USER INSTRUCTIONS FOR
ROADMAPS EXCEL BASED TOOL (ROADMAPS-ET)
Gantt charts based excel tool for the INPRO project
‘Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems’
(ROADMAPS)

INTERNATIONAL ATOMIC ENERGY AGENCY, 2021

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1. INTRODUCTION

1.1. BACKGROUND

ROADMAPS Excel based tool (hereinafter ROADMAPS-ET) is an open-source, flexible, universal and user friendly tool designed for analyzing and presenting nuclear energy system (NES) deployment strategies at the national, regional and global levels elaborated within the INPRO collaborative project 'Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems (ROADMAPS)' [1].

ROADMAPS-ET is not a computational code but an analytical decision support tool for structuring and unifying data presentation on issues related to the transition to NESs with enhanced sustainability using Gantt charts, which are very popular in project management applications to illustrate a project schedule and can serve as one of the planning methods [2].

ROADMAPS-ET is developed on basis of recommendations from Member States that participated in technical and consultancy meetings on the ROADMAPS collaborative project, the INPRO Dialogue Forum 11 "Roadmaps for a transition to globally sustainable nuclear energy systems" convened in October 2015 at IAEA [3]. The tool was further elaborated by taking into account requests and suggestions of the direct-acting users from Armenia, Belarus, Romania, Russian Federation, Ukraine, some newcomer-countries participating in series of web-conferences under the active supervision of the INPRO/ROADMAPS secretariat including a group of external consultants and the INPRO staff.

ROADMAPS-ET can be used for strategic planning, analytical studies, preparation of reporting documentation for management and summaries for the media regarding issues related to the transition to NESs with enhanced sustainability.

ROADMAPS-ET is expected to be used by qualified experts who are interested in the integration of all the factors and aspects (technological, collaborative, institutional) influencing nuclear energy development in a sustainable manner and provides the unified presentation of NES deployment strategies within a common roadmap framework. In case of need, along with ROADMAPS-ET other specialized software tools can be used to prepare input data for roadmaps. The specific features of ROADMAPS-ET are as follows:

- The tool incorporates feedbacks from trial road mapping studies performed within the ROADMAPS collaborative project;
- The tool is consistent with the existing IAEA and other open access nuclear power and nuclear fuel cycle related databases and information sources (PRIS [4], NFCIS [5], WNA [6], WISE-URANIUM [7], etc.);
- The aggregation functionality is included enabling the construction of regional or global roadmaps based on the national and regional roadmaps with a given level of detail;
- A capability to be integrated with external material flow analysis tools and nuclear fuel cycle calculators is included;
- When found necessary, the tool can be easily modified by the end user;
- Ease of use (no installation is needed; no macros are included — it is simply a spreadsheet).

The ROADMAPS-ET tool and the User Instruction are provided on a CD attached to the final report on the ROADMAPS collaborative project. To support the application guidance provided in the User Instruction, the CD also offers a hypothetical example of the roadmap development.

1.2. STRUCTURE OF THE ROADMAPS EXCEL-BASED TOOL

ROADMAPS-ET includes several structural elements combined by common logic to characterize the current state and plans for NES development in the long-term as well as provide necessary data and analytical support of experts and decision-makers on issues related to the transition to NESs with enhanced sustainability:

- 'Country profile' — to characterize the current state of economic and energy surroundings where the NES is being deployed;
- 'Key developments and events' — to construct Gantt charts reflecting the main events, developments and milestones that require implementation within different timeframes to ensure the transition to NESs with enhanced sustainability;
- 'Metrics' — to specify the NES features in technological and collaborative contexts within various timeframes;
- 'Condensed roadmap' — to represent a concise, illustrative, and interactive report per one sheet/screen;
- 'Nuclear fuel cycle material flows' — to reflect the existing and planned reactor fleet, the requirements for products and services of the nuclear fuel cycle front-end and back-end, the availability and plans for the deployment of the fuel cycle infrastructure and the supply-demand balances for the capacities of fuel cycle facilities in relation to the given reactor fleet evolution within selected timeframes;
- 'Aggregations' — to construct aggregated roadmaps for groups of countries.

ROADMAPS-ET consists of 20 excel worksheets combined into the following sections:

- Main (Navigation panel);
- Country Nuclear Power Profile:
  - Country Profile;
  - Metrics;
  - Key Developments;
  - Condensed Roadmap;
- Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities:
  - Reactor Fleet;
  - Energy Production;
  - Uranium Mining and Milling;
  - Conversion;
  - Enrichment;
  - Fuel Fabrication;
  - Spent Fuel Storage;
  - Spent Fuel Reprocessing;
  - Geological Disposal;
  - Status Monitoring;
- Supporting Tools and References:
  - Reactor Database;
  - Lists;
  - Metric Integration;
  - Averaged Data Preparation;
  - About.

The above worksheets are the basic ones: the user can add new worksheets, modify them, if necessary, to reflect specifics of a particular study to be considered (HLW flows, plutonium stocks etc.). However, modifications in the 'Metrics' worksheet are not applicable, since the data will be used to prepare the 'Metric integration' worksheet with the unified structure. The user should prepare 'Metrics' worksheet in accordance with this User Instructions, but if changes are necessary in terms of specific development of NES, it is recommended to create a copy of the ‘Metrics’ worksheet and make changes there.

1.3. NAVIGATION PANEL

The first worksheet is designed to help the user navigate through ROADMAPS-ET. This worksheet contains a list of all pages, and when the user clicks on the name of a relevant worksheet, it navigates to that worksheet through a hyperlink (Fig. 1). Returning to the ‘Main’ worksheet is carried out by clicking on A1 cell at each worksheet.

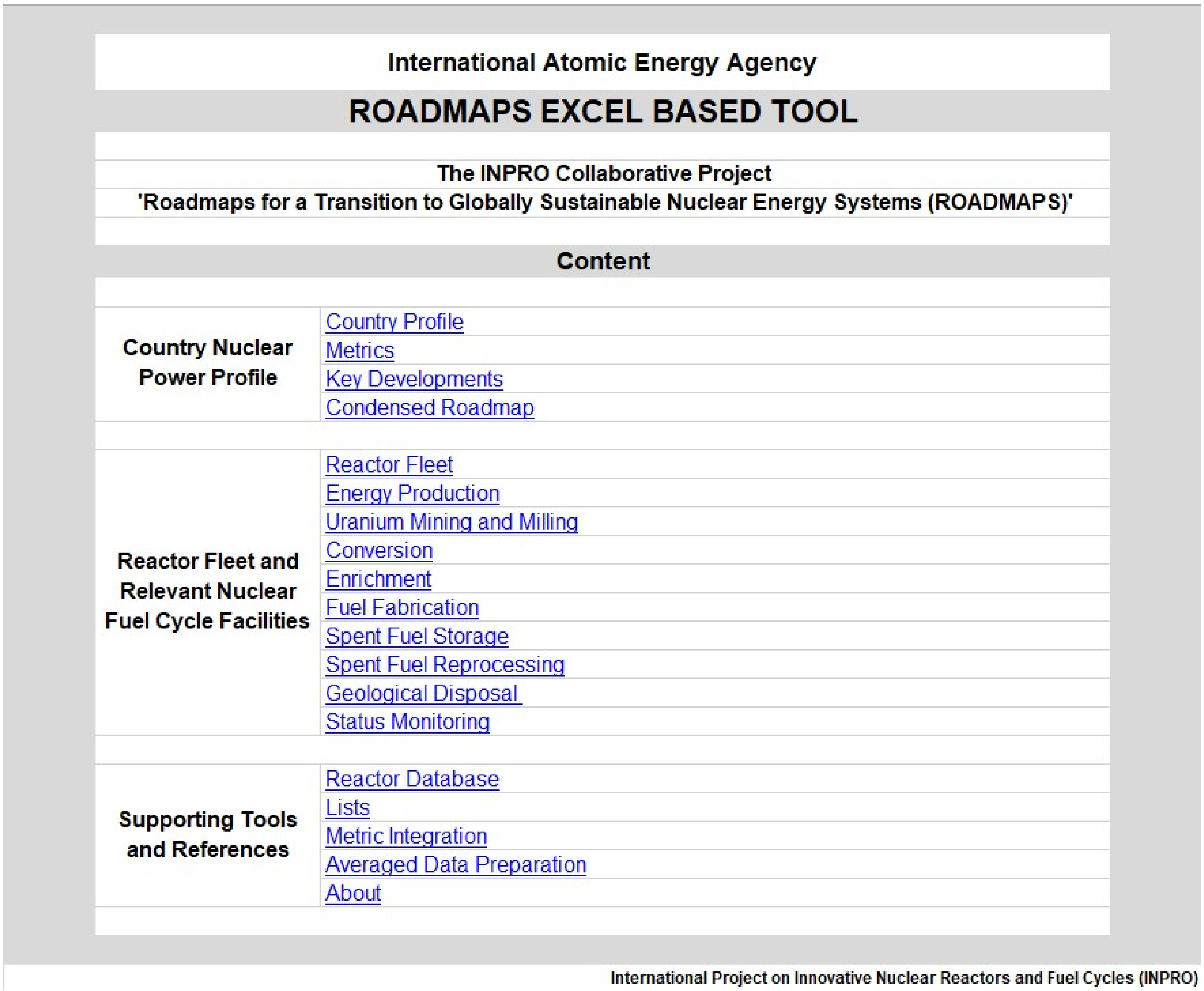


FIG. 1. Navigation panel – the ‘Main’ worksheet.

All worksheets of ROADMAPS-ET are divided into groups corresponding to the information and data contained therein:

- *‘Country Nuclear Power Profile’* section – worksheets of this section contain basic information about the country, status and plans for the development of nuclear power and marked aspects of international activities in the field of nuclear power development.
- *‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities* section – worksheets of this section provide more detailed information and data on the installed capacity and structure of nuclear reactor fleet, requirements for nuclear fuel cycle front-end and back-end facilities and their available capacities.
- *‘Supporting Tools and References’* section – worksheets of this section include supplementary excel worksheets and worksheets containing reactor database.

2. ‘COUNTRY NUCLEAR POWER PROFILE’ SECTION

2.1. ‘COUNTRY PROFILE’ WORKSHEET

This worksheet presents the country’s key energy statistics. This information characterizes the general situation in the energy sector and economics that affect the nuclear power deployment and the prospects for its further development. All data are divided into the following 4 groups.

‘General’ – this section specifies the name of the country, year of data provided, population, overall GDP and GDP per capita. The user should specify these data in the right column (Fig. 2).

General

Country	
Year	
Population, mln	
GDP, bln USD	
GDP per capita, 10^3 USD/c	-

FIG. 2. ‘General’ data.

‘Primary Energy Supply and Demand’ – this section provides data on the total primary energy supply, contribution of different energy sources to the primary energy supply; The total primary energy supply per capita and per unit of GDP are calculated based on data provided by the user in the marked cells (Fig. 3).

The data on the energy demand by sectors demonstrate the structure of energy utilization by various economic sectors in the country. The tool uses, by default, the most common units for the supply/demand of primary energy sources – million tonnes of oil equivalent (Mtoe); for the primary energy supply per capita – toe/person; and for the primary energy supply per unit of GDP – toe/USD.

Energy Supply and Demand

Total Primary Energy Supply, Mtoe	
Coal	
Oil	
Natural gas	
Nuclear	
Hydro	
Renewables	
Energy imports	
Energy exports	
Energy supply per capita, toe/c	-
Energy supply per unit GDP, toe/10^3 USD	-

Energy Demand by Sector	
Industry	
Transportation	
Agriculture	
Commercial & public services	
Residential	
Non-energy use and other	

FIG. 3. Supply and demand of primary energy sources.

'*Electricity and Emissions*' – this section illustrates data regarding the total amount of electricity generated in the country and its structure; the ratio of the total electricity supply produced per capita and per unit of GDP (Fig. 4). The most common units are used by default for the total electricity supply – TW·h; for the ratio of the total electricity supply per capita – MW·h/person; and for the ratio of the total amount of electricity supply per unit of GDP – kW·h/USD.

The section also provides data on the total amount of CO_2 emissions and their production by different economic sectors, the ratio of the total amount of emissions per capita and per unit of GDP. The following units are used by default: the total amount of CO_2 emissions – million tons; the ratio of total amount of CO_2 emission per capita – tons of CO_2 / person; the ratio of total amount of CO_2 emissions per unit of GDP ratio – tons of CO_2 / thousand USD.

Electricity and Emissions

Total Electricity Supply, TWh	
Coal	
Oil	
Natural Gas	
Nuclear	
Hydro	
Renewables	
Imports	
Export	
Electricity supply per capita, MW·h/c	-
Electricity supply per unit GDP, kW·h/USD	-

CO_2 Emissions, Mt	
Industry	
Transport	
Non-energy use	
Others	
CO_2 emissions per capita, t/c	-
CO_2 emissions per unit GDP, t/10^3 USD	-

FIG. 4. Electricity production and CO_2 emissions.

'Nuclear Power' – this section characterizes national nuclear power (Fig. 5) and includes four sub-sections: reactor fleet, nuclear fuel cycle facilities, nuclear fissile material stocks, and spent nuclear fuel:

- 'Reactor Fleet' sub-section indicates the total installed capacity of nuclear reactors combined in the following groups: HWR, PWR, BWR, AGR and GCR, FR and others (by default MW(e) are used as units).
- 'Nuclear Fuel Cycle Facilities' sub-section identifies the available capacities for uranium mining, conversion, enrichment, fuel fabrication, spent fuel storage and reprocessing facilities, spent fuel /HLW geological disposal (units used are shown in Fig.5).
- 'Nuclear Fissile Material Stocks' sub-section specifies the available stocks of fissile materials (highly enriched uranium and civilian plutonium); tonnes are used as units by default. This sub-section is designed for technology user/holder countries, which have facilities for uranium enrichment and reprocessing of spent nuclear fuel with separation of plutonium from other minor actinides.
- 'Spent Nuclear Fuel' subsection reflects the total amount of accumulated spent fuel produced by different reactor types in t HM.

Nuclear Power

Reactor Fleet, GW	
HWR	
PWR	
BWR	
AGR & GCR	
FR	
Others	
Nuclear Fuel Cycle Facilities, capacity	
Uranium mining and milling, t U	
Conversion, t U	
Enrichment, t SW	
Fuel fabrication, t HM	
SNF storage, t HM	
SNF reprocessing, t HM	
SNF/HLW disposal, t HM	
Nuclear Fissile Material Stocks, t	
HEU	
Plutonium (civilian)	
Spent Nuclear Fuel, t HM	
HWR	
PWR	
BWR	
AGR & GCR	
FR	
Others	

FIG. 5. Information on national nuclear power.

The data required to fill the ‘Country Profile’ worksheet can be obtained from databases, publications, annual reports of different national and international energy and nuclear power related organizations (such as the IEA, IAEA, NEA/OECD, etc.) or informational sources of various associated companies, responsible ministries and agencies in the specific country. Some reference sources, which may be used to populate the tables of the ‘Country Profile’ worksheet, are given below and shown in the area indicating the used references (Fig. 6) at the bottom of the base ‘Country Profile’ worksheet:

- http://www.world-nuclear.org/
- http://www-pub.iaea.org/MTCD/Publications/PDF/CNPP2014_CD/countryprofiles/
- https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf
- https://www.oecd-nea.org/rwm/profiles

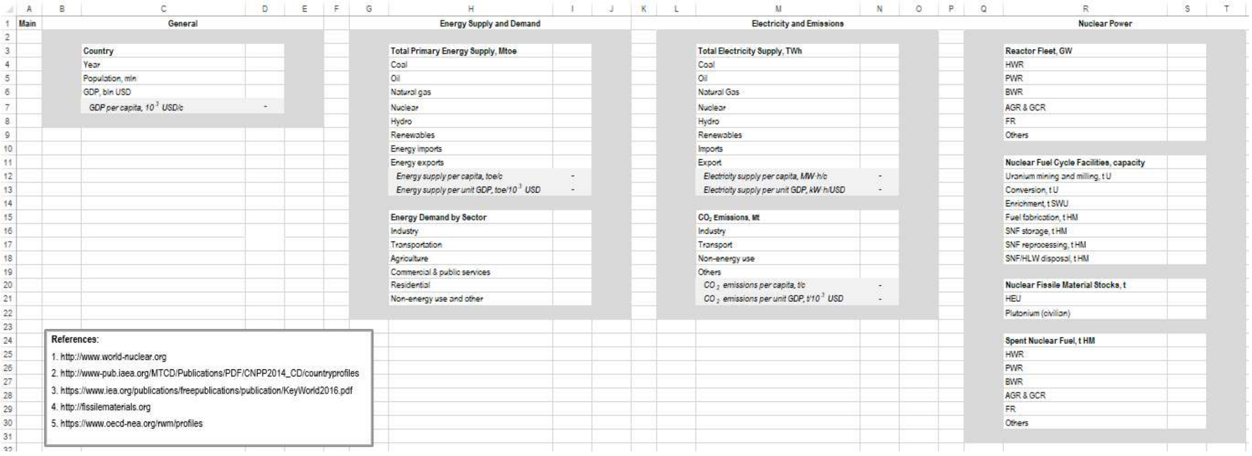


FIG. 6. 'Country Profile' worksheet and reference area.

2.2. 'METRICS' WORKSHEET

The 'Metrics' worksheet provides a qualitative characterization of the current state of nuclear power industry in the country and prospects for its further development. In this worksheet, seven sections have to be filled in by selecting the most appropriate item from the drop-down lists. The data presented in this worksheet characterizing different countries may be combined to provide integrated statistics (see 'Metric Integration' worksheet).

2.2.1. Signal status indicators

Signal status indicators offer a unified presentation of general information regarding the current situation in the national nuclear industry. An appropriate value has to be selected from the drop-down menu for each indicator (Fig. 7). Colour gradations of indicator values are implemented: green – excellent, yellow – good, orange – fair, red – poor, and grey – no data available or applicable ('not applicable').

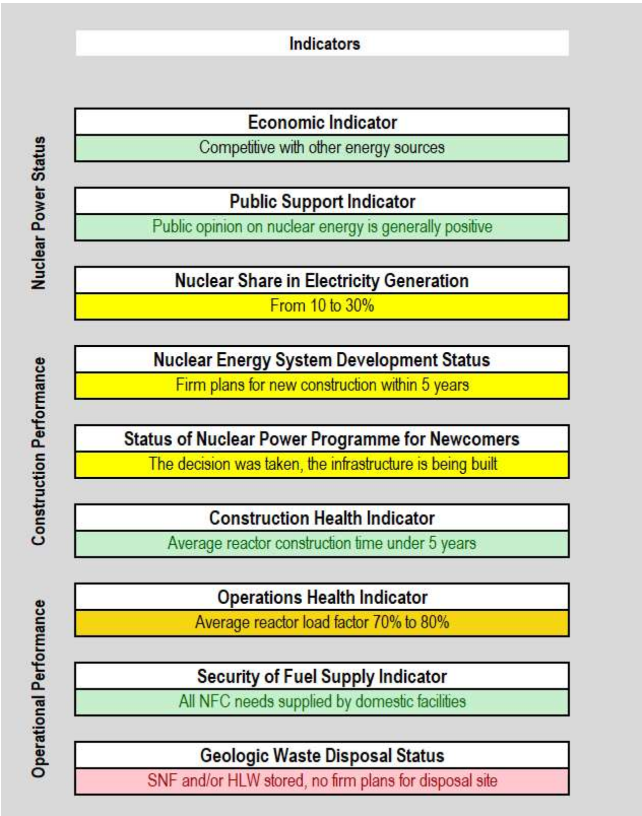


FIG. 7. Form of signal status indicators.

'Economic Indicator' represents the nuclear power economics and may be assessed based on the results of national studies on the economic indicators of different energy sources (for instance, the recommendations of the INPRO methodology to determine the levelized cost of electricity, the total investment and the internal rate of return, etc.). The following items may be selected from the drop-down list to characterize the nuclear power economics:

- Competitive with other energy sources;
- Competitive in most markets;
- Competitive in limited markets;
- Loss of competitiveness.

'Public Support Indicator' indicates the public attitude to nuclear power taking into account the following general positions on acceptance:

- Public opinion on nuclear energy is generally positive;
- Public opinion on nuclear energy is mixed/improving;
- Public opinion on nuclear energy is mixed/declining;
- Public opinion on nuclear energy is generally negative.

'Nuclear Share in Electricity Generation' shows the nuclear share of electricity net generation:

- Not Applicable
- Greater than 30 %
- From 10 to 30%
- Less than 10%

'Nuclear Energy System Development Status' presents the plans for the construction of a new NPP in the country, which characterize the attitude of the country for further development of nuclear power by the following items:

- Not applicable;
- Reactors currently under active construction;
- Firm plans for new construction within 5 years;
- Plans for new construction, beyond 5 years;
- No plans for new construction.

'Status of Nuclear Power Program for Newcomers' characterizes the status of nuclear power program in a newcomer country:

- Not Applicable;
- The first NPP under construction or commissioning;
- The decision was taken, the infrastructure is being built;
- Active feasibility studies under way;
- Expressing interest in a national nuclear energy programme.

'Construction Health Indicator' indicates the average reactor construction time, which characterizes the level of the NPP construction performance and includes the following items:

- Not Applicable;
- Average reactor construction time under 5 years;
- Average reactor construction time under 6 years;
- Average reactor construction time under 7 years;
- Average reactor construction time over 7 years.

'Operations Health Indicator' reflects the operational status of NPPs by the items below:

- Not Applicable;
- Average reactor load factor over 90%;
- Average reactor load factor 80% to 90%;
- Average reactor load factor 70% to 80%;
- Average reactor load factor below 70%.

'Security of Fuel Supply Indicator' characterizes the assurance of nuclear fuel supply in the country and includes the following items:

- Not Applicable;
- All NFC needs supplied by domestic facilities;
- Signed agreements with 3 or more independent suppliers;
- Signed agreements with 2 independent suppliers;
- 1 signed supplier agreement (monopoly);
- No confirmed fuel suppliers.

'Geologic Waste Disposal Status' addresses the issues regarding the status of spent fuel and HLW geological disposal and contains the following items:

- Not Applicable;
- Active geological disposal of SNF or HLW;
- Disposal site under construction;
- Disposal site selected;
- SNF and/or HLW stored, no firm plans for disposal site.

For some specific studies, the set of used signal status indicators may be extended or modified by the user, if needed. The lists of all indicators are located in the 'Lists' worksheet.

2.2.2. Prospects for nuclear energy: size and growth

This section specifies the existing and expected growth of nuclear power capacities and total installed capacity of nuclear power (Fig. 8). The following items describe the capacity growth: decrease, stabilization, small growth (below 0.1 GW(e)/year), medium growth (0.1–0.5 GW(e)/year) and significant growth (>0.5 GW(e)/year).

The items characterizing the total installed capacities of nuclear power are as follows: small (0–10 GW(e)), medium (10–50 GW(e)) and large (>50 GW(e)). Each of these options is considered under four timeframes: current (c.y. – abbreviation for 'current year'), from c.y. to 2030 (short-term), from 2031 to 2050 (medium-term) and from 2051 to 2100 (long-term).

The user has to select one of the two items from the drop-down list in the cell: the mark "þ" means that information is approved officially – 'official plans' (displayed as ☑), whereas the mark "ü" means intentions (experts' opinion) – 'prospect' (displayed as ✓).

Prospects for Nuclear Energy: Size and Growth

Nuclear Energy Growth	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
Decreasing				
Stabilization	☑			
Small growth (below 0.1 GWe/year)		✓		
Medium growth (0.1 - 0.5 GWe/year)				
Significant growth (>0.5 GWe/year)				

Nuclear Energy Size	c.y.	c.y. – 2030	2030 – 2050	2050 – 2100
No nuclear				
Small (0-10 GWe)	☑			
Medium (10-50 GWe)		✓		
Large(>50 GWe)				

FIG. 8. 'Prospects for Nuclear Energy: Size and Growth' section.

2.2.3. Country group classification

In this section, the user identifies and assigns the country to a specific country group according to possible categorization under general and GAINS classifications (Fig.9). Within the general classification, the countries are placed in terms of nuclear power maturity into the following groups: technology holder countries, technology user countries and newcomer countries. The user specifies a corresponding option by selecting one of the two items from the drop-down list in the cell.

Within the GAINS classification proposed in the INPRO Collaborative Project 'GAINS', all countries may be subdivided into the NG1, NG2, NG3 country groups:

- **NG1:** The general strategy in this country group is to recycle spent fuel – the group plans to build, operate and manage spent fuel recycling facilities and permanent geological disposal facilities for highly radioactive waste.
- **NG2:** The general strategy is to either directly dispose of spent fuel, or reprocess spent fuel abroad – the group plans to build, operate and manage permanent geological disposal facilities for highly radioactive waste (in the form of spent fuel and/or reprocessing waste) and/or it works synergistically with another group to have its fuel recycled.
- **NG3:** The general strategy is to use fresh fuel, and send spent fuel abroad for either recycling or disposal, or the back end strategy is undecided – the group has no plans to build, operate and manage spent fuel recycling facilities or permanent geological disposal facilities for highly radioactive waste. They may obtain fabricated fuel from abroad and may arrange for export of their spent fuel.

Country Group Classification

General Classification	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
Holder		✓		
User	☑			
Newcomer				

GAINS Classification	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
NG1				
NG2		✓		
NG3	☑			

FIG. 9. 'Country Group Classification' section.

2.2.4. Technology options and domestic technology status

The ‘Technology option’ section designates available domestic technology options and technology options to which the country has access from abroad (Fig. 10). Several options may be specified simultaneously. All potential technology options should be provided for four time ranges: current, short-term, medium-term and long-term. The technology options are identical both for ‘National’ and ‘Abroad’ cases and include the following items:

- One-through nuclear fuel cycle;
- Recycle of spent fuel with only physical reprocessing;
- Limited recycling of spent fuel;
- Complete recycle of spent fuel;
- Minor actinides or minor actinides & fission products transmutation;
- Final geological disposal of all wastes.

The ‘Domestic technology status’ section includes four identical subsections specifying actual and expected national technological capabilities within specific timeframes (current, short-term, medium-term or long-term) with the identification of their status (research, prototype, demonstration, operating) (Fig. 11). The following options are included:

- Light water reactor;
- Heavy water reactor;
- High temperature gas cooled reactor;
- Small and medium sized reactor;
- Fast reactors;
- Accelerator driven system;
- Molten salt reactors;
- Uranium mining and milling;
- Conversion;
- Enrichment;
- Uranium fuel fabrication;
- Mixed uranium–plutonium fuel fabrication;
- Advanced fuel fabrication;
- Wet spent fuel storage;
- Dry spent fuel storage;
- Aqueous spent fuel reprocessing;
- Advanced spent fuel reprocessing;
- HLW forms;
- Geological disposal;
- Related industrial activities;
- Others.

Technology Options

National Technology Options

	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
Once-through nuclear fuel cycle	☑			
Recycle of SNF with only physical processing				
Limited recycling of spent fuel		✓		
Complete recycle of spent fuel				
MA or MA & FP transmutation				
Final geological disposal of all wastes				

Access to Technology Options Abroad

	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
Once-through nuclear fuel cycle				
Recycle of SNF with only physical processing	☑			
Limited recycling of spent fuel		✓		
Complete recycle of spent fuel				
MA or MA & FP transmutation				
Final geological disposal of all wastes				

FIG. 10. ‘Technology options’ section.

Domestic Technology Status

c.y.

	Research	Prototype	Demonstration	Operating
LWR				☑
HWR	✓			
HTGR				
SMR				
FR				
ADS				
MSR				
Uranium mining and milling				
Conversion				
Enrichment				
Uranium fuel fabrication				
Mixed uranium-plutonium fuel fabrication				
Advanced fuel fabrication				
Wet SNF storage				
Dry SNF storage				
Aqueous SNF reprocessing				
Advanced SNF reprocessing				
HLW forms				
Geological disposal				
Related industrial activities				
Others				

FIG.11. ‘Current year’ subsection of the ‘Domestic Technology Status’ section.

2.2.5. Collaboration with other countries and collaboration agreements

The ‘Collaboration with other countries’ section specifies country’s activities related to collaboration with other countries by marking areas in which such collaboration takes place or is planned within the different timeframes (current, short-term, medium-term and long-term) (Fig. 12). The following possible collaborative activities are included:

- Participate in information exchange activities;
- Joint R&D programs;
- Sharing of R&D facilities;
- Collaboration on nuclear fuel cycle front-end;
- NPP selling;
- NPP purchasing;
- Offer NPP operations services;
- Use NPP operations services;

– Offer NPP refuelling outage services;
– Use NPP refuelling outage services;
– Collaboration on nuclear fuel cycle international centres;
– Share an NPP with another country;
– Offer nuclear fuel cycle back end services;
– Use nuclear fuel cycle back end services;
– Offer nuclear fuel cycle full services;
– Use nuclear fuel cycle full services.

Collaboration with Other Countries

Collaboration Strategy

	c.y.	c.y. – 2030	2031 – 2050	2051 – 2100
Participate in information exchange activities	☑			
Joint R&D programs		☑		
Sharing of R&D facilities				
Collaboration on NFC front end			✓	
NPP selling				
NPP purchasing				
Offer NPP operations services				
Use NPP operations services				
Offer NPP refuelling outage services				
Use NPP refuelling outage services				
Collaboration on NFC international centres				✓
Share an NPP with another country				
Offer NFC back end services				
Use NFC back end services				
Offer NFC full services				
Use NFC full services				

FIG. 12. 'Collaboration with Other Countries' section.

The 'Collaboration agreements' section illustrates country's national, bi-lateral, multi-lateral and multi bi-lateral agreements for various nuclear fuel cycle stages and is subdivided in four subsections in a similar way as the 'Technology Options' section corresponding to selected time ranges (Fig. 13). The following possible collaborative activities are included:

– Produce/Offer uranium;
– Obtain uranium;
– Produce/Offer converted uranium;
– Obtain converted uranium;
– Produce/Offer enriched uranium;
– Obtain enriched uranium;
– Fabricate/Offer fuel;
– Obtain fuel fabrication service;
– Produce/Offer NPP design;
– Use NPP design service;
– Offer NPP operation service;
– Use NPP operation service;
– National spent fuel storage/Offer spent fuel storage service;
– Use spent fuel storage service;
– National reprocessing/Offer spent fuel reprocessing service;
– Use spent fuel reprocessing service;
– National disposal/Offer spent fuel disposal service;
– Use spent fuel disposal service;
– National HLW disposal/Offer HLW disposal service;
– Use HLW disposal service;
– Others.

Collaboration Agreements

c.y.

	National	Bi-lateral	Multi-lateral	Multiple bi-lateral
Produce/Offer uranium	☑			
Obtain uranium		☑		
Produce/Offer converted uranium			✓	
Obtain converted uranium				
Produce/Offer enriched uranium				✓
Obtain enriched uranium				
Fabricate/Offer fuel				
Obtain fuel fabrication service				
Produce/Offer NPP design				
Use NPP design service				
Offer NPP operation service				
Use NPP operation service				
National SNF storage/Offer SNF storage service				
Use SNF storage service				
National reprocessing/Offer SNF reprocessing service				
Use SNF reprocessing service				
National disposal/Offer SNF disposal service				
Use SNF disposal service				
National HLW disposal/Offer HLW disposal service				
Use HLW disposal service				
Others				

FIG. 13. 'Current year' subsection of the 'Collaboration Agreements' section.

Some options, filled with 'tan, background 2'colour in the 'National' column, are not applicable (Fig. 13).

Please note. *Do not forget to add an explanation of used symbols illustrating official plans (☑) and prospect (✓). Such explanation may be given in the picture, the figure title or directly in the text.*

2.3. 'KEY DEVELOPMENTS' WORKSHEET

Key events and developments, the implementation of which contributes to enhanced NES sustainability, can be specified in the roadmaps for different time intervals. Development of technological, infrastructural and institutional areas along with the development of collaborative mechanisms gives an opportunity to enhance sustainability by stepwise achieving the desirable targets, for example, set out in each subject area of the INPRO methodology for NES sustainability assessment. The key subject areas are economics, safety and security, resources, waste management, proliferation resistance, policy and public acceptance.

Non-official plans and plans unknown need to be defined in the timelines indicating key events and developments, as well as in official plans. Projections could be based on the continuation of the official plans but, if current plans could not be continued, it is better to indicate that plans are undetermined/undefined.

The 'Key Developments' worksheet of ROADMAPS-ET is intended to visualize timelines (Gantt chart diagrams) of important aspects of nuclear energy development in the country, which should be identified by the experts. The working area of the 'Key Developments' worksheet contains the following elements (Fig. 14):

- Zone 1 specifies a list of key events and developments to be reflected as timelines in the form of Gantt charts. The required number of aspects and subject areas within each aspect and key events/developments within each area should be identified by the user, and corresponding rows and their formatting should be provided (by clicking on its number by right mouse button and using the functions: 'insert' or 'delete' – it is preferable to add/delete rows in the middle of the table to keep the format intact).

- Zone 2 provides a construction of timelines by filling cells within the identified time ranges in which the corresponding key event/development takes place. After inserting any number in the cell of Zone 2, it is filled by blue colour for visualization (if the user needs to reflect the number put into the cell, it is necessary to select the appropriate colour at the excel panel).
- If it is necessary to distinguish between official plans and prospects in the constructed timelines, it can be done by, for instance, indicating them in a different colour or placing a special object or sign on the corresponding timeline, etc.

The user can change time steps depending on the task to be considered. An additional column may be added by selecting an entire column and by clicking on the column name and inserting a new column (the preferable way is to add columns in the middle of the table to keep the formatting unchanged).

FIG. 14. 'Key developments' worksheet.

> ***Please note.*** *Do not forget to add an explanation of used colours illustrating official plans and prospect. Such explanation may be given in the picture, the figure title or directly in the text.*

Figure 15 provides is a non-binding example of setting the key events and developments. A set of six areas important for enhancing NES sustainability (sustainability areas) was selected as basis for the identification of key events and developments. Each sustainability area contains several key events/developments, the achievement of which enhances sustainability of a NES in this area.

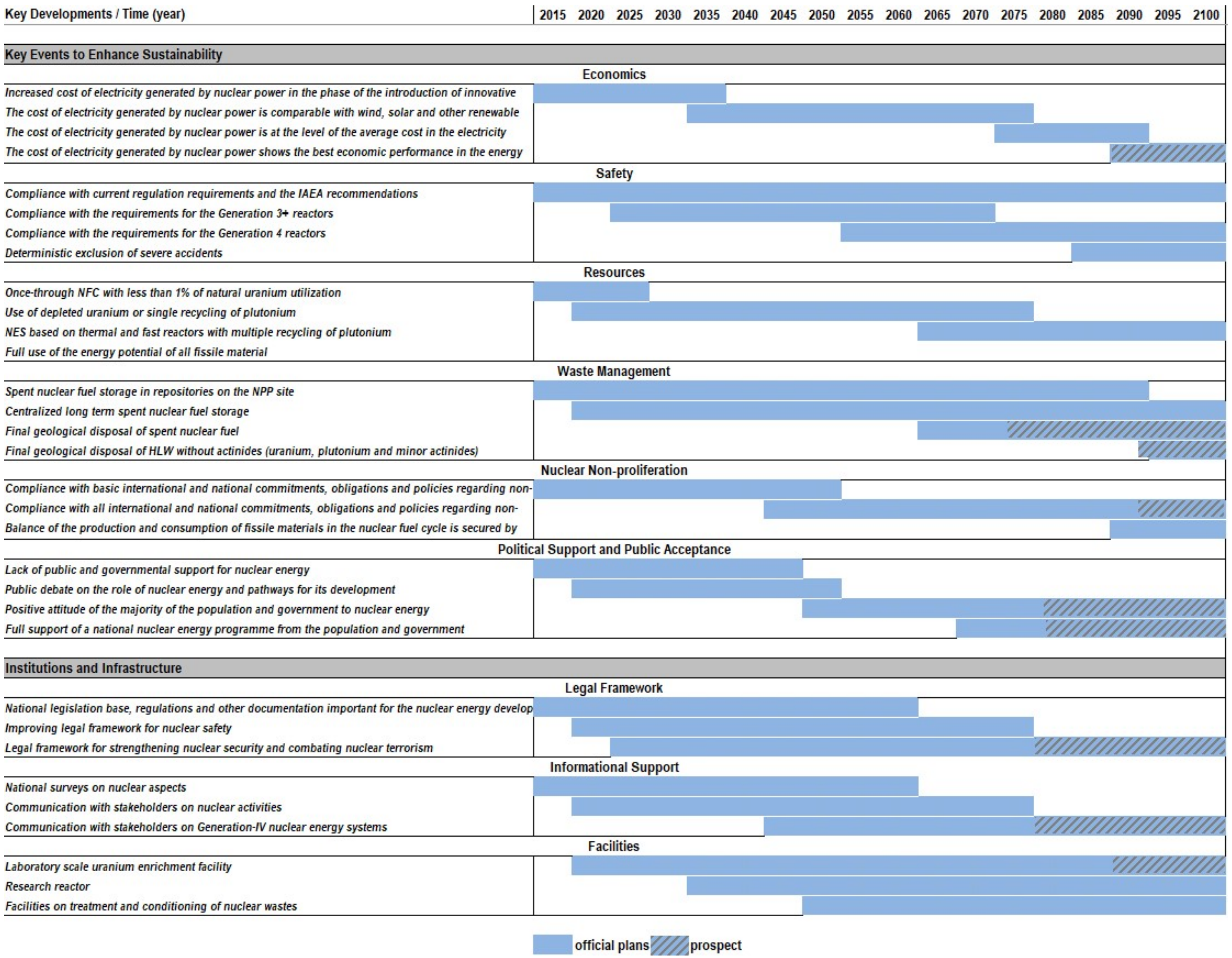


FIG. 15. Example of the 'Key Developments' presentation for a hypothetical case.

2.4. ‘CONDENSED ROADMAP’ WORKSHEET

The roadmaps include detailed information on national plans and projections for enhancing nuclear energy sustainability, such as long term nuclear power profile(s), material flows in the nuclear fuel cycle, etc. Along with the detailed roadmap, it appears reasonable to provide a condensed roadmap version, which would present a concise, illustrative, and interactive report in one figure based on the detailed roadmap. Such condensed presentation of the roadmap allows interested stakeholders, first of all, decision makers, to faster and more effectively understand the main aspects of the elaborated detailed roadmap.

Moreover, the limitations on data and information disclosure can be a significant issue, while the detailed roadmap can contain certain information and data that are sensitive or confidential. For this reason, the condensed roadmaps can also be useful for communications to broader public or targeted new foreign partners, etc.

The ‘Condensed roadmap’ worksheet allows constructing a simple and illustrative report, concentrated in a single diagram. The condensed roadmap can include several key structural elements combined by common logic to characterize the current state and plans/projections for NES development in the short, medium and long term (Fig. 16).

Time (year)	20__ 20__	20__ 20__	20__ 20__
	Short term	Medium term	Long term
Element			
Element item 1	specification of item 1		
Element item 2	specification of item 2		
…		specification of item i	
Element item N	specification of item N		

FIG. 16. Illustration of the condensed roadmap development.

Timeline

‘Timeline’ displays chronological order of NES deployment scenario within short, medium and long-term periods. In this area user has to specify time step and determine main periods for NES development. Usually, the time step is 5 years. User can change the time step for entire timeline, as well as for any of its periods. For example, the timeline can be divided into 3 periods: short-term (from current year to 2030), medium-term (2031–2050) and long-term (2051–2100).

Element

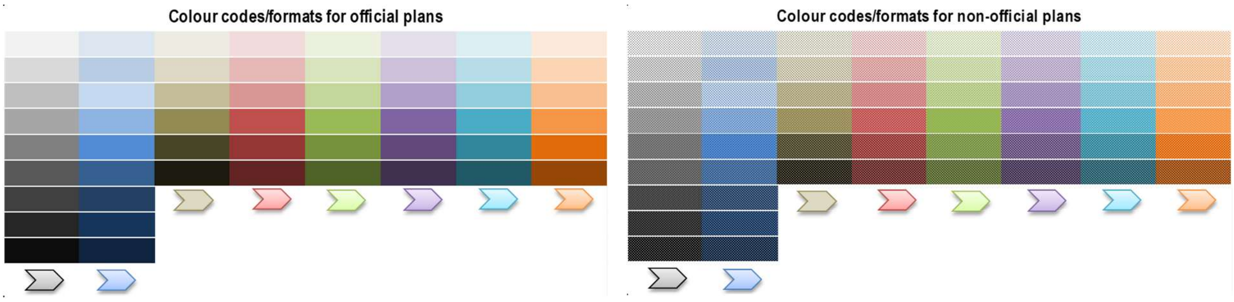
The ‘Elements’ are the main components needed for NES sustainability enhancement chosen by, experts from a country to present the official plans and projections for national NES evolution. Basically, the Element presents an information block, which can describe both the growth and the scale of a NES, or the directions of the nuclear fuel cycle development, or collaboration with other countries and forms of its implementation, etc.

Element item

‘Element item’ characterizes the evolution (e.g., development or deployment) of an element over particular periods of time, including technical parameters, economic performance and infrastructure and institutional arrangements. A country expert can specify Element items for each Element or according to his preferences. For example, element items within the ‘Nuclear power status’ element may include nuclear energy growth, nuclear energy size and energy products.

Specification of item

‘Specification of items’ is provided to reflect the official plans and non-official projections, including alternative scenarios, of NES evolution towards enhanced sustainability. To visually represent different item specifications the ‘Condensed roadmap construction toolkit’ is proposed (Fig. 17). The user can differentiate specification of items by selecting one of the cells from the construction toolkit, then using function “format painter” to apply it for selecting cells in the condensed roadmap. The difference between official plans and prospects in the constructed timelines is distinguished by dotted filling (Fig. 17 (b)).



a – Colour codes/formats for official plans *b – Colour codes/formats for non-official plans*

FIG. 17. Colour codes/formats.

The user may use additional elements to clarify transition points, decisions made[1] and correlation of scenarios within different elements (Fig. 18). Different elements on the Gantt charts can be used to clarify transition points, points in which decisions are to be made, and correlations between scenarios, etc. To use one of these elements, the user has to copy it from a legend, paste, and then drag-and-drop it to the selected place in the condensed roadmap. Transition nodes can be copied from the construction toolkit also.

‘Decision node’ indicates an independent decision to be made.	‘Chance node’ shows multiple uncertain outcomes, which depend on the decisions of third-parties and stakeholders.	‘Transition node’ assumes transition to the next scenario.	‘Links’ present connections between different scenarios.

FIG. 18. Elements for presentation of key points at roadmaps.

Other unspecified graphical elements such as borders, lines etc. may be applied to improve the visual presentation of the picture (it is up to the user vision, see Fig.19). For instance, the length of arrows may additionally if needed, characterize the intensity of relevant efforts associated with the considered aspects (financial resources, time efforts, etc.). All of these structural elements combined allow developing a complete condensed roadmap, taking into account any areas considered by a country.

[1] A decision and event nodes concept is borrowed from the decision tree approach. A decision tree is a map of the possible outcomes of a series of related choices.

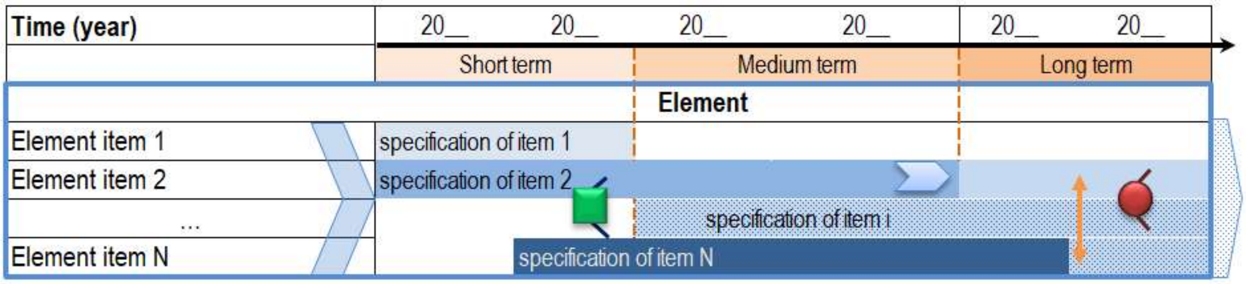


FIG. 19. Illustration of the condensed roadmap development.

Figure 20 provides a condensed roadmap example. This example is only for illustration purposes. The presented condensed roadmap includes the elements described in brief below.

Nuclear power status

This Element specifies the currently observed and expected growth of the nuclear power capacities and of the total installed capacity of nuclear power. The following scenarios describe the capacity growth: stabilization, small growth (below 0.1 GW(e)/year) and medium growth (0.1–0.5 GW(e)/year).

The items characterizing the total installed capacities of nuclear power are as follows: small (0–10 GW(e)), medium (10–50 GW(e)) and large (>50 GW(e)). Each of these is considered under three timeframes: short term (from the current year till 2030), medium term (2030–2050) and long term (2050–2100).

The items characterizing energy products include electricity and, in this example, hydrogen production; combined heat and power applications can be included also.

Technology options

This Element indicated available domestic technology options and the technology options to which the country has access from abroad. Several options can be specified simultaneously. The following items may be included: once-through nuclear fuel cycle, recycle of spent nuclear fuel with only physical processing, limited recycling of spent nuclear fuel, complete recycle of spent nuclear fuel, transmutation/incineration of minor actinides or minor actinides and fission products, final geological disposal of all wastes.

Reactor fleet and nuclear fuel cycle activities

This Element specifies the reactor types to be considered in the reactor fleet. It is possible to list individual reactors (for countries with small nuclear programmes) or reactor groups (for countries with a large reactor fleet employing different reactor types).

Collaboration with other countries

This Element specifies the types of collaboration (trade) with other countries in the areas where such collaboration takes place or is planned (or projected) within the different timeframes. The following possible forms of collaboration (trade) are included: national only, under a bi-lateral agreement, under multiple bi-lateral agreements, under a multi-lateral agreement.

Key events and developments

This Element is intended to visualize the important aspects of nuclear industry development in a country. The inputs are to be identified by country's experts. The following Element items (to be specified throughout the timeline) are included: legal base, institutions and infrastructure.

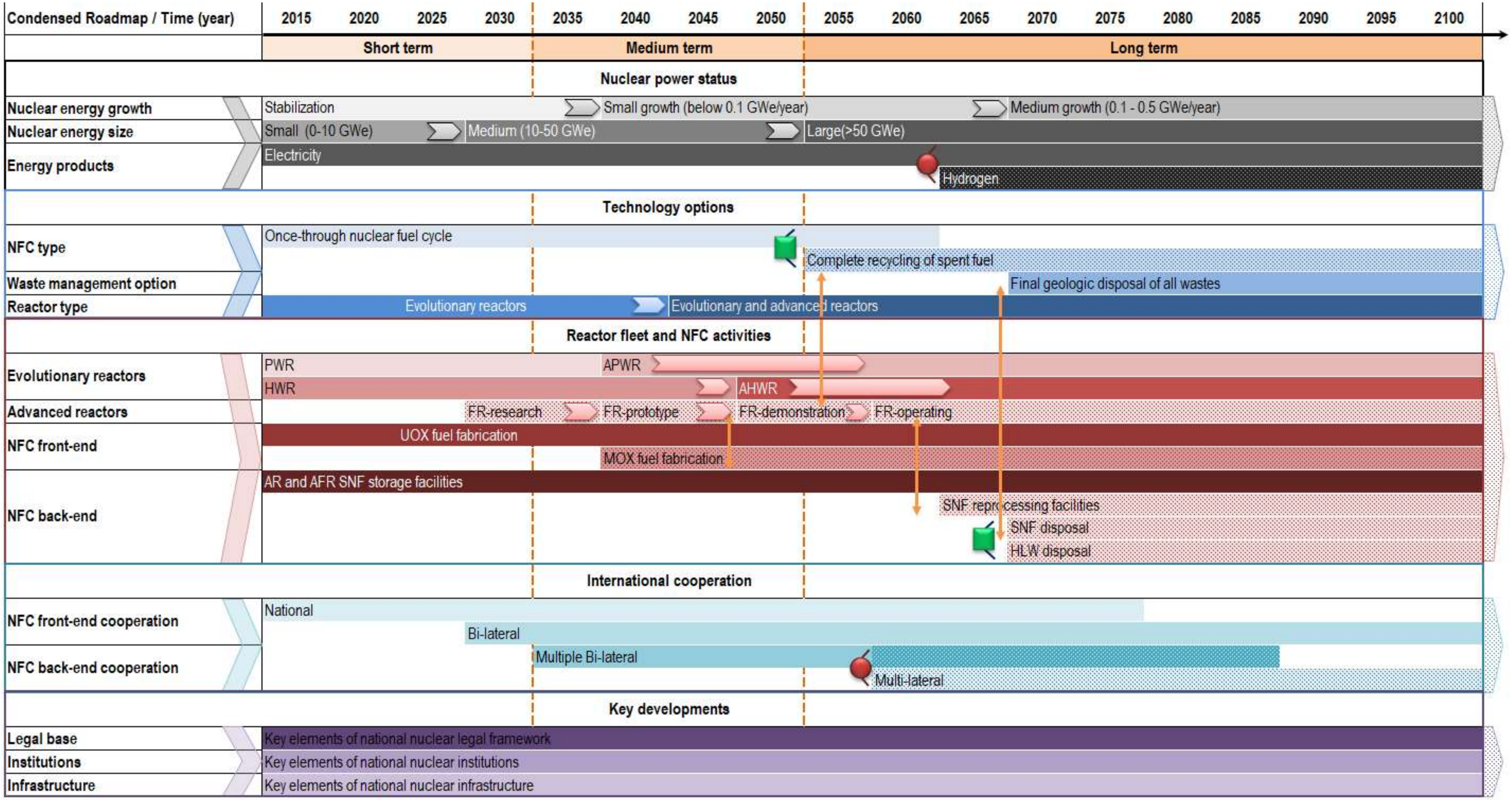


FIG. 20. Example of a condensed roadmap.

3. ‘REACTOR FLEET AND RELEVANT NUCLEAR FUEL CYCLE FACILITIES’ SECTION

3.1. GENERAL DESCRIPTION

The architecture of ROADMAPS-ET is open that allows users to modify the existing worksheets or add additional ones to calculate the supply-demand balances for other possible nuclear fuel cycle and related industrial activities (such as plutonium storing, transportation, HLW storage, etc.).

3.2. DATA AVERAGING

Each of the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section worksheet contains two areas:

- Gantt chart area for visualization of data presented in the table form with the utilization of excel conditional formatting,
- stacked area for visualization of associated data (see figures below).

Data represented in the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section worksheets to keep adequate reproduction of energy and mass flows should be averaged within the considered time steps if the associated steps cover several years. Such aggregation is reasonable to be applied for simplification of data presentation in the case study report. The relevant procedures of averaged data preparation are considered in the ‘Averaged data preparation’ worksheet of ROADMAPS-ET.

For example, we need to assess energy/mass flow for a certain nuclear fuel cycle step averaged in 5 years in case when we have annual data from 2016 till 2020 for energy/mass flows with annual production which linearly grows from 1000 up to 5000 c.u. per year (Fig. 21). As it is seen in Fig. 21, the 5-years period averaged flow is (1000+2000+3000+4000+5000)/5=3000, and the averaged cumulative flow is 1000+2000+3000+4000+5000=3000×5=15000.

The cumulative and averaged cumulative flows are equal, which demonstrates the correctness of the procedure of averaged initial data preparation – conservation of cumulative energy/mass flows. This averaged data should be used for preparing data for the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section.

Annual Data

Time (year)	**2016**	**2017**	**2018**	**2019**	**2020**
Flow (c.u. per year)	1000	2000	3000	4000	5000
Cumulative flow (c.u.· year)	1000	3000	6000	10000	15000

Averaged Data

Time range	**2016-2020**
Averaged flow (c.u. per period)	3000
Averaged cumulative flow (c.u.· year)	15000

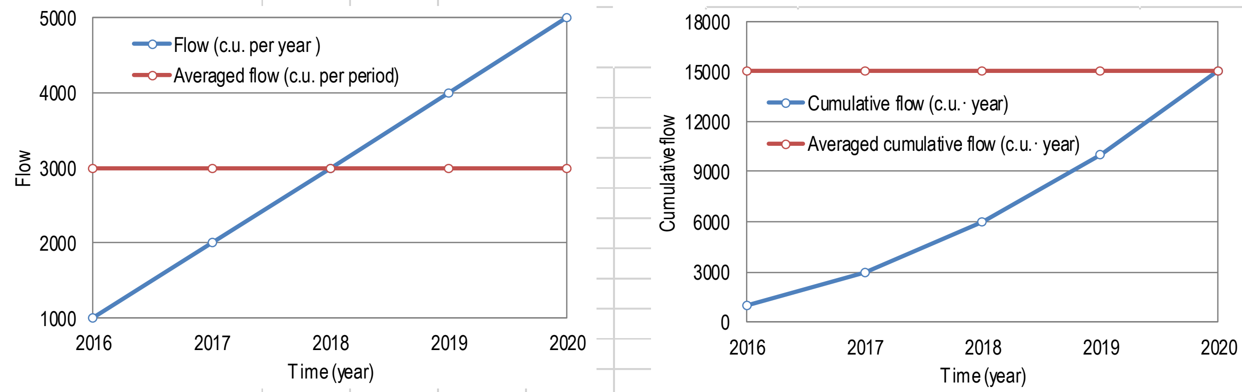


FIG. 21. Example of averaged data preparation.

Let us consider the following example how to prepare the averaged data for a time step covering several years if new reactor units are being commissioned within this time period. Let us suppose that the installed capacity of a reactor group will increase during 5 year period (from 2016 to 2020) (see Fig. 22). For the first year the installed capacity is 5000 MW(e). A new reactor unit with capacity of 1000 MW(e) is added to the group this year. Every next year one reactor unit with the same capacity will be added. The reactor added in 2017 will be operating from 2017 to 2020 that is 4 years. The reactor added in 2018 will be operating from 2018 to 2020 that is 3 years. It means that installed capacity in 2016 is 6 000 MW(e), in 2017 – 7000 MW(e), in 2018 – 8000 MW(e) and so on. The sum of installed capacities (40 000 MW(e)) should be divided into time step (5 years) to result in the net averaged installed capacity (8000 MW(e)) for the time range from 2016 to 2020 (Fig. 22).

	Annual Data					Averaged Data
MW	**2016**	**2017**	**2018**	**2019**	**2020**	**2016-2020**
Installed capacity	5000	5000	5000	5000	5000	5000
New unit 1	1000	1000	1000	1000	1000	1000
New unit 2		1000	1000	1000	1000	800
New unit 3			1000	1000	1000	600
New unit 4				1000	1000	400
New unit 5					1000	200
Total installed capacity	**6000**	**7000**	**8000**	**9000**	**10000**	**8000**

FIG. 22. Example of net installed capacity calculation of the one reactor group in time range 5 years.

The number of time-steps and their duration should be specified by the user and implemented within all worksheets of the 'Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities' section in a similar manner. Using the 'insert' and 'delete' columns functionality by the users, any appropriate number of time-steps may be provided.

The principal part of the 'Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities' section is specification of reactor types to be reflected in a roadmap. The number of reactor types and their aggregation in groups should be identified by the user: It may be individual reactor unit, the entire nuclear power plant, specific reactor type (e.g. PWR, BWR, WWER, CANDU, HWR, ACR, AGR, GCR, etc.), generalized reactor type (e.g. LWR, HWR, FR, etc.), group of reactor type (e.g. thermal reactors, fast reactors, etc.). Specification of main model assumptions is the area of responsibility of the expert elaborating a roadmap. Once the model assumptions are fixed, they should be used within the whole study. If it is required to create aggregated roadmaps, the same model assumptions should be selected and implemented for all local roadmaps.

Official plans and prospects should be marked both in the Gantt chart and stacked areas visualization. A possible option is to use different colours for data in the Gantt diagrams (for instance, black colour for official plans, white colour for prospects) and highlight the stacked graphs by a certain area (for instance, shaded area overlapping the prospects, see figures below).

Please note. *Do not forget to add an explanation of the used approach to illustrate official plans and prospects. Such explanation may be given in the picture, the figure title or directly in the text.*

3.3.DATA POPULATING AND VISUALIZING

The ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section includes the following three groups of worksheets:

- The first group contains ‘Reactor Fleet’ and ‘Energy Production’ worksheets specifying total installed capacities and energy production of a considered reactor fleet.
- The second group includes ‘Uranium Mining and Milling’, ‘Conversion’, ‘Enrichment’, ‘Fuel Fabrication’, ‘Spent Fuel Storage’, ‘Spent Fuel Reprocessing’ and ‘Geological Disposal’ worksheets characterizing activities in the nuclear fuel cycle front-end and back-end.
- The third group consists of a single worksheet, ‘Status Monitoring’ to monitor NES evolution toward NES with enhanced sustainability by a set of qualitative indicators specified by experts within a particular study.

Within the mentioned groups, the corresponding worksheets have the similar structure (the number of sections and elements to be populated) (Fig. 23). All these worksheets have two sections: the table with data represented in the Gantt chart format and ‘stacked area’ or ‘stacked column’ plots representing the data contained in the associated tables in a traditional visual form.

The first step in populating these worksheets is indicating reactor types to be considered in the ‘Reactor Fleet’ worksheet. It is possible to list individual reactors (for countries with small nuclear programs) or reactor groups (for the country with a large reactor fleet with different reactor types). Once reactor titles are specified in the ‘Reactor Fleet’ worksheet, all other worksheets (except ‘Status Monitoring’) will automatically use these reactor titles. The number of time steps and their duration for all worksheets should be the same.

Cells in the data area are automatically coloured in blue after inserting numbers that allow a Gantt chart to be painted based on this data. If it is necessary to indicate the official plans and prospects, different colours for numbers may be used (for instance, black – for official plans, and white – for prospects).

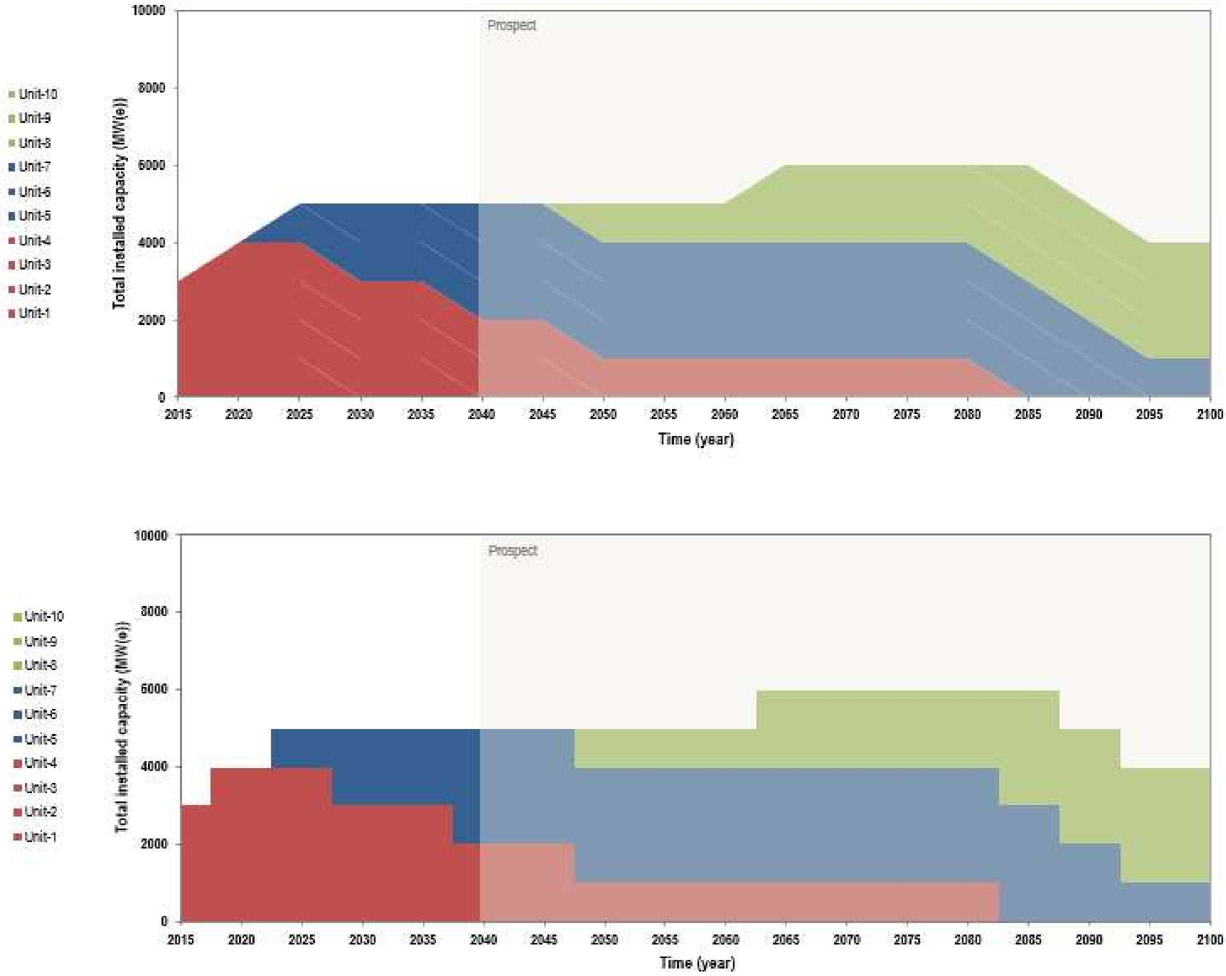
The final step is plotting a figure based on the data specified by inserting and adapting the ‘stacked area’ or ‘stacked column’ figure (other possible options are also available depending on the user visions and requests). Indicating the ‘prospect’ area in the graph may be represented, for instance, by covering a rectangle with white shape fill and 60% of the transparency from ‘shapes’. For a better visual presentation of the whole composition, the figure should have approximately the same length as the table. It is assumed that the user has an experience in working with MS Excel and, in particular, is able to build and customize graphs. In this regard, the corresponding steps do not describe herein.

To populate these worksheets, relevant data should be prepared and the following options may be proposed. The first option is to collect and adapt data from vendors or from open-access information sources (project reports, databases, etc.). The second option is to evaluate necessary data using the reactor database of ROADMAPS-ET or other nuclear fuel cycle material flow calculators/ software tools.

If it is decided to use data from the reactor database of ROADMAPS-ET or any other simple nuclear fuel cycle calculators, the following sequence of actions could be recommended to populate the worksheets of the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section (the relationships between the parameters are indicated in the corresponding subsections of this document):

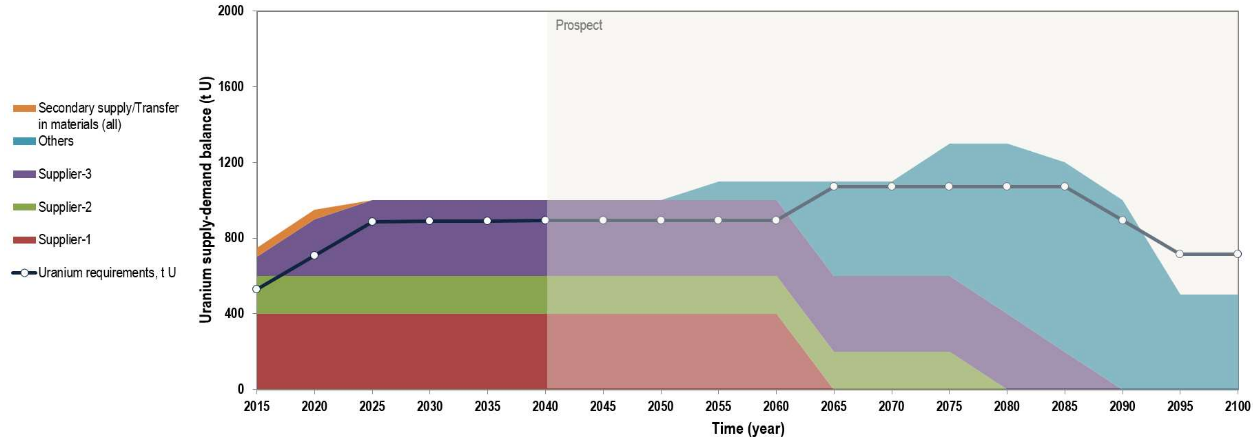
Reactor Fleet → Energy Production → Fuel Fabrication → Enrichment→ Conversion → Uranium Mining and Milling → Spent Fuel Storage → Spent Fuel Reprocessing → Geological Disposal → Status Monitoring

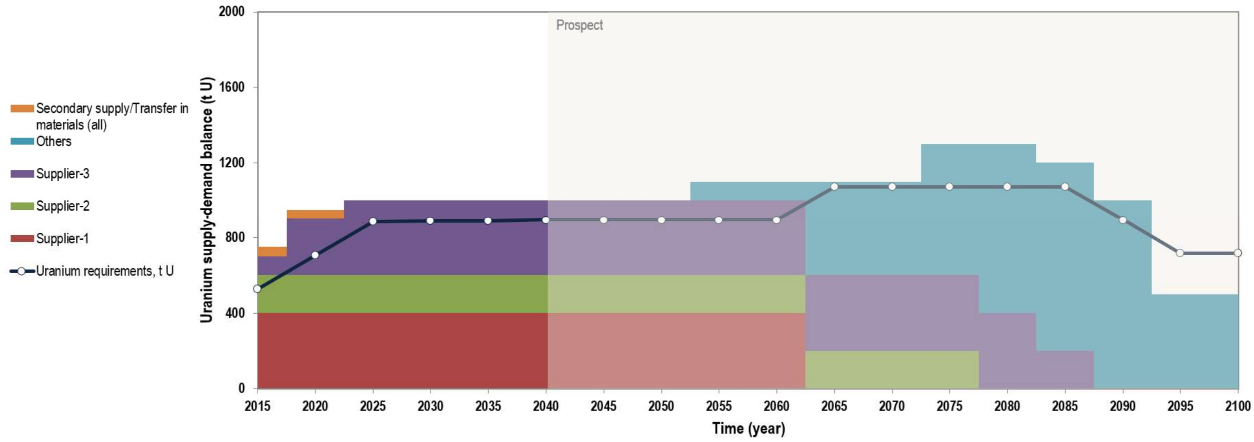
Total installed capacity, MW(e)	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Unit-1	1000	1000	1000															
Unit-2	1000	1000	1000	1000	1000													
Unit-3	1000	1000	1000	1000	1000	1000	1000											
Unit-4		1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000				
Unit-5			1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000			
Unit-6				1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000		
Unit-7						1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Unit-8								1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Unit-9											1000	1000	1000	1000	1000	1000	1000	1000
Unit-10															1000	1000	1000	1000
Total, MW(e)	3000	4000	5000	5000	5000	5000	5000	5000	5000	5000	6000	6000	6000	6000	5000	5000	4000	4000



a – Typical presentation of worksheets of the first group

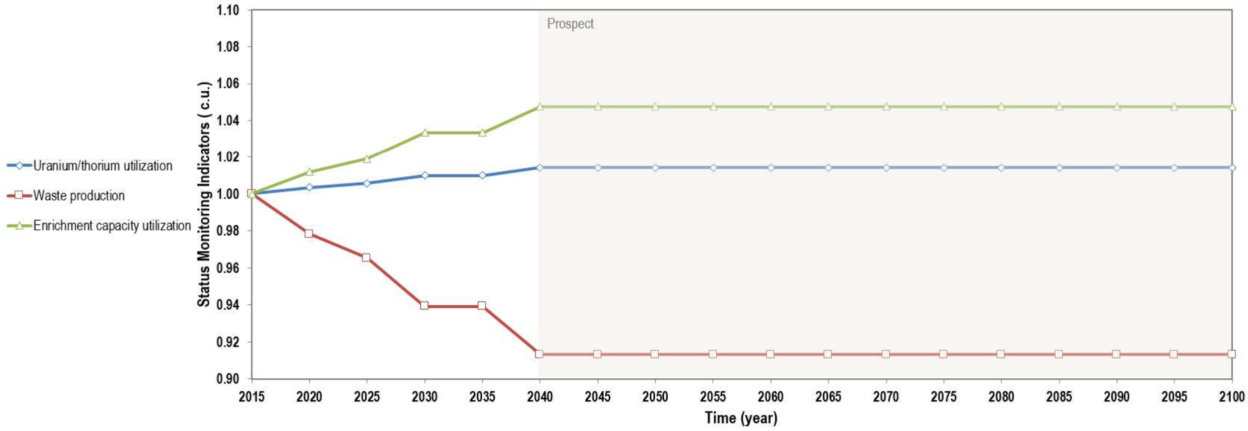
Uranium requirements, t U	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Uranium requirements for Unit-1	175	175	175															
Uranium requirements for Unit-2	175	175	175	175	175													
Uranium requirements for Unit-3	179	179	179	179	179	179	179											
Uranium requirements for Unit-4		179	179	179	179	179	179	179	179	179	179	179	179	179				
Uranium requirements for Unit-5			179	179	179	179	179	179	179	179	179	179	179	179	179			
Uranium requirements for Unit-6				179	179	179	179	179	179	179	179	179	179	179	179	179		
Uranium requirements for Unit-7						179	179	179	179	179	179	179	179	179	179	179	179	179
Uranium requirements for Unit-8								179	179	179	179	179	179	179	179	179	179	179
Uranium requirements for Unit-9											179	179	179	179	179	179	179	179
Uranium requirements for Unit-10															179	179	179	179
Total, t U	529	708	886	890	890	894	894	894	894	894	1073	1073	1073	1073	1073	894	715	715
Provide services/Transfer out materials																		
Provide services/Transfer out materials, t U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer out materials (all)																		
Supply																		
Primary supply/Utilize services, t U	700	900	1000	1000	1000	1000	1000	1000	1100	1100	1100	1100	1300	1300	1200	1000	500	500
Supplier-1	400	400	400	400	400	400	400	400	400	400								
Supplier-2	200	200	200	200	200	200	200	200	200	200	200	200	200					
Supplier-3	100	300	400	400	400	400	400	400	400	400	400	400	400	400	200			
Others									100	100	500	500	700	900	1000	1000	500	500
Secondary supply/Transfer in materials, t U	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary supply/Transfer in materials (all)	50	50																
Total supply, t U	750	950	1000	1000	1000	1000	1000	1000	1100	1100	1100	1100	1300	1300	1200	1000	500	500
Surplus (supply - demand)																		
Surplus, t U	221	242	114	110	110	106	106	106	206	206	27	27	227	227	127	106	-215	-215





b – Typical presentation of worksheets of the second group

Status Monitoring (Quantitative Indicators)	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Uranium/thorium utilization	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Waste production	1.00	0.98	0.97	0.94	0.94	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Enrichment capacity utilization	1.00	1.01	1.02	1.03	1.03	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
...																		



c – Typical presentation of worksheet of the third group

FIG. 23. Typical presentation of worksheets of the first (a), second (b), third (c) groups.

All the worksheets of the second group ('Uranium Mining and Milling', 'Conversion', 'Enrichment', 'Fuel Fabrication', 'Spent Fuel Storage', 'Spent Fuel Reprocessing', 'Geological Disposal' worksheets) have additional sections specifying available options to provide/utilize for services and transfer out/transfer in for materials (primary and secondary sources of nuclear fuel cycle products or services) as well as the surplus section estimating the supply-demand balance on corresponding fuel cycle products or services. These worksheets contain the following subsections:

- The first subsection specifies the requirements in a certain fuel cycle product or service for the given nuclear reactor fleet listed in the 'Reactor Fleet' worksheet, which are required for production of fresh nuclear fuel or spent fuel management. The cells are coloured in blue after data inputting.
- The 'Provide services/Transfer out materials' subsection specifies country obligations to provide a certain fuel cycle product or service for foreigner consumers and may be detailed depending on the availability of data. The cells are coloured in light blue after data inputting.
- The 'Supply' subsection contains data regarding possible supply options to cover the expected demand on a certain fuel cycle product or service and is divided into three parts (the cells are coloured in green after data inputting):
  - *Primary supply/Utilize services* specifies data on national and foreign capacities to provide a certain fuel cycle service by indicating the names of the companies and their current and prospect capacities for the given time steps.
  - *Secondary supply/Transfer in materials* identifies data on possible secondary sources of a certain fuel cycle product (government and industry inventories, secondary fissile materials etc.). Also it may characterize a potential import of a certain fuel cycle product from foreign suppliers.
- Based on the data presented in the requirements and supply subsections, the surplus (differences between supply and demand for a certain fuel cycle product or service) is calculated according to the following formula:

$$Surplus_{i,t} = TotalSupply_{i,t} - TotalDemand_{i,t}$$

where $TotalSupply_{i,t}$ is the total supply including import of the *j*-th product or service in the time step *t*; $TotalDemand_{i,t}$ is the total demand for the *j*-th product or service in the time step *t*. The formatting for this subsection is as follows (it is used excel conditional formatting): the cells are coloured in blue if the inserted number is positive or zero, and in red if the number is negative.

Users are responsible for the selection of a type of data for presentation in the worksheets: it may be requirements for materials or fuel cycle services. Double counting should be avoided.

At the worksheet bottom, the plots demonstrating requirements in a certain fuel cycle product or service and available options to cover these requirements are created based on the data presented in the tables. These graphs represent a combination of 'stacked area'/'stacked column' and 'line' plot types (Fig. 25).

Please note. *Do not forget to add an explanation of used approach to illustrate official plans and prospect. Such explanation may be given in the picture, the figure title or directly in the text. Keep in mind that it is necessary to select a suitable font size for all numbers and letters in the worksheets to provide an appropriate quality of associated pictures or screenshots to be placed in the case study report.*

3.4. 'REACTOR FLEET' WORKSHEET

This worksheet reflects the expected evolution of a given nuclear reactor fleet for the selected timeframe and reactors aggregation in groups (Fig.24). The user should identify the reactor fleet types to be considered and their total installed capacities. In case when each of reactors is described individually, the associated row shows the reactor installed capacity from its commissioning till decommissioning year.

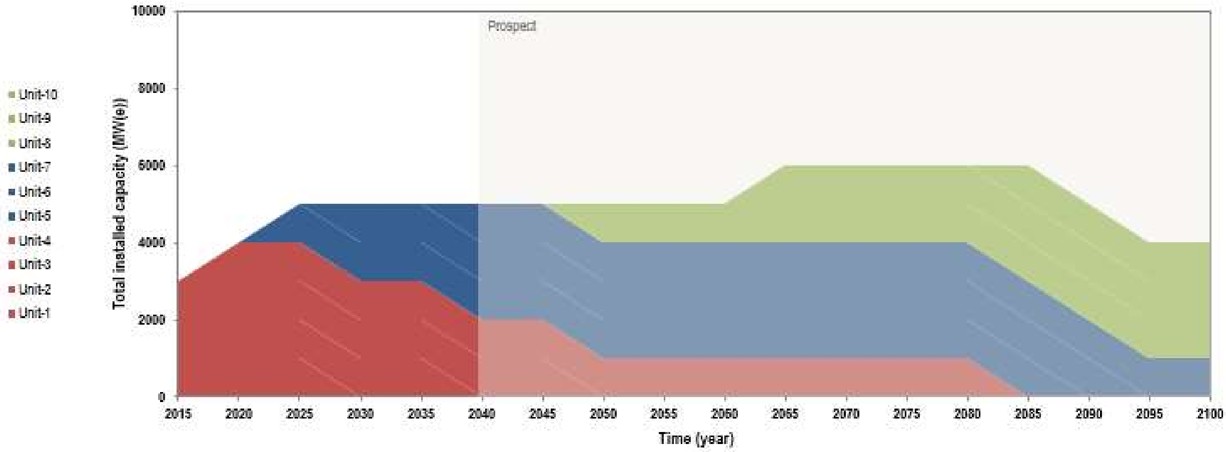
If it is decided to reflect the evolution of a group of reactors within a single row, the user should prepare data to be put in the row with account of increasing and decreasing total installed capacities of this reactor group due to commissioning and decommissioning of individual reactor units within this group.

The plots below the Gantt chart area demonstrate 'stacked area' and 'stacked column' graphs based on the data specified in the table to illustrate the evolution of the present and planned capacities of the considered nuclear reactor fleet. In total, the worksheet shows both the Gantt chart and stacked graphs of reactors, their capacities with account of commissioning and decommissioning. As mentioned above, the white colour demonstrated prospects and black colour indicated official plans at the Gantt chart.

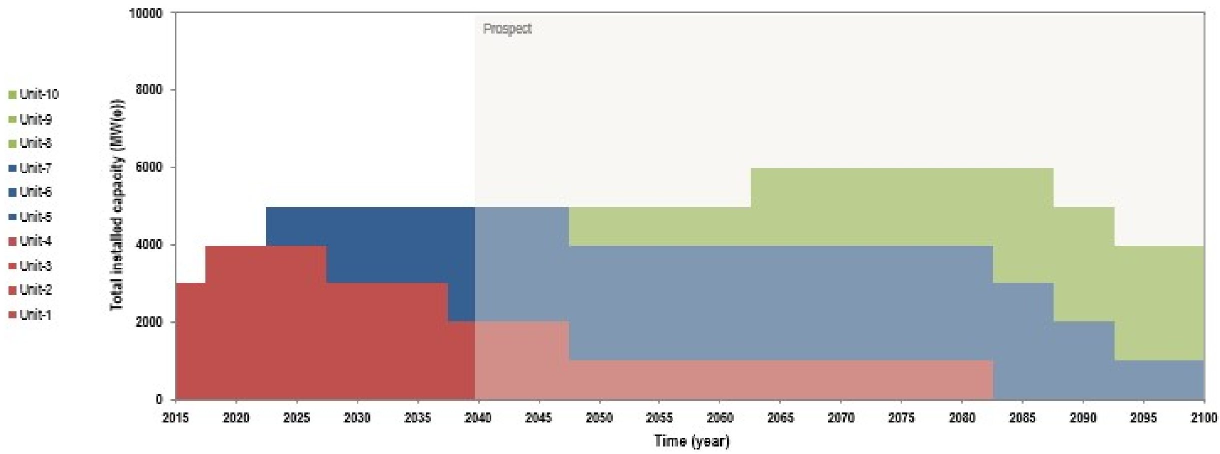
Individual segments or the whole composition presented in the worksheet including the associated Gantt chart and stacked plots may be screenshotted to be placed in the case study report. The user is responsible for the selection of an appropriate size of letters and numbers to provide a qualitative presentation of the graphs in the report.

Total installed capacity, MW(e)	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Unit-1	1000	1000	1000															
Unit-2	1000	1000	1000	1000	1000													
Unit-3	1000	1000	1000	1000	1000	1000	1000											
Unit-4		1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000				
Unit-5			1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000			
Unit-6				1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000		
Unit-7						1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Unit-8								1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Unit-9											1000	1000	1000	1000	1000	1000	1000	1000
Unit-10															1000	1000	1000	1000
Total, MW(e)	3000	4000	5000	5000	5000	5000	5000	5000	5000	5000	6000	6000	6000	6000	6000	5000	4000	4000

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

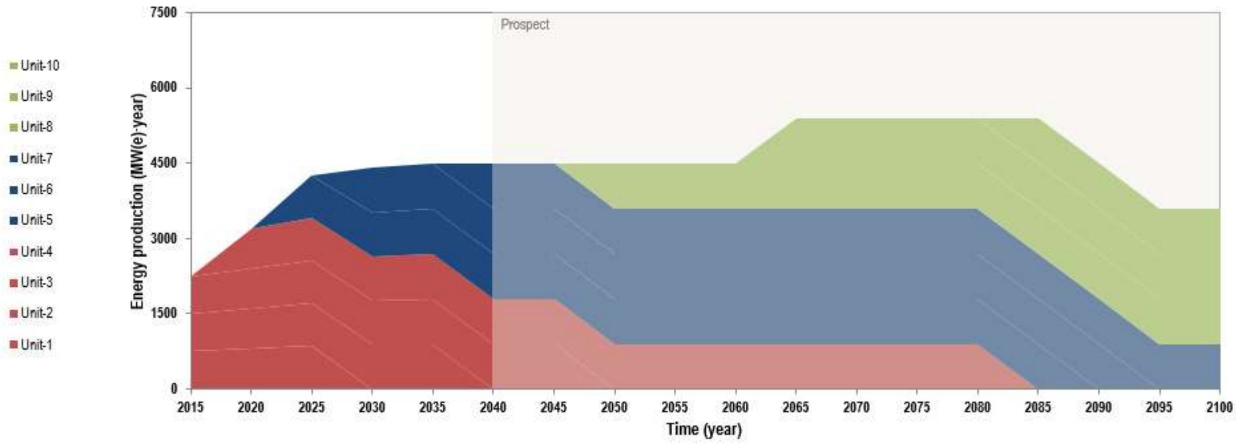
FIG 24. Example of 'Reactor Fleet' presentation.

3.5. ‘ENERGY PRODUCTION’ WORKSHEET

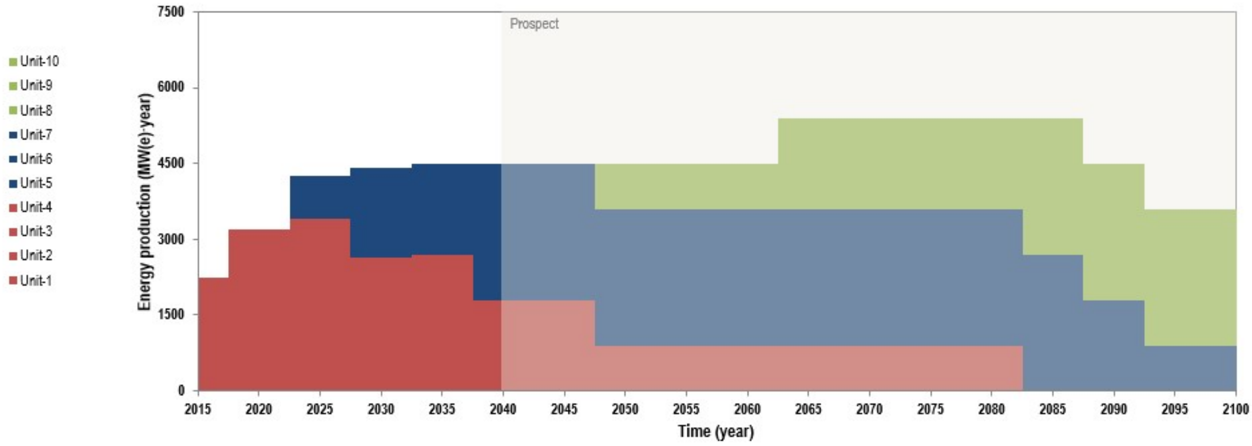
This worksheet reflects energy production by a given nuclear reactor fleet averaged within the corresponding time steps (Fig. 25). Related energy production data may be obtained by using detailed energy planning models and directly put in the table or simply evaluated by multiplying average installed capacities on corresponding average load factors to be specified in the worksheet additionally. Data on load factors may be prepared for each individual reactor unit or for the whole nuclear reactor fleet. This worksheet, if necessary, may be included into the case study report in addition to the ‘Reactor Fleet’ presentation.

Energy production, MW(e)·year	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Unit-1	750	800	850															
Unit-2	750	800	850	880	900													
Unit-3	750	800	850	880	900	900	900											
Unit-4		800	850	880	900	900	900	900	900	900	900	900	900	900				
Unit-5			850	880	900	900	900	900	900	900	900	900	900	900	900			
Unit-6				880	900	900	900	900	900	900	900	900	900	900	900	900		
Unit-7						900	900	900	900	900	900	900	900	900	900	900	900	900
Unit-8								900	900	900	900	900	900	900	900	900	900	900
Unit-9											900	900	900	900	900	900	900	900
Unit-10															900	900	900	900
Total, MW(e)·year	2250	3200	4250	4400	4500	4500	4500	4500	4500	4500	5400	5400	5400	5400	5400	4500	3600	3600

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG.25. Example of ‘Energy Production’ presentation.

3.6. 'URANIUM MINING AND MILLING' WORKSHEET

This worksheet specifies natural uranium consumption in tonnes of uranium by the considered reactors or reactor groups. Data on the required natural uranium consumption for a given reactor type utilizing nuclear fuel with a certain enrichment can be directly taken from different reference sources or calculated, for instance, using the reactor database of ROADMAPS-ET (Fig. 26).

The following formula is used for evaluating the mass of natural uranium required to produce M_p tonnes of enriched nuclear fuel:

$$M_f = \frac{(e_p - e_t)}{(0.711\% - e_t)} \cdot M_p ,$$

where M_p is the mass of enriched nuclear fuel in t HM; M_f is the mass of natural uranium in t U; e_p is the fuel enrichment in %; e_t is the tails assay in %.

If a county has certain export obligations to deliver natural uranium abroad, the 'Provide services/Transfer out materials' section can reflect such responsibilities. The level of detailing of this section should be specified by the experts depending on the problem considered and data available.

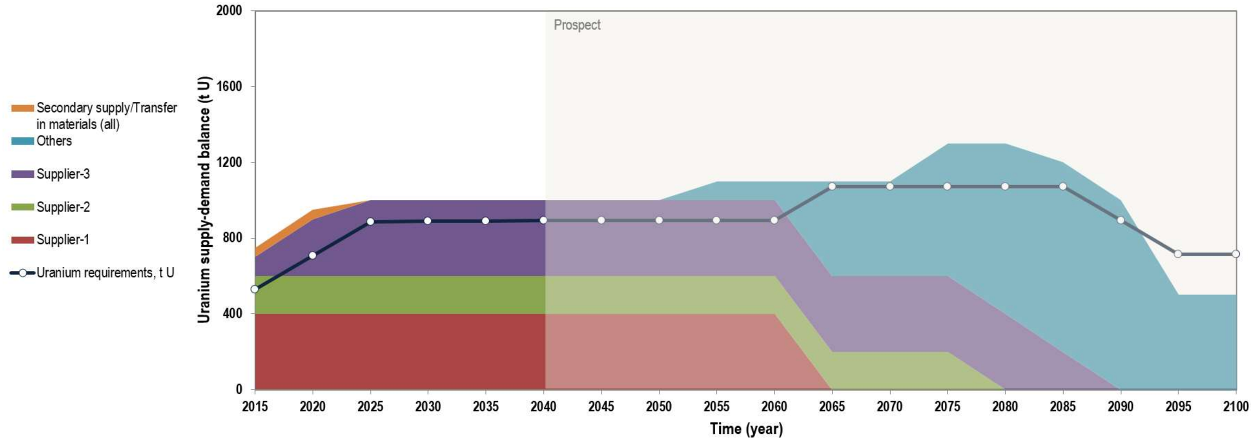
In the 'supply' section of the worksheet, all existing primary and secondary supply options for natural uranium production should be indicated which seem of interest for the specific problem. The primary supply includes current, under development, planned, prospective mines and secondary supply assumes commercial inventories, government inventories, re-enrichment of depleted uranium and others.

The 'Surplus' section demonstrates the balance of the existing and required capacities for uranium mining and milling taking into account the domestic requirements and export obligations from one side and all available primary and secondary supply sources of natural uranium.

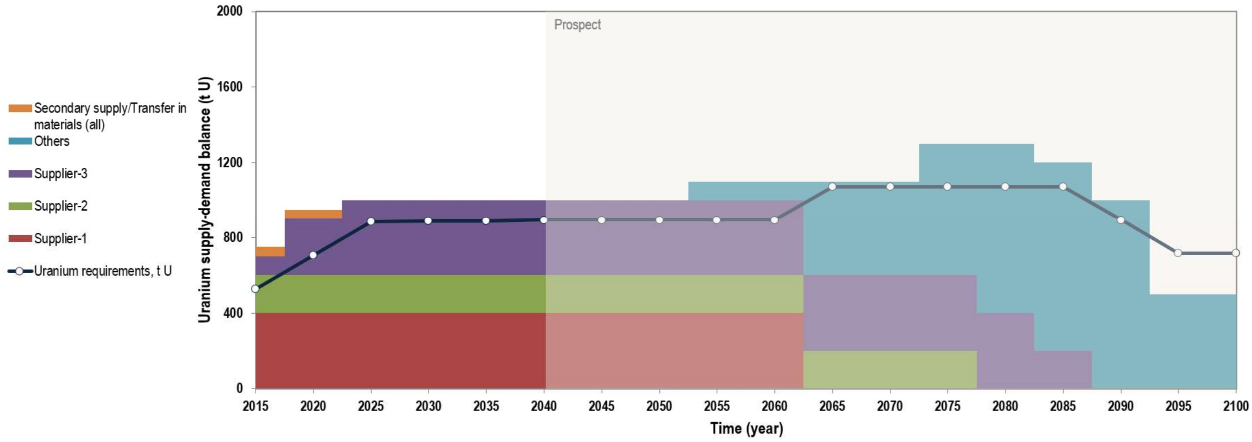
The graphic section provides visualization of natural uranium requirements and the potential uranium supply structure. Different possibilities of building such graphs (e.g. domestic requirements and export commitments are reflecting together or independently etc.) are available and should be selected by the expert depending on the problem to be analyzed.

Uranium requirements, t U	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Uranium requirements for Unit-1	175	175	175															
Uranium requirements for Unit-2	175	175	175	175	175													
Uranium requirements for Unit-3	179	179	179	179	179	179	179											
Uranium requirements for Unit-4		179	179	179	179	179	179	179	179	179	179	179	179	179				
Uranium requirements for Unit-5			179	179	179	179	179	179	179	179	179	179	179	179	179			
Uranium requirements for Unit-6				179	179	179	179	179	179	179	179	179	179	179	179	179		
Uranium requirements for Unit-7						179	179	179	179	179	179	179	179	179	179	179	179	179
Uranium requirements for Unit-8								179	179	179	179	179	179	179	179	179	179	179
Uranium requirements for Unit-9											179	179	179	179	179	179	179	179
Uranium requirements for Unit-10															179	179	179	179
Total, t U	529	708	886	890	890	894	894	894	894	894	1073	1073	1073	1073	1073	894	715	715
Provide services/Transfer out materials																		
Provide services/Transfer out materials, t U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer out materials (all)																		
Supply																		
Primary supply/Utilize services, t U	700	900	1000	1000	1000	1000	1000	1000	1100	1100	1100	1100	1300	1300	1200	1000	500	500
Supplier-1	400	400	400	400	400	400	400	400	400	400								
Supplier-2	200	200	200	200	200	200	200	200	200	200	200	200	200					
Supplier-3	100	300	400	400	400	400	400	400	400	400	400	400	400	400	200			
Others									100	100	500	500	700	900	1000	1000	500	500
Secondary supply/Transfer in materials, t U	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary supply/Transfer in materials (all)	50	50																
Total supply, t U	750	950	1000	1000	1000	1000	1000	1000	1100	1100	1100	1100	1300	1300	1200	1000	500	500
Surplus (supply - demand)																		
Surplus, t U	221	242	114	110	110	106	106	106	206	206	27	27	227	227	127	106	-215	-215

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 26. Example of 'Uranium Mining and Milling' presentation.

3.7. 'CONVERSION' WORKSHEET

This worksheet specifies the domestic requirements and possible export commitments (if the country have obligations to provide conversion services to foreign customers) for uranium conversion services (in tonnes of U) for each reactor or reactors group as well as possible options to meet the conversion demand (Fig. 27).

As is known, the uranium conversion includes two groups of activities: producing UO_2 for reactors using natural uranium and hexafluoride (UF_6) for reactors fuelled with enriched uranium. Options to be reflected in the worksheet should be selected by the expert taking into account the context of the problem under consideration.

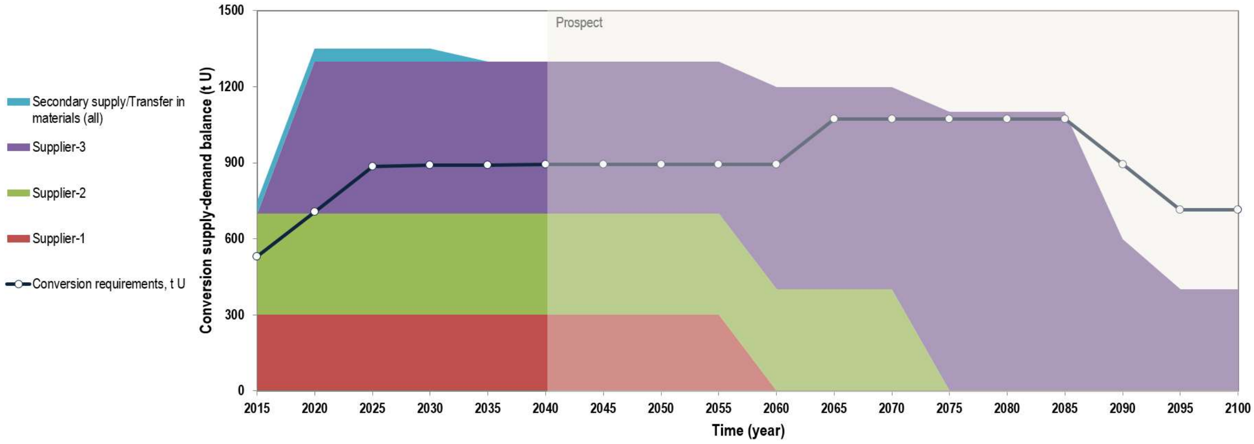
The required services on uranium conversion for nuclear fuel production for individual reactor type can be obtained from specific data obtained from the vendors and different information sources or calculated using the reactor database of ROADMAPS-ET. If the uranium conversion services are expressed in terms of tonnes of uranium (tU), the same formula as for calculations of natural uranium requirements can be used.

The 'Supply' section includes primary (such as domestic facilities, joint ventures, regional centres), secondary (such as commercial inventories, government inventories, re-enrichment of depleted uranium) supply options and potential import of the conversion services abroad. This section may be detailed based on the available data and the problem statement.

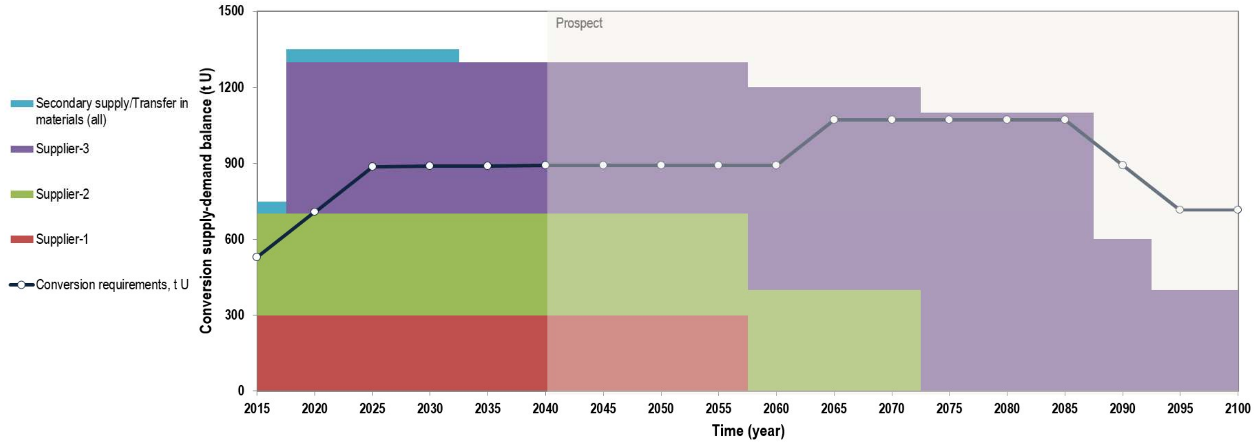
Based on the data specified in the requirements and supply sections, the surplus of the existing and required capacities for uranium conversion is evaluated and the corresponding data are represented graphically to demonstrate the existing and planned suppliers of uranium conversion service and associated requirements in this service for a given nuclear reactor fleet and export commitments, if any.

Conversion requirements, t U	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Conversion requirements for Unit-1	175	175	175															
Conversion requirements for Unit-2	175	175	175	175	175													
Conversion requirements for Unit-3	179	179	179	179	179	179	179											
Conversion requirements for Unit-4		179	179	179	179	179	179	179	179	179	179	179	179	179				
Conversion requirements for Unit-5			179	179	179	179	179	179	179	179	179	179	179	179	179			
Conversion requirements for Unit-6				179	179	179	179	179	179	179	179	179	179	179	179	179		
Conversion requirements for Unit-7						179	179	179	179	179	179	179	179	179	179	179	179	179
Conversion requirements for Unit-8								179	179	179	179	179	179	179	179	179	179	179
Conversion requirements for Unit-9											179	179	179	179	179	179	179	179
Conversion requirements for Unit-10															179	179	179	179
Total, t U	529	708	886	890	890	894	894	894	894	894	1073	1073	1073	1073	1073	894	715	715
Provide services/Transfer out materials																		
Provide services/Transfer out materials, t U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer out materials (all)																		
Supply																		
Primary supply/Utilize services, t U	700	1300	1300	1300	1300	1300	1300	1300	1300	1200	1200	1200	1100	1100	1100	600	400	400
Supplier-1	300	300	300	300	300	300	300	300	300									
Supplier-2	400	400	400	400	400	400	400	400	400	400	400	400						
Supplier-3		600	600	600	600	600	600	600	600	800	800	800	1100	1100	1100	600	400	400
Secondary supply/Transfer in materials, t U	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary supply/Transfer in materials (all)	50	50	50	50														
Total supply, t U	750	1350	1350	1350	1300	1300	1300	1300	1300	1200	1200	1200	1100	1100	1100	600	400	400
Surplus (supply - demand)																		
Surplus, t U	221	642	464	460	410	406	406	406	406	306	127	127	27	27	27	-294	-315	-315

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 27. Example of 'Conversion' presentation.

3.8. 'ENRICHMENT' WORKSHEET

This worksheet characterizes requirements and export obligations of the country in the uranium enrichment services (in tons of separative work (SW)) for the considered reactor fleet and possible primary and secondary sources of enriched uranium including import possibilities (Fig. 28).

The data needed to populate this worksheet (i.e. requirements in separative work to produce enriched uranium with certain parameters) may be obtained from different reference sources or assessed using the reactor database of ROADMAPS-ET. The uranium enrichment requirements may be evaluated using the following relationships:

$$SWU = M_p \cdot V_p - M_t \cdot V_t - M_f \cdot V_f$$

$$M_t = M_f - M_p$$

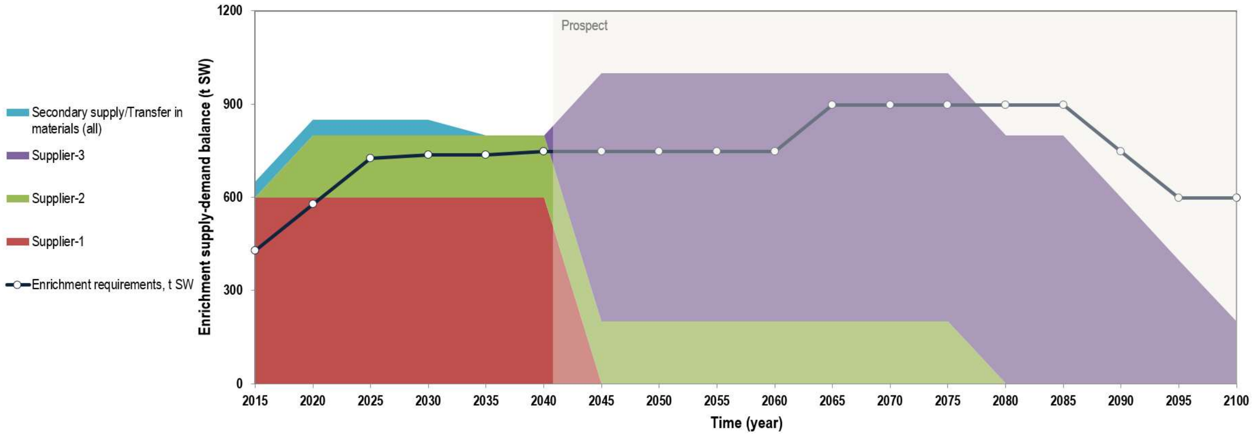
$$V_x = (2e_x - 1) \cdot \ln\left(\frac{e_x}{1-e_x}\right)$$

where SWU is the separative work amount; M_p is the mass of enriched nuclear fuel in t HM; M_f is the mass of natural uranium in t U; M_t is the mass of depleted uranium in t U; e_p is the enrichment of nuclear fuel in %; e_t is the tails assay in %; e_f is the natural uranium enrichment in %; x is the subscript for f, p or t.

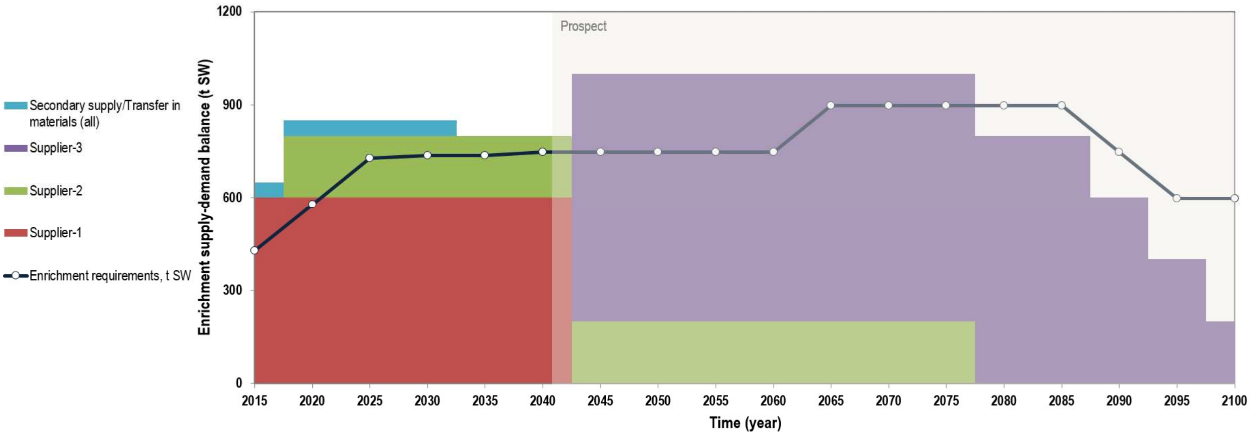
Similar to the 'Uranium Mining and Milling' and 'Conversion' worksheets, populating this worksheet requires specifying the 'supply' section including primary, secondary supply options and potential import of the enrichment service abroad to evaluate the surplus of the existing and required capacities for uranium enrichment and visualize the existing and planned suppliers for uranium enrichment service and requirements in this service for a given nuclear reactor fleet and export commitments.

Enrichment requirements, t SW	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Enrichment requirements for Unit-1	139	139	139															
Enrichment requirements for Unit-2	139	139	139	139	139													
Enrichment requirements for Unit-3	149	149	149	149	149	149	149											
Enrichment requirements for Unit-4		149	149	149	149	149	149	149	149	149	149	149	149	149				
Enrichment requirements for Unit-5			149	149	149	149	149	149	149	149	149	149	149	149	149			
Enrichment requirements for Unit-6				149	149	149	149	149	149	149	149	149	149	149	149	149		
Enrichment requirements for Unit-7						149	149	149	149	149	149	149	149	149	149	149	149	149
Enrichment requirements for Unit-8								149	149	149	149	149	149	149	149	149	149	149
Enrichment requirements for Unit-9											149	149	149	149	149	149	149	149
Enrichment requirements for Unit-10															149	149	149	149
Total, t SW	428	577	727	737	737	747	747	747	747	747	896	896	896	896	896	747	598	598
Provide services/Transfer out materials																		
Provide services/Transfer out materials, t SW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer out materials (all)																		
Supply																		
Primary supply/Utilize services, t SW	600	800	800	800	800	800	1000	1000	1000	1000	1000	1000	1000	800	800	600	400	200
Supplier-1	600	600	600	600	600	600												
Supplier-2		200	200	200	200	200	200	200	200	200	200	200	200					
Supplier-3							800	800	800	800	800	800	800	800	800	600	400	200
Secondary supply/Transfer in materials, t SW	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary supply/Transfer in materials (all)	50	50	50	50														
Total supply, t SW	650	850	850	850	800	800	1000	1000	1000	1000	1000	1000	1000	800	800	600	400	200
Surplus (supply - demand)																		
Surplus, t SW	222	273	123	113	63	53	253	253	253	253	104	104	104	-96	-96	-147	-198	-398

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 28. Example of 'Enrichment' presentation.

3.9. 'FUEL FABRICATION' WORKSHEET

This worksheet provides data on fuel fabrication activities including requirements in fuel fabrication services and export obligations (in t HM) for the considered reactor fleet and available domestic and overseas fuel fabrication capacities (Fig. 29).

The main sections in this worksheet are the same as in the 'Uranium Mining and Milling', 'Conversion' and 'Enrichment' worksheets, which makes it possible to evaluate the surplus for fuel fabrication and visualize the existing and planned suppliers for fuel fabrication services and associated requirements in these services for a given nuclear reactor fleet and export commitments.

However, in distinction from the uranium, conversion, enrichment markets, the fuel fabrication market does not provide a fungible high-tech product to be used as a nuclear fuel for any reactor type. On the contrary, the final product, i.e., nuclear fuel, is rather an individual product adapted for a specific reactor type.

This leads to the necessity to make distinctions between different nuclear fuel types for an adequate reflection of supply and demand balances on fuel fabrication services in regard to different nuclear fuel types in the 'surplus' and graphs sections.

In case when reactors utilize different fuel types, the user may insert additional lines to the 'Total' subsection specifying different fuel types and corresponding total requirements (applying the command 'Format Painter' to the new lines will keep the used format). The same procedure should be used in the 'surplus' subsection where balances may be calculated based on the supply and demand data for different fuel types.

If there are no special data on nuclear fuel consumption by reactors, the annual fuel requirements may be simply evaluated using the following formula:

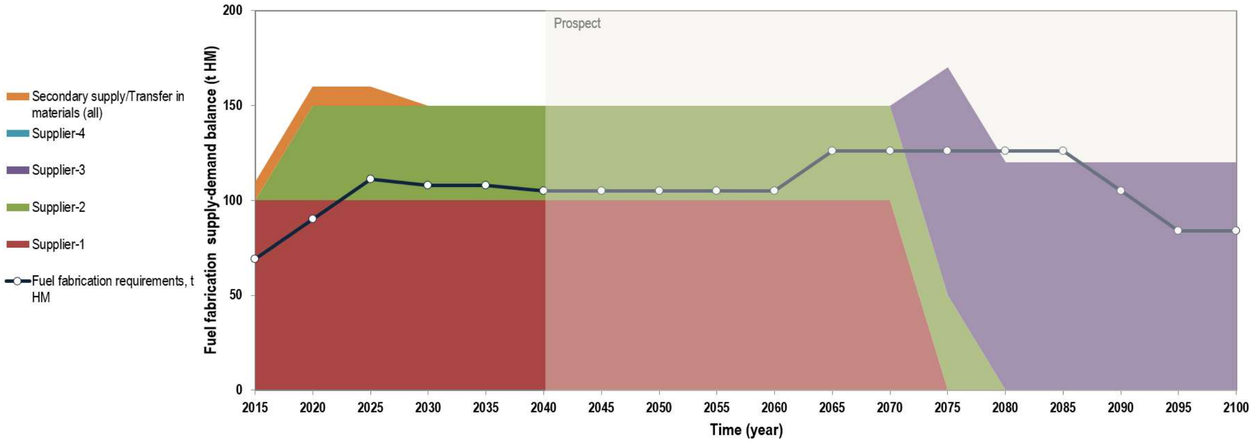
$$M = \frac{N_e \cdot \varphi \cdot 365}{\eta \cdot B_d},$$

where N_e is the installed electric capacity; φ is the capacity factor; η is the thermal efficiency; B_d is the discharge burnup.

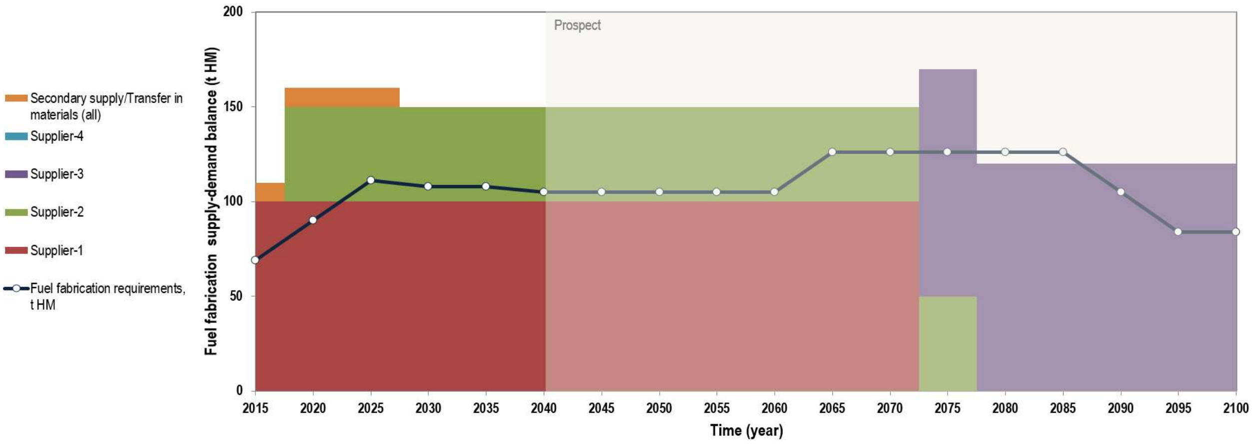
The demand for fuel fabrication services increases if new installed reactor capacities are put into operation leading to short-term demand peaks for fuel fabrication services. These fuel fabrication peaks also lead to corresponding peaks in uranium, conversion and enrichment demands and, if necessary, may be taken into consideration within roadmaps.

Fuel fabrication requirements, t HM	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Fuel fabrication requirements for Unit-1	24	24	24															
Fuel fabrication requirements for Unit-2	24	24	24	24	24													
Fuel fabrication requirements for Unit-3	21	21	21	21	21	21	21											
Fuel fabrication requirements for Unit-4		21	21	21	21	21	21	21	21	21	21	21	21	21				
Fuel fabrication requirements for Unit-5			21	21	21	21	21	21	21	21	21	21	21	21	21			
Fuel fabrication requirements for Unit-6				21	21	21	21	21	21	21	21	21	21	21	21	21		
Fuel fabrication requirements for Unit-7						21	21	21	21	21	21	21	21	21	21	21	21	21
Fuel fabrication requirements for Unit-8								21	21	21	21	21	21	21	21	21	21	21
Fuel fabrication requirements for Unit-9											21	21	21	21	21	21	21	21
Fuel fabrication requirements for Unit-10															21	21	21	21
Total, t HM	69	90	111	108	108	105	105	105	105	105	126	126	126	126	126	105	84	84
Provide services/Transfer out materials																		
Provide services/Transfer out materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer out materials (all)																		
Supply																		
Primary supply/Utilize services, t HM	100	150	150	150	150	150	150	150	150	150	150	150	170	120	120	120	120	120
Supplier-1	100	100	100	100	100	100	100	100	100	100	100	100						
Supplier-2		50	50	50	50	50	50	50	50	50	50	50	50					
Supplier-3													120	120	120	120	120	120
Supplier-4																		
Secondary supply/Transfer in materials, t HM	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary supply/Transfer in materials (all)	10	10	10															
Total supply, t HM	110	160	160	150	150	150	150	150	150	150	150	150	170	120	120	120	120	120
Surplus (supply - demand)																		
Surplus, t HM	41	70	49	42	42	45	45	45	45	45	24	24	44	-6	-6	15	36	36

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 29. Example of 'Fuel Fabrication' presentation.

3.10. ‘SPENT FUEL STORAGE’ WORKSHEET

This worksheet illustrates the supply-demand balance for spent fuel storage services in terms of the cumulative flows of spent fuel to be stored at different domestic storage facilities (at-reactor, away-from-reactor dry and wet storage facilities) or forwarded abroad/ regional spent fuel storage facilities for the follow-up handling (Fig. 30).

It should be highlighted that in the demand section it is reasonable to reflect all spent fuel discharged from reactors to simplify evaluations. In this case, a cumulative volume of reprocessed spent fuel should also be accounted when the supply section is specified. But it is also possible to reflect only the spent fuel that is planned to be stored: in this case, the spent fuel to be reprocessed should be excluded from considerations to avoid double counting. It is up to the expert what options to select, but once the corresponding option has been selected, it should be described in the case study report.

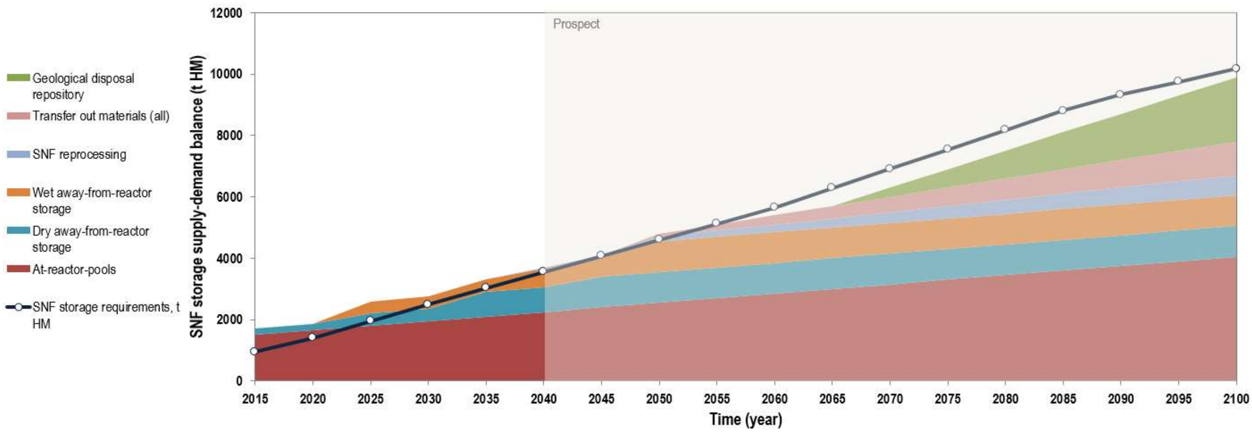
Another important aspect is the need for gathering or evaluating the spent fuel amount for all reactor types, produced before the first considered time step that may be carried out outside the tool and inputted in the roadmap as an initial data.

Let us demonstrate the data preparation for this worksheet. The following assumption may be taken into account: spent fuel arising per a given period, in general, is approximately equal to the fresh fuel requirements per the same period (in terms of tHM + fission products) specified in the ‘Fuel Fabrication’ worksheet. Assume that the accumulated spent fuel amount of a certain reactor was 100 t HM by 2016 and this reactor discharges 20 t HM of spent fuel per year. Consequently, for the 5 years this reactor produce $20 \times 5 = 100$ t HM and the total amount of spent fuel at the storage facility will be $100 + 20 \times 5 = 200$ t HM in 2020.

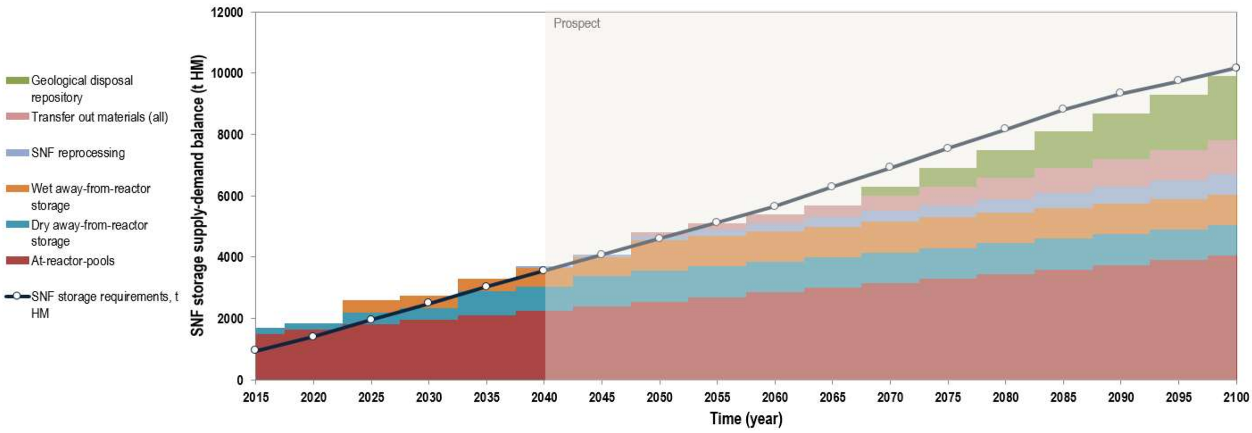
If needed, the user may specify the ‘Provide services/Transfer in materials’ and ‘Transfer out materials’ sections if the country has obligations to return foreign spent fuel or plans to send its spent fuel abroad for further processing. Based on this data, the surplus (i.e., the differences between the existing and required capacities of spent fuel storage facilities) are calculated and stacked graphs are constructed to reflect both the existing options for spent fuel storing and associated requirements for domestic and foreign reactor fleets.

SNF storage requirements, t HM	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
SNF storage requirements for Unit-1	320	440	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560
SNF storage requirements for Unit-2	320	440	560	680	800	800	800	800	800	800	800	800	800	800	800	800	800	800
SNF storage requirements for Unit-3	305	410	515	620	725	830	935	935	935	935	935	935	935	935	935	935	935	935
SNF storage requirements for Unit-4		105	210	315	420	525	630	735	840	945	1050	1155	1260	1365	1365	1365	1365	1365
SNF storage requirements for Unit-5			105	210	315	420	525	630	735	840	945	1050	1155	1260	1365	1365	1365	1365
SNF storage requirements for Unit-6				105	210	315	420	525	630	735	840	945	1050	1155	1260	1365	1365	1365
SNF storage requirements for Unit-7						105	210	315	420	525	630	735	840	945	1050	1155	1260	1365
SNF storage requirements for Unit-8							0	105	210	315	420	525	630	735	840	945	1050	1155
SNF storage requirements for Unit-9							0	0	0	0	105	210	315	420	525	630	735	840
SNF storage requirements for Unit-10							0	0	0	0	0	0	0	0	105	210	315	420
Total, t HM	945	1395	1950	2490	3030	3555	4080	4605	5130	5655	6285	6915	7545	8175	8805	9330	9750	10170
Provide services/Transfer in materials																		
Provide services/Transfer in materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer in materials (all)																		
Supply																		
Primary supply/Utilize services, t HM	1700	1850	2600	2750	3300	3700	4100	4700	4900	5100	5300	5500	5700	5900	6100	6300	6500	6700
At-reactor-pools	1500	1650	1800	1950	2100	2250	2400	2550	2700	2850	3000	3150	3300	3450	3600	3750	3900	4050
Dry away-from-reactor storage	200	200	400	400	800	800	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Wet away-from-reactor storage			400	400	400	600	600	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
SNF reprocessing						50	100	150	200	250	300	350	400	450	500	550	600	650
Geological disposal repository												300	600	900	1200	1500	1800	2100
Transfer out materials, t HM	0	0	0	0	0	0	0	100	200	300	400	500	600	700	800	900	1000	1100
Transfer out materials (all)								100	200	300	400	500	600	700	800	900	1000	1100
Total supply, t HM	1700	1850	2600	2750	3300	3700	4100	4800	5100	5400	5700	6000	6300	6600	6900	7200	7500	7800
Surplus (supply - demand)																		
Surplus, t HM	755	455	650	260	270	145	20	195	-30	-255	-585	-915	-1245	-1575	-1905	-2130	-2250	-2370

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 30. Example of 'Spent Fuel Storage' presentation.

3.11. 'SPENT FUEL REPROCESSING' WORKSHEET

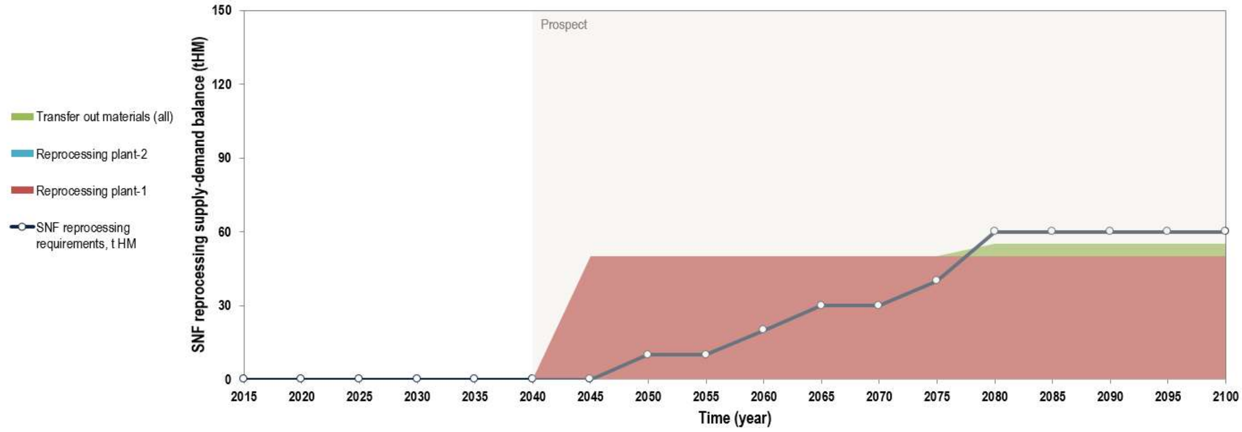
This worksheet demonstrates the supply-demand balance for spent fuel reprocessing services in terms of averaged flows for certain periods (Fig. 31). Populating this worksheet, in general, is similar to filling the 'Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities' section worksheets related to the nuclear fuel cycle front-end. In this worksheet, the user specifies the requirements for spent fuel reprocessing for spent fuel from each reactor type of a given reactor fleet within different time steps. The 'Provide services/Transfer in materials' line accounts for the country's obligations to reprocess foreign spent fuel and, if needed, may be subdivided into individual components.

The supply side consists of the 'Primary supply/Utilize services' and 'Transfer out materials' areas that characterize correspondingly the domestic available capacities of spent fuel reprocessing plants and spent fuel amount which is intended to be sent abroad for reprocessing. Detailing of this line depends on available data and the scope of the problem considered. The surplus line reflects the balance of the existing and required capacities of spent fuel reprocessing and, depending on the problem, the balance may be specified with or without regard to export and import capabilities.

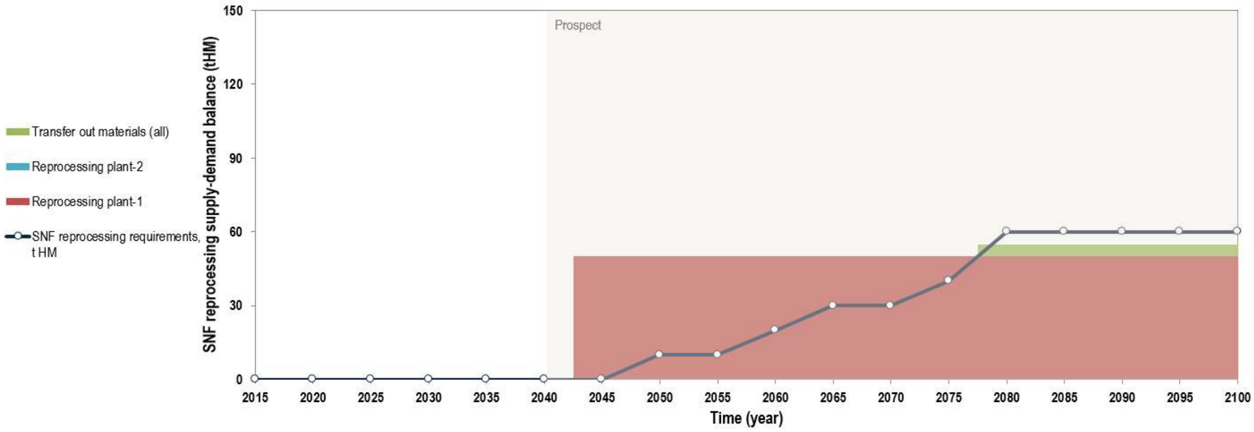
The graphic section visualizes the supply-demand balance for spent fuel reprocessing services to demonstrate the existing and planned capacities for spent fuel reprocessing from various suppliers, requirements for these capacities for domestic and foreign reactor fleets, if any.

SNF reprocessing requirements, t HM	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
SNF reprocessing requirements for Unit-1																		
SNF reprocessing requirements for Unit-2																		
SNF reprocessing requirements for Unit-3																		
SNF reprocessing requirements for Unit-4																		
SNF reprocessing requirements for Unit-5																		
SNF reprocessing requirements for Unit-6								10	10	10	20	20	20	20	20	20	20	20
SNF reprocessing requirements for Unit-7										10	10	10	20	20	20	20	20	20
SNF reprocessing requirements for Unit-8														20	20	20	20	20
SNF reprocessing requirements for Unit-9																		
SNF reprocessing requirements for Unit-10																		
Total, t HM	0	0	0	0	0	0	0	10	10	20	30	30	40	60	60	60	60	60
Provide services/Transfer in materials																		
Provide services/Transfer in materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer in materials (all)																		
Supply																		
Primary supply/Utilize services, t HM	0	0	0	0	0	0	50	50	50	50	50	50	50	50	50	50	50	50
Reprocessing plant-1							50	50	50	50	50	50	50	50	50	50	50	50
Reprocessing plant-2																		
Transfer out materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5
Transfer out materials (all)														5	5	5	5	5
Total supply, t HM	0	0	0	0	0	0	50	50	50	50	50	50	50	55	55	55	55	55
Surplus (supply - demand)																		
Surplus, t HM	0	0	0	0	0	0	50	40	40	30	20	20	10	-5	-5	-5	-5	-5

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 31. Example of 'Spent Fuel Reprocessing' presentation.

3.12. 'GEOLOGICAL DISPOSAL' WORKSHEET

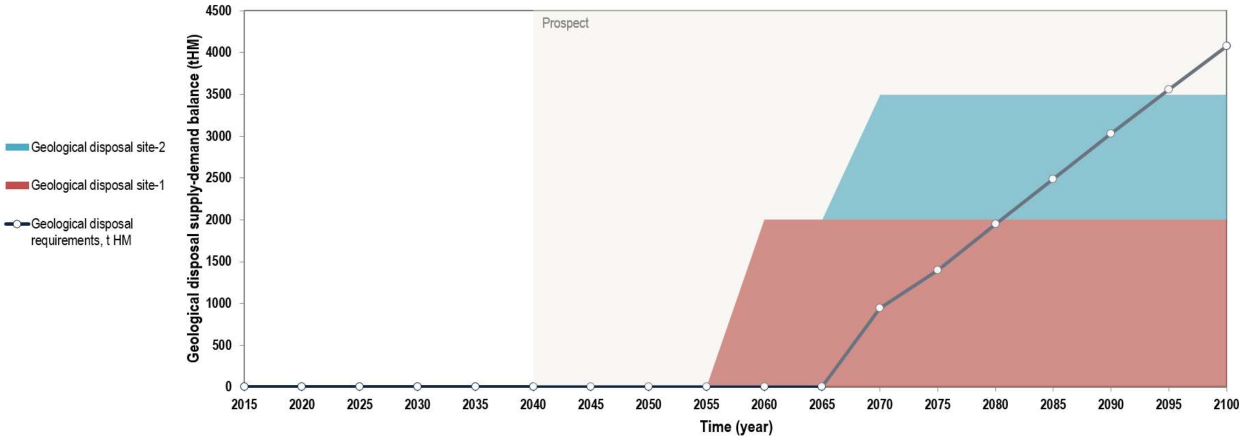
This worksheet provides the supply-demand balance for geological disposal services (Fig. 32). Similar to the spent fuel storage worksheet, this worksheet also assumes the reproduction of cumulative flows of spent fuel or HLW to be disposed (domestic and foreign) and corresponding capacities of repositories (domestic and potentially available from abroad).

Due to the fact that, in most countries, the final decisions to select waste management strategy are currently postponed, this worksheet may contain no data or the user will have the problem to populate this worksheet. In this regard, this worksheet may be excluded from the case study report.

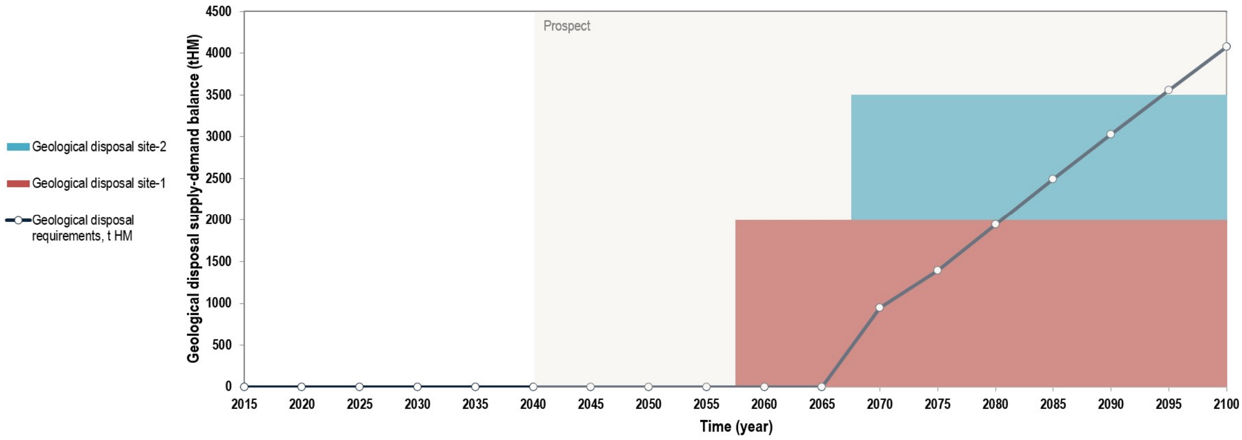
The 'Geological Disposal' worksheet of ROADMAPS-ET is the final one within the second group of the worksheets reflecting activities in the nuclear fuel cycle front-end and back-end. Depending on the issues considered in the case study, additional worksheets may be added, if necessary, to reflect some other specific activities in the nuclear fuel cycle, such as plutonium consumption, thorium utilization, HLW management, transportation, etc. This is the area of the user's responsibility depending on the specific problem context, which may vary in different case studies.

Geological disposal requirements, t HM	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Geological disposal requirements for Unit-2												320	440	560	680	800	800	800
Geological disposal requirements for Unit-3												305	410	515	620	725	830	935
Geological disposal requirements for Unit-4													105	210	315	420	525	630
Geological disposal requirements for Unit-5														105	210	315	420	525
Geological disposal requirements for Unit-6															105	210	315	420
Geological disposal requirements for Unit-7																	105	210
Geological disposal requirements for Unit-8																		
Geological disposal requirements for Unit-9																		
Geological disposal requirements for Unit-10																		
Total, t HM	0	0	0	0	0	0	0	0	0	0	0	945	1395	1950	2490	3030	3555	4080
Provide services/Transfer in materials																		
Provide services/Transfer in materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provide services/Transfer in materials (all)																		
Supply																		
Primary supply/Utilize services, t HM	0	0	0	0	0	0	0	0	0	2000	2000	3500	3500	3500	3500	3500	3500	3500
Geological disposal site-1										2000	2000	2000	2000	2000	2000	2000	2000	2000
Geological disposal site-2												1500	1500	1500	1500	1500	1500	1500
Transfer out materials, t HM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transfer out materials (all)																		
Total supply, t HM	0	0	0	0	0	0	0	0	0	2000	2000	3500	3500	3500	3500	3500	3500	3500
Surplus (supply - demand)																		
Surplus, t HM	0	0	0	0	0	0	0	0	0	2000	2000	2555	2105	1550	1010	470	-55	-580

a – Gantt chart



b – Stacked area chart type



c – Stacked column chart type

FIG. 32. Example of 'Geological Disposal' presentation.

3.13. ‘STATUS MONITORING’ WORKSHEET

ROADMAPS-ET incorporates provisions for progress monitoring regarding NES deployment strategy towards enhanced sustainability – the ‘Status Monitoring’ worksheet (Fig. 33). It is based on a set of quantitative indicators specified by experts in line with the specific objectives (targets, milestones) of the performed road mapping. The indicators can be defined to perform evaluation in relative terms. Tracking/monitoring of NES deployments strategy against roadmap milestones involves: The monitoring indicators that characterize the expected enhancement of NES sustainability in different areas owing to technological and institutional innovations and/or increased collaboration with other countries. The key points (or milestones) that, when reached, indicate that certain sustainability enhancements have been achieved.

Status Monitoring (Quantitative Indicators)	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Uranium/thorium utilization	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Waste production	1.00	0.98	0.97	0.94	0.94	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Enrichment capacity utilization	1.00	1.01	1.02	1.03	1.03	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
...																		

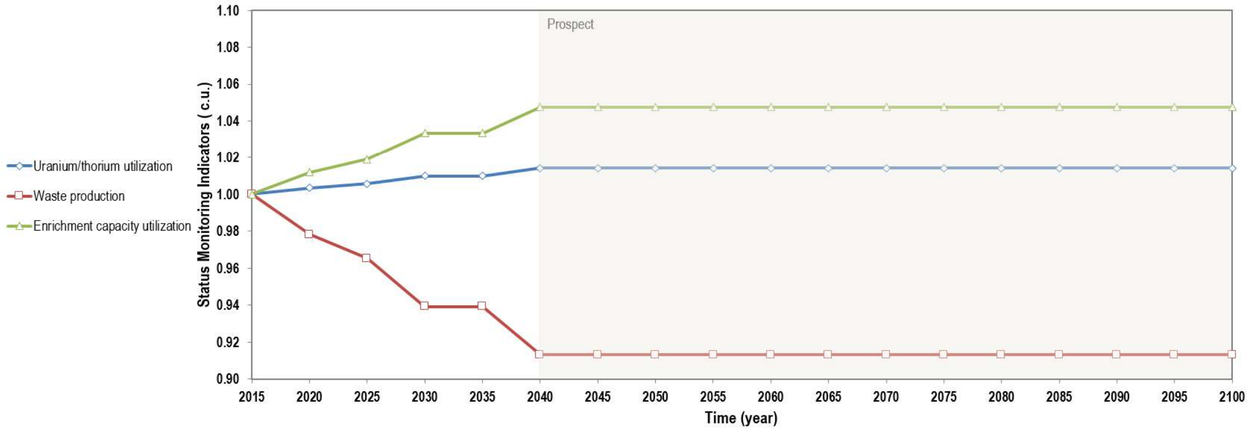


FIG. 33. Example of ‘Status Monitoring’ presentation.

4. ‘SUPPORTING TOOLS AND REFERENCES’ SECTION

4.1. ‘REACTOR DATABASE’ WORKSHEET

This worksheet provides reference data on several reactor types from well-known international sources (Fig. 34); these data may be used for the population of specific roadmaps.

Reactors	Reactor zone	Major Input Data														
		Reactor Type Specifications					NPP Characteristics									
		Spectrum	Coolant	Moderator	Fuel type	Share of fuel	Output (MWe)	Load factor (%)	Efficiency (%)	EFPD (days)	Burn-up (GW·day/t HM)	SPD (MW/t)	Core/blanket (t HM)	Reloads (t HM)	Tail assay (%)	^{235}U
Source - INPRO/GAINS																
LWR		Thermal	Water	Water	UOX		1000	80%	33%	1168	45,00	38,53	78,65	20,89	0,30%	4,00%
ALWR		Thermal	Water	Water	UOX		1500	85%	34%	1760	60,00	34,09	129,36	22,80	0,30%	4,95%
LWR medium burnup		Thermal	Water	Water	UOX		1000	85%	34%	1514	51,00	33,69	87,30	17,89	0,30%	4,30%
HWR		Thermal	Heavy water	Heavy water	UOX		600	85%	30%	292	70,00	23,97	83,43	88,64	0,30%	0,71%
CANDU-ThO_2 PuO_2/average whole core		Thermal	Heavy water	Heavy water	Th-PU		668	85%	32%	825	20,29	24,60	71,40	31,56	0,30%	
CANDU Th-^{233}U-Pu		Thermal	Heavy water	Heavy water	Th-^{233}U-Pu		668	85%	32%	810	19,85	24,51	71,40	32,26	0,30%	
FR-break even	Average whole core	Fast	Sodium	None			870	85%	41%	436	37,68	86,46	24,29	17,29		
	Core	Fast	Sodium	None	MOX	0,54				420	65,94	157,00	13,12	9,34		
	Axial blanket	Fast	Sodium	None	Dep U	0,24				420	4,82	11,47	5,71	4,06		
	Radial blanket	Fast	Sodium	None	Dep U	0,23				490	4,18	8,53	5,46	3,89		
FR-1500/average whole core	Average whole core	Fast	Sodium	None			1500	85%	42%	2160	53,53	24,78	144,07	20,69		
	Core	Fast	Sodium	None	MOX	0,89				2160	151,45	70,12	128,65	18,48		
	Axial blanket	Fast	Sodium	None	Dep U	0,09				2160	11,83	5,48	12,39	1,78		
	Radial blanket	Fast	Sodium	None	Dep U	0,02				2160	3,81	1,76	3,03	0,43		
FR-500/average whole core	Average whole core	Fast	Sodium	None			500	85%	40%	679	31,06	45,74	27,33	12,49		
	Core	Fast	Sodium	None	MOX	0,92				540	76,46	141,59	25,14	11,49		
	Axial blanket	Fast	Sodium	None	Dep U	0,03				540	3,88	7,19	0,82	0,37		
	Radial blanket	Fast	Sodium	None	Dep U	0,05				540	4,02	4,47	1,37	0,62		
FR-Th blanket	Average whole core	Fast	Sodium	None			880	85%	42%							
	Core	Fast	Sodium	None	MOX	0,54				441	72,00		12,50	12,17		
	Blanket	Fast	Sodium	None	Th oxide	0,24				441			33,00	23,22		

a – input data section

Reactors	Major Output Data for Roadmaps Model																			
	Data for Roadmaps Model (per reactor unit)								Data for Roadmaps Model (per GWe)						Data for Roadmaps Model (per tonne HM of annual fuel reload)					
	Core/blanket (t HM)	Reload (t HM)	totNatU (t U)	totConvU (t U)	totSWU (t SW)	SNF (t HM+t FP)	Dep U (t U)	Rep U (t U)	Core/blanket (t HM/GW)	Reload (t HM/GW)	NatU/GWe (t U/GW)	ConU/GWe (t HM/GW)	SWU/GWe (t SW/GW)	SNF/GWe (t HM/GW)	Core/blanket (t HM/t HM)	Reload (t HM/t HM)	totNatU (t U/t HM)	totConvU (t U/t HM)	totSWU (t SW/t HM)	SNF (t HM/t HM)
Source - INPRO/GAINS																				
LWR	78.65	20.89	188.08	188.08	110.24	20.89			78.65	20.89	188.08	188.08	110.24	20.89	3.76	1.00	9.00	9.00	5.28	1.00
ALWR	129.36	22.80	257.99	257.99	161.92	22.80			86.24	15.20	171.99	171.99	107.95	15.20	5.67	1.00	11.31	11.31	7.10	1.00
LWR medium burnup	87.30	17.89	174.13	174.13	104.62	17.89			87.30	17.89	174.13	174.13	104.62	17.89	4.88	1.00	9.73	9.73	5.85	1.00
HWR	83.43	88.64	88.64	88.64	-	88.64			139.05	147.74	147.74	147.74	-	147.74	0.94	1.00	1.00	1.00	-	1.00
CANDU-ThO_2 PuO_2/average whole core	71.40	31.56	-	-	-	31.56			106.88	47.24	-	-	-	47.24	2.26	1.00	-	-	-	1.00
CANDU Th-^{233}U-Pu	71.40	32.26	-	-	-	32.26			106.88	48.29	-	-	-	48.29	2.21	1.00	-	-	-	1.00
FR-break even	24.29	17.29	-	-	-	17.29			27.92	19.88	-	-	-	19.88	1.40	1.00	-	-	-	1.00
	13.12	9.34	-	-	-	9.34			15.08	10.73				10.73	1.40	1.00	-	-	-	1.00
	5.71	4.06	-	-	-	4.06	4.06		6.56	4.67				4.67	1.40	1.00	-	-	-	1.00
	5.46	3.89	-	-	-	3.89	3.89		6.28	4.47				4.47	1.40	1.00	-	-	-	1.00
FR-1500/average whole core	144.07	20.69	-	-	-	20.69			96.05	13.80	-	-	-	13.80	6.96	1.00	-	-	-	1.00
	128.65	18.48	-	-	-	18.48			85.77	12.32				12.32	6.96	1.00	-	-	-	1.00
	12.39	1.78	-	-	-	1.78	1.78		8.26	1.19				1.19	6.96	1.00	-	-	-	1.00
	3.03	0.43	-	-	-	0.43	0.43		2.02	0.29				0.29	6.96	1.00	-	-	-	1.00
FR-500/average whole core	27.33	12.49	-	-	-	12.49			54.66	24.97	-	-	-	24.97	2.19	1.00	-	-	-	1.00
	25.14	11.49	-	-	-	11.49			50.28	22.97				22.97	2.19	1.00	-	-	-	1.00
	0.82	0.37	-	-	-	0.37	0.37		1.64	0.75				0.75	2.19	1.00	-	-	-	1.00
	1.37	0.62	-	-	-	0.62	0.62		2.73	1.25				1.25	2.19	1.00	-	-	-	1.00
FR-Th blanket									-	-	-	-	-	-						
	12.50	12.17	-	-	-	12.17			14.20	13.83				13.83	1.03	1.00	-	-	-	1.00
	33.00	23.22	-	-	-	23.22	23.22		37.50	26.38				26.38	1.42	1.00	-	-	-	1.00

b – output data

FIG. 34. ‘Reactor Database’ worksheet.

The reactor database is subdivided into several main blocks:

- Input data:
  - The ‘Reactors’ and ‘Reactor zone’ columns indicate the reactors’ titles and reactors’ zones;
  - A qualitative description of the reactors block provides information about the type of coolant, moderator, fuel type and neutron spectrum;
  - The NPP characteristics with a given reactor type block indicates installed capacities of reactor unit, efficiency and load factor;
  - The fuel characteristics block represents data about the fuel campaign, burn-up, initial loading and annual reloading.
- Output data:
  - Material flows data for one reactor unit – this block evaluates the requirements for natural uranium, conversion, enrichment and fuel fabrication services, annual spent fuel arisings for a single reactor unit;
  - Material flows data per GW(e) of installed capacity – this block specifies the requirements for natural uranium, conversion, enrichment and fuel fabrication services, annual spent fuel arisings per GW(e) of reactor installed capacity.

– Material flows data per tHM of fuel – this block provides the requirements for natural uranium, conversion, enrichment and fuel fabrication services, annual spent fuel arisings per t HM.

- The ‘Fuel Composition’ section specifies fresh and spent fuel isotopic composition. These data may be included in to the roadmaps in some specific cases.

4.2. ‘LISTS’ WORKSHEET

This auxiliary worksheet contains basic items to be reflected in drop-down lists placed in other ROADMAPS-ET worksheets. If the user wants to modify some items to be displayed, it is necessary to make the corresponding modification in this worksheet according to the task being considered (Fig. 35).

	A	B	C	D	E	F	G
1	**Main**						
2		**Economic Indicator**			**Spectrum**	**Coolant**	**Moderator**
3		Competitive with other energy sources			Thermal	Water	None
4		Competitive in most markets			Epithermal	Heavy water	Heavy water
5		Competitive in limited markets			Fast	Sodium	Water
6		Loss of competitiveness				Lead	Graphite
7						Salt	Lithium
8						Helium	Beryllium
9		**Public Support Indicator**				Other	Other
10		Public opinion on nuclear energy is generally positive					
11		Public opinion on nuclear energy is mixed/improving					
12		Public opinion on nuclear energy is mixed/declining					
13		Public opinion on nuclear energy is generally negative					
14							
15							
16		**Nuclear Energy System Development Status**					
17		Not Applicable					
18		Reactors currently under active construction					
19		Firm plans for new construction within 5 years					
20		Plans for new construction, beyond 5 years					
21		No plans for new construction					
22							
23					**Check List**		
24		**Construction Health Indicator**					
25		Not Applicable			☑	official	
26		Average reactor construction time under 5 years			✓	non-official	
27		Average reactor construction time under 6 years					
28		Average reactor construction time under 7 years					
29		Average reactor construction time over 7 years					

FIG. 35. ‘Lists’ worksheet.

4.3. ‘METRIC INTEGRATION’ WORKSHEET

This worksheet represents information from the ‘Metrics’ worksheet into a form suitable for further statistical processing for constructing aggregated roadmaps (Fig. 36).

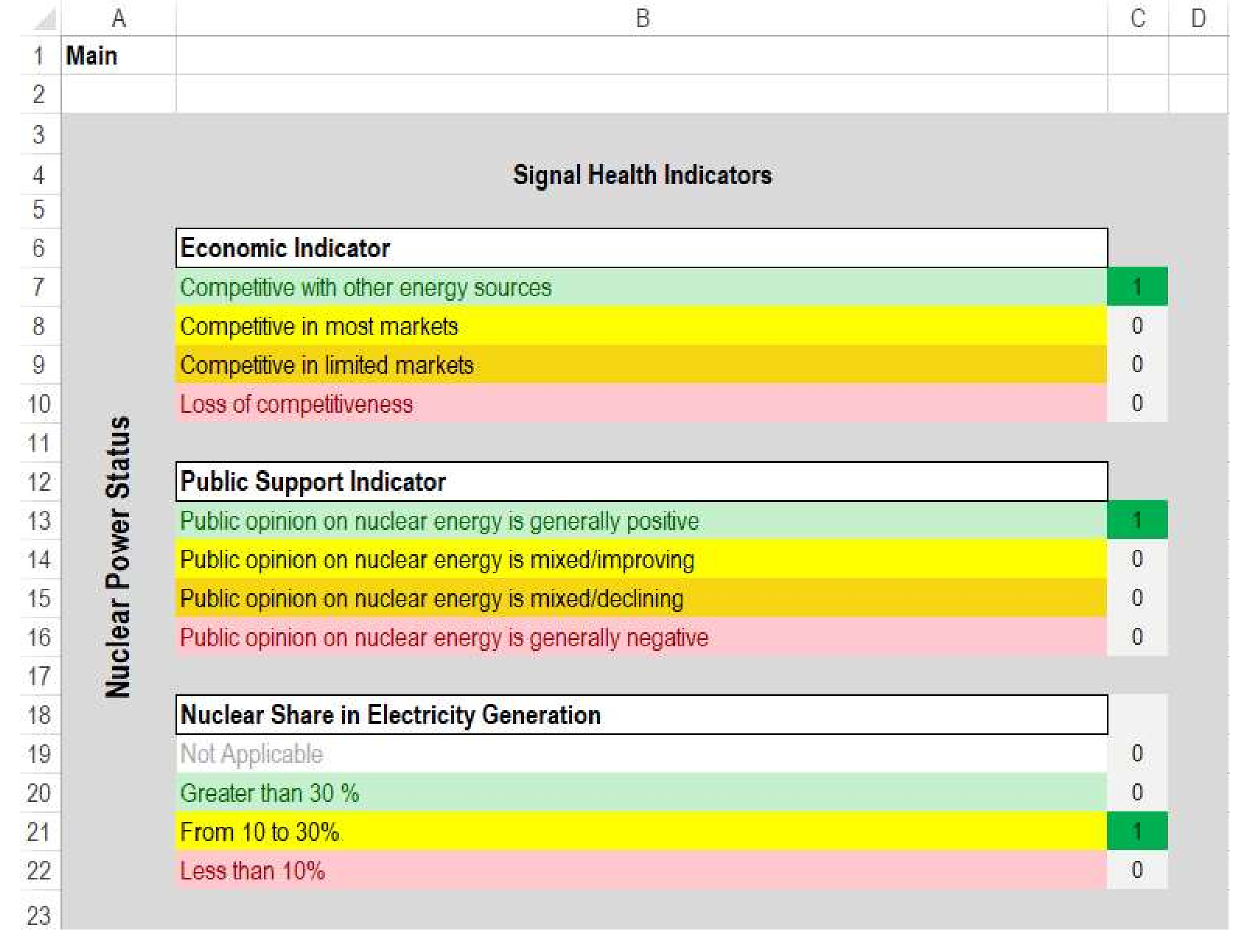


FIG. 36. ‘Metric Integration’ worksheet.

4.4. ‘AVERAGED DATA PREPARATION’ WORKSHEET

The ‘Averaged data preparation’ worksheet describes procedures of data averaging for the population of the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section, in order to keep adequate reproduction of energy and mass flows within the considered time steps if the associated steps cover several years.

The examples considered in this worksheet (Fig. 37) are also presented in the Section 3.2 ‘Data averaging’, since the user may need this information prior to working with the ‘Reactor Fleet and Relevant Nuclear Fuel Cycle Facilities’ section worksheets.

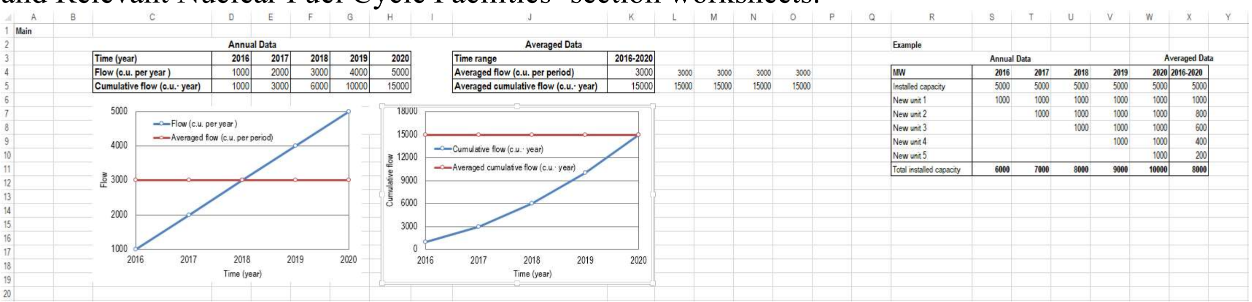
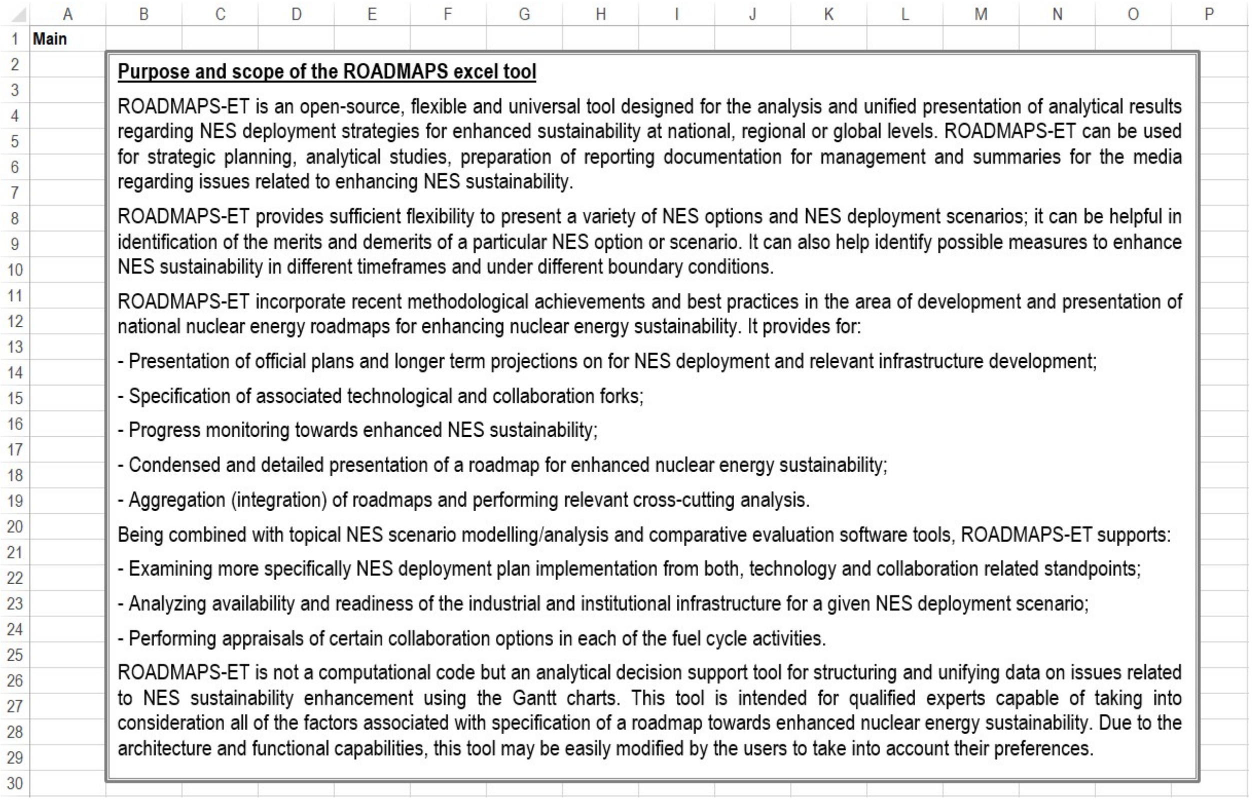


FIG. 37. ‘Averaged data preparation’ worksheet.

4.5. 'ABOUT' WORKSHEET

This worksheet shortly describes the application scope and main features of ROADMAPS-ET (Fig. 38).



Main

Purpose and scope of the ROADMAPS excel tool

ROADMAPS-ET is an open-source, flexible and universal tool designed for the analysis and unified presentation of analytical results regarding NES deployment strategies for enhanced sustainability at national, regional or global levels. ROADMAPS-ET can be used for strategic planning, analytical studies, preparation of reporting documentation for management and summaries for the media regarding issues related to enhancing NES sustainability.

ROADMAPS-ET provides sufficient flexibility to present a variety of NES options and NES deployment scenarios; it can be helpful in identification of the merits and demerits of a particular NES option or scenario. It can also help identify possible measures to enhance NES sustainability in different timeframes and under different boundary conditions.

ROADMAPS-ET incorporate recent methodological achievements and best practices in the area of development and presentation of national nuclear energy roadmaps for enhancing nuclear energy sustainability. It provides for:

- Presentation of official plans and longer term projections on for NES deployment and relevant infrastructure development;
- Specification of associated technological and collaboration forks;
- Progress monitoring towards enhanced NES sustainability;
- Condensed and detailed presentation of a roadmap for enhanced nuclear energy sustainability;
- Aggregation (integration) of roadmaps and performing relevant cross-cutting analysis.

Being combined with topical NES scenario modelling/analysis and comparative evaluation software tools, ROADMAPS-ET supports:

- Examining more specifically NES deployment plan implementation from both, technology and collaboration related standpoints;
- Analyzing availability and readiness of the industrial and institutional infrastructure for a given NES deployment scenario;
- Performing appraisals of certain collaboration options in each of the fuel cycle activities.

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 using the Gantt charts. This tool is intended for qualified experts capable of taking into consideration all of the factors associated with specification of a roadmap towards enhanced nuclear energy sustainability. Due to the architecture and functional capabilities, this tool may be easily modified by the users to take into account their preferences.

FIG. 38. 'About' worksheet.

5. CONCLUSION

ROADMAPS-ET is an open-source, flexible and universal tool designed for the analysis and unified presentation of analytical results regarding NES deployment strategies for enhanced sustainability at national, regional or global levels. ROADMAPS-ET can be used for strategic planning, analytical studies, preparation of reporting documentation for management and summaries for the media regarding issues related to enhancing NES sustainability.

ROADMAPS-ET provides sufficient flexibility to present a variety of NES options and NES deployment scenarios; it can be helpful in identification of the merits and demerits of a particular NES option or scenario. It can also help identify possible measures to enhance NES sustainability in different timeframes and under different boundary conditions.

ROADMAPS-ET incorporates recent methodological achievements and best practices in the area of development and presentation of national nuclear energy roadmaps for enhancing nuclear energy sustainability. It provides for:

- Presentation of official plans and longer term projections on for NES deployment and relevant infrastructure development;
- Specification of associated technological and collaboration forks;
- Progress monitoring towards enhanced NES sustainability;
- Condensed and detailed presentation of a roadmap for enhanced nuclear energy sustainability;
- Aggregation (integration) of roadmaps and performing relevant cross-cutting analysis.

Being combined with topical NES scenario modelling/analysis and comparative evaluation software tools, ROADMAPS-ET supports:

- Examining more specifically NES deployment plan implementation from both, technology and collaboration related standpoints;
- Analyzing availability and readiness of the industrial and institutional infrastructure for a given NES deployment scenario;
- Performing appraisals of certain collaboration options in each of the fuel cycle activities.

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 using the Gantt charts. This tool is intended for qualified experts capable of taking into consideration all of the factors associated with specification of a roadmap towards enhanced nuclear energy sustainability. Due to the architecture and functional capabilities, this tool may be easily modified by the users to take into account their preferences.

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ABBREVIATIONS

GAINS	Global Architecture of Innovative Nuclear Energy Systems Based on Thermal and Fast Reactors Including a Closed Fuel Cycle
GDP	Gross domestic product
HLW	High level waste
HM	Heavy metal
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
NEA	Nuclear Energy Agency
NES	Nuclear energy system
NFCIS	Nuclear Fuel Cycle Information System
NG	Nuclear strategy group (INPRO)
NPP	Nuclear power plant
OECD	Organization for Economic Co-Operation and Development
R&D	Research and development
ROADMAPS	Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems
PRIS	Power Reactor Information System
SW	Separative work
t	Ton
toe	Ton of oil equivalent
USD	US Dollar
WNA	World Nuclear Association