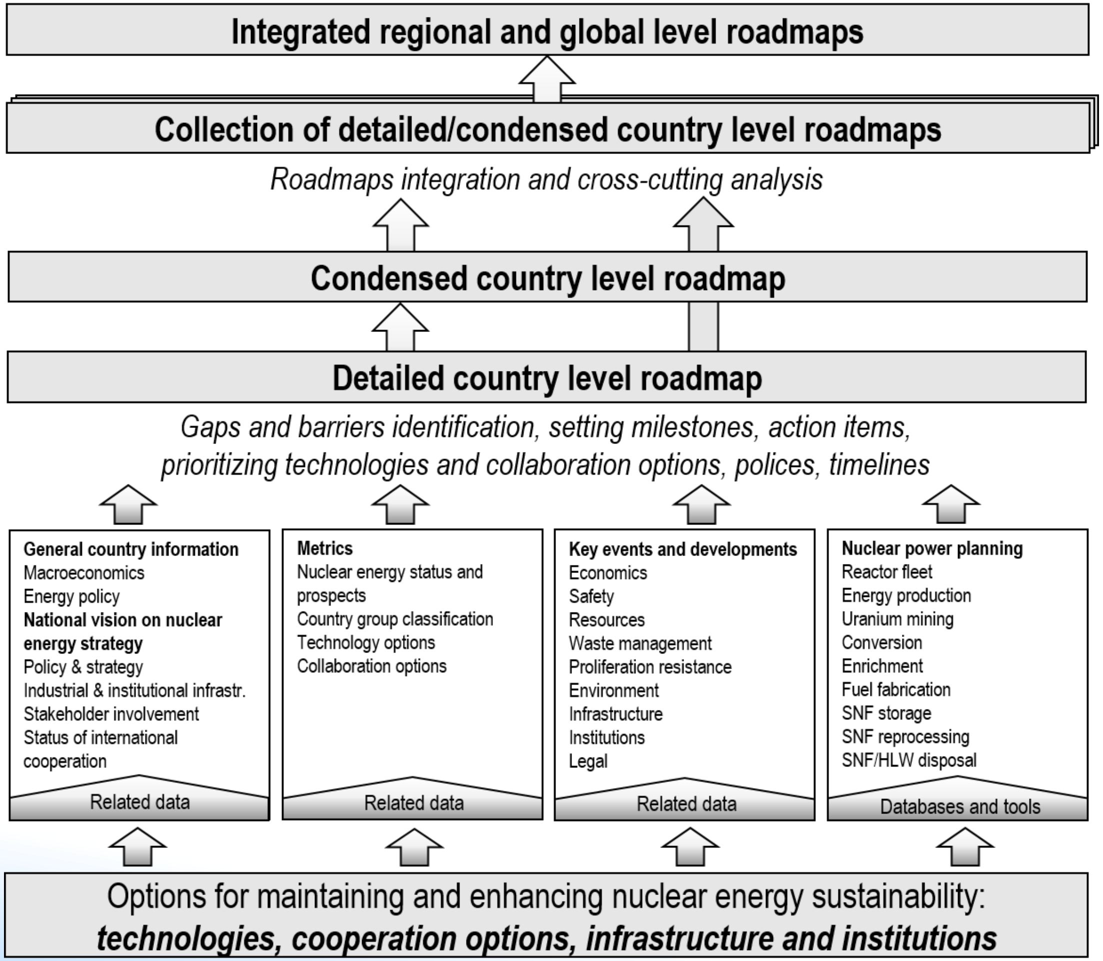
Benefits of road mapping

IAEA

- Carrying out road mapping for a national NES could assist in strategic planning for national nuclear energy development;
- When road mapping is performed in cooperation among technology users and possible technology providers, additional benefits resulting thereof are strategic insights on international market of products and services for peaceful applications of nuclear energy. With this, *providers could better plan expansions or cut-downs of their industrial capacities for certain products and services, while recipients would have a clearer picture of wherefrom the desired products and services could be procured and where could be the bottlenecks.*

Roadmap template

INPRO developed a *roadmap template* representing a structured framework for documenting actions, scope of work and timeframes for specific technological and collaborative efforts made by particular stakeholders to enhance, maintain and monitor enhancements towards more sustainable nuclear energy.



ROADMAPS Excel based tool (ROADMAPS-ET)

- ROADMAPS-ET is not a computational code but an analytical decision support tool for structuring and unifying data on issues related to NES sustainability enhancement.
- ROADMAPS-ET includes 20 sheets in an Excel workbook for specifying various elements of a roadmap
- The tool combines all these elements, following technical and practical logic, to help experts and decision-makers understand the main issues related to enhancing sustainability of nuclear energy.
- The outputs are visualized by means of the Gantt Charts showing key developments on a timeline and implementation schedule of action items.
- Included is nuclear fuel cycle material flow information for the existing and future reactors and the associated fuel cycle front-end and back-end. *This makes it possible to evaluate the adequacy of nuclear fuel cycle infrastructure and derive the supply−demand balances for nuclear cycle facilities in relation to a given NES evolution over time.*

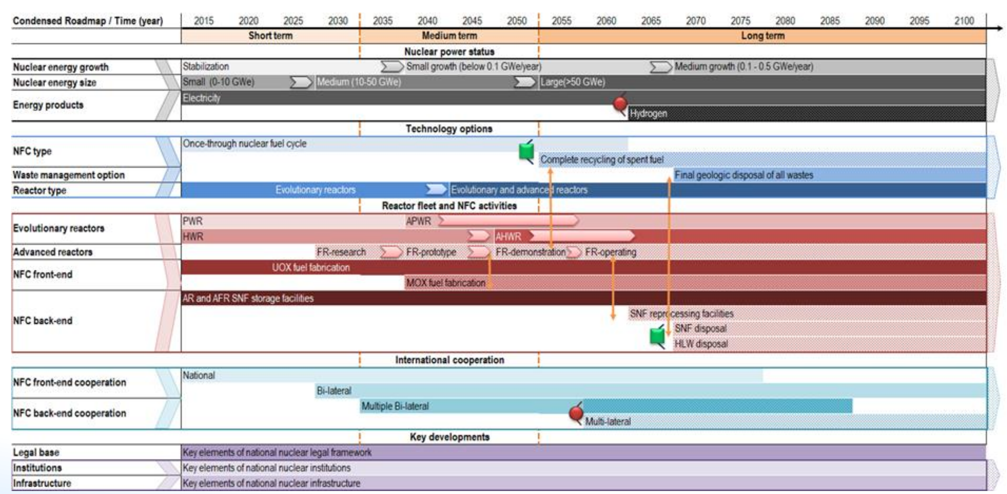
International Atomic Energy Agency

ROADMAPS EXCEL BASED TOOL

The INPRO Collaborative Project
'Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems (ROADMAPS)'

Content

General	Country Profile Metrics Key Developments Condensed Roadmap
Nuclear Fuel Cycle	Reactor Fleet Energy Production Uranium Mining and Milling Conversion Enrichment Fuel Fabrication Spent Fuel Storage Spent Fuel Reprocessing Geologic Disposal Status Monitoring
References	Reactor Database Lists Metric Integration Averaged Data Preparation About



INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

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Delivery of ASENES: Training

- INPRO developed **a series of training courses** for ASENES:
  - ✓ *Pilot (e-learning) training (self-paced study, distant learning)*
  - ✓ *Short (express) face-to-face training (duration: ~1 week)*
  - ✓ *Full-fledged face-to-face training (duration: ~2-3 weeks)*
- All training courses include the following **modules**:
  - ✓ *Economic analysis and evaluation*
  - ✓ *Scenario analysis and modelling*
  - ✓ *Comparison and ranking*
  - ✓ *Road mapping*

A wide range of skills could be acquired, from **familiarization with basic concepts and tools**, including skills in data processing, modification of pre-developed models, to **developing models from scratch** and adapting the tools for specific case studies

Delivery of ASENES: On-the-job training and support for national studies

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As part of this service, INPRO offers:

- on-the-job training providing national experts with an opportunity to work with the INPRO staff and experts, under various arrangements, and acquire experience on NES scenario analyses and relevant decision support;
- technical guidance and support for the conduct of national studies on exploring alternative strategies for development of sustainable nuclear energy.

The areas of potential application of the INPRO tools are rather wide. There are many on-going and planned IAEA activities (along with projects within other international nuclear organizations, such as OECD/NEA, WNA, etc.) in which utilization of the INPRO tools can be beneficial in terms of extending and supplementing analyses that are being or have been planned to be carried out.

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Contact us, *if you have further questions or wish to be a recipient of ASENES*

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Thank you!