ANNEX XXII.

SCENARIOS WITH REPLACEMENT OF EXISTING HEAT GENERATION

XXII-1. INTRODUCTION

Research work was performed to implement the Ukrainian study under Task 2 of the SYNERGIES collaborative project, including research on the possibility of wide deployment of nuclear reactors for non-electric applications (heat production) and assessment of nuclear energy development based on the Generation IV reactors. Proposals are made for international cooperation in the development of the nuclear energy system (NES) of Ukraine in the medium- and long-term using Generation III+ and Generation IV reactors. Neither of these scenarios were considered during the GAINS project.

XXII-2. OBJECTIVE AND PROBLEM FORMULATION

The future deployment of nuclear power in Ukraine must take into consideration the high cost of NFC options and the low cost of non-nuclear electricity generation. Current power generation is largely based on coal and gas consumption, which produces CO_2 emissions. Economic development of Ukraine is likely to increase overall CO_2 emissions. In this context, Ukraine is considering wide deployment of nuclear power as a means to limit CO_2 emissions, as well as to strengthen the security of energy supply and decrease the costs of national electricity generation.

Nuclear infrastructure in Ukraine is based on open fuel cycle options, which produce a significant amount of spent nuclear fuel (SNF). Reprocessing facilities are not widely in use, and their high cost suggests there will be no such facilities in Ukraine in the foreseeable future. Moreover, the high capital cost of nuclear power generation is largely responsible for decreasing development of nuclear reactors based on Generation III and III+ technologies. A significant improvement of the technical and economical parameters of innovative nuclear reactors shall be considered as a means to enhance the economic attractiveness of electricity production by nuclear generation in Ukraine.

XXII-3. ASSUMPTIONS

XXII-3.1. General assumptions

The modelling was performed under the following boundary conditions:

- The energy system of Ukraine was modelled by generation forms independent of specific power units and regional features. Nuclear generation, however, was represented by different reactor types: LWRs installed, advanced LWRs, and Small-sized reactors for Scenario 1; and LWR installed, advanced LWR and SCWR for Scenario 2.
- Economic parameters (price for resources, capital construction, etc.) were given in short-term prices (overnight cost).

The modelling of non-nuclear-generated energy was performed under the following boundary conditions:

- Solar power plants and bio-energy make a very small contribution to electricity production and do not affect significantly the energy mix of the country. A&R are represented in the model by hydropower, wind and solar power;
- Renewable energy resources (hydropower, wind) are unlimited in volume and cost nothing. Only commissioning rate of the generation capacities is limited;
- Coal reserves are enough to cover energy needs in full scope and thus are considered to be unlimited. The mining rate is also unlimited. Coal import is allowed, if necessary;
- Gas for energy generation is imported, therefore its reserves are assumed to be unlimited. Supply rate is also unlimited;
- Electric power losses in the grids are decreased in accordance with the draft of the updated Energy Strategy till 2030 [XXII-1], and then they remain unchanged till 2050;
- Modelling period – till 2100;
- Total capacity of boiler plants was 117.8 thousand GCal/year at the end of 2012;
- The commissioning of new co-generation plants is not more than 600 MW per year;
- The commissioning of new boiler plants is not more than 200 MW per year.

The modelling of the nuclear energy system was performed using the following boundary conditions and assumptions:

- Nuclear energy sector of Ukraine in the beginning of the year 2010 is taken for the initial condition;
- Nuclear generation is represented absolutely as a basic component of the energy system of Ukraine;
- SMR can be deployed after 2030;
- Centralized dry storage facility will be commissioned in 2018;
- Nuclear share of the energy mix of Ukraine will be limited (not more than 50%);
- 1/3 of heat consumed by population and communal domestic households may be generated by NPPs;
- The commissioning of new SMR will not be more than 1 unit per year (325 MW).

XXII-3.2. Assumptions for the NFC analysis

Here, the assumptions were as follows:

- Five light-water reactors (2 LWR installed and 3 advanced LWR) with UOX-fuel will be commissioned by 2030 (in accordance with the basic scenario of the energy strategy of Ukraine on 2013);
- There is a possibility to commission annually not more than 1 reactor of any type after 2030;
- In case the optimized modelling demonstrates that a technology “is squeezed off” from the system, a “prioritized” (compelled) technology is allowed to be used in the model.

XXII-4. METHODS, CODES AND INPUT DATA USED

XXII-4.1. Codes and methods

The modelling of the energy system was performed with the MESSAGE software [XXII-2]. MESSAGE methodology is based on optimization of target function addressing specific set of constraints. MESSAGE is aimed at achieving the given parameters of electricity generation at minimum cost of the entire system with constraints of resources, fuel availability, market, investments, waste accumulation, etc.

MESSAGE provides two approaches to description of system components:

- INS component is modelled as "technology", i.e., production deployed on the territory of Ukraine;
- INS component is modelled as "service", purchased either at domestic market or imported.
- To describe components in terms of "technology" the following minimum input data is required:
    - material balance of raw materials and end product;
    - capital costs, construction period and operating lifetime;
    - fixed operating & maintenance costs independent of actual output (salary, water, electricity, expendable materials, rent, loans, etc.);
    - variable production costs (raw materials, fuel, etc.).
- To describe components in terms of "service" the following input data is required:
    - material balance of raw materials and end product;
    - cost of service.

The compliance of established model with actual conditions and, hence, forecast probability significantly depend on completeness and reliability of input data on technologies or, more specifically, on implementation status of related INS components.

XXII-4.2. Input data

Input data for both scenarios is present in Appendix I to this Annex.

XXII-5. SUMMARY PRESENTATION OF THE RESULTS

This chapter considers two scenarios: (1) replacement heat generation by small nuclear units and (2) wide deployment of the Supercritical Water Reactor (SCWRs).

XXII-5.1. Replacement of existing heat generation facilities by small nuclear units

According to the Updated Energy Strategy of Ukraine (2013), the total heat consumption ranges between 216 and 244 million GCal per year. Domestic household (44%) and industry (35%) were the main consumers. Other sectors of the economy consumed about 21%. The Updated Energy Strategy predicts an increase of heat consumption up to 290 million GCal (25%) by 2030.

In the case that fossil-fuel generation is replaced by nuclear generation for heat production in domestic households, nuclear reactors would be located not far from the large consumers, i.e., in large cities and industrial centers. However, it will not be possible to

replace all fossil-fuel generation; conservatively, one may expect that 1/3 of heat consumed by population and communal domestic households could be generated by NPPs.

In the long-term, heat consumption in domestic households is proposed to be constant at the level of 100 million GCal per year. It is constant because the strategies declare the measures on energy consumption will decline and energy efficiency will grow. Thus, the substitution level of fossil-fuel generation to nuclear generation may be 33 million GCal.

The following constraints are used:

(a) nuclear power application for district heating is possible after 2030;
(b) commissioning is possible of only 1 reactor per year.

Under consideration for heat generation purposes, they may be operated in co-generation mode. In case of small-sized reactors in Ukraine, the generation share and structure are presented in Figures XXII-1 and XXII-2. NPP share increases, and by 2050 would make up 50% of the total generation.

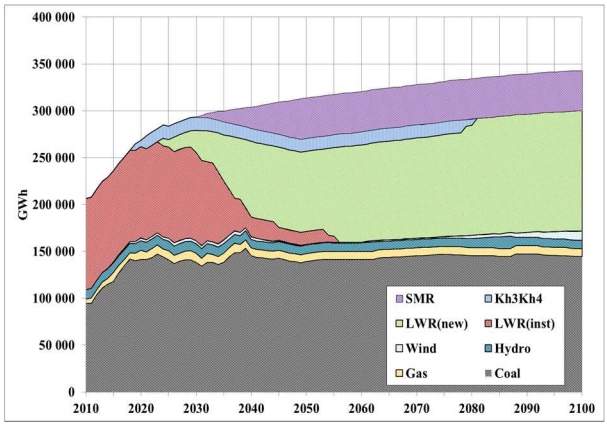

FIG-XXII 1. Electricity generation structure.

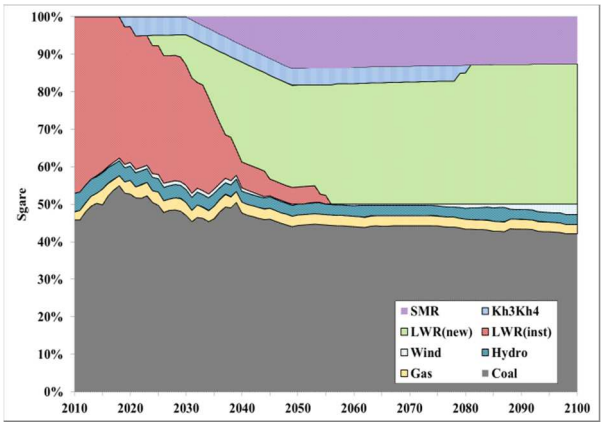

Fig. XXII-2. Generation share.

Total installed capacities of the large-sized reactors are maintained at the level of 15 GW in the long-term. The growth of nuclear capacities refers to the commissioning of SMRs as reason for the electricity and heat generation, Fig. XXII-3a. The dynamic of ALWR and SMR commissioning is presented in Fig. XXII-3b.

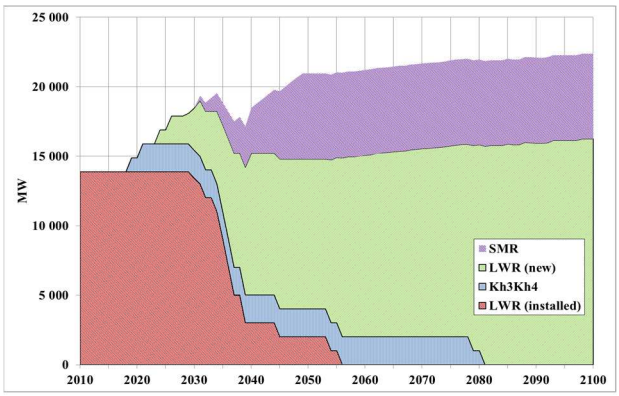

FIG. XXII-3a. Total installed capacities

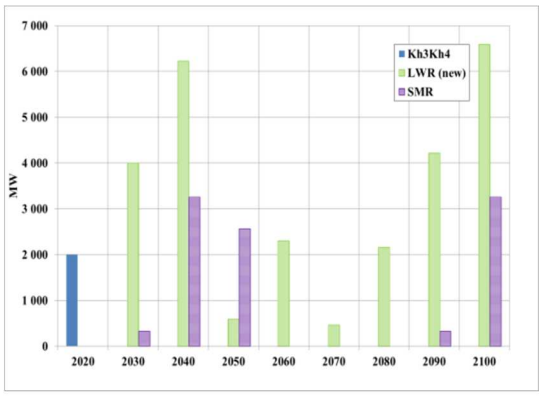

FIG. XXII-3b. Schedule of new capacities commissioning.

The SNF accumulation is presented in Fig. XXII-4.

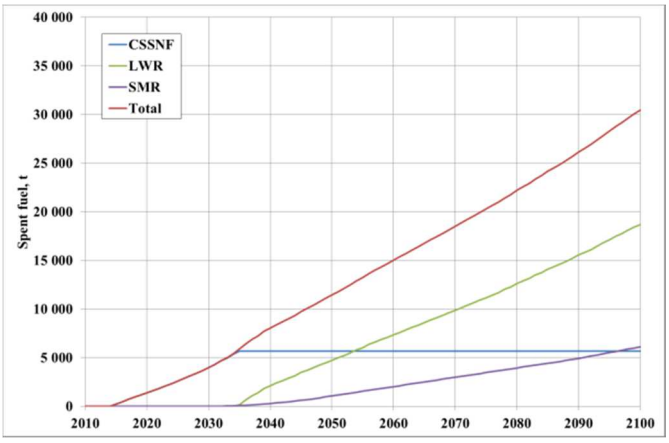

FIG. XXII-4. SNF accumulation.

The viability of nuclear technologies application for heating should be assessed taking into account the impact of technologies currently in use, namely boiler plants and the combined heat and power plants (CHP). Later on, another scenario was studied. It considered heat generation by boiler plants, CHP and small-sized reactors which operate in the mode of electricity and heat co-generation.

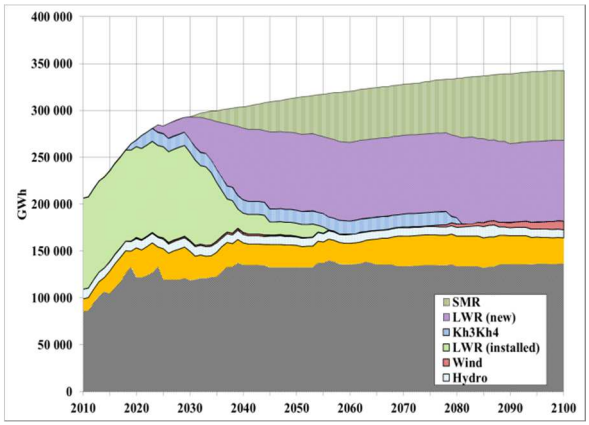

FIG. XXII-5. Electricity generation structure.

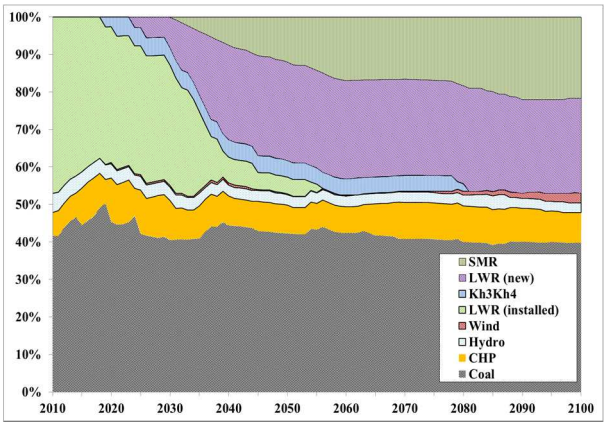

FIG. XXII-6. Generation share.

The total installed nuclear capacity and the schedule of new capacities to be commissioned are presented in Figures XXII-7 and XXII-8.

The spent nuclear fuel accumulation is presented in Fig. XXII-9.

XXII-5.2. Wide deployment of Super Critical Water Reactors (SCWRs)

The electricity generation structure and generation share for a scenario in which SCWRs are widely deployed in the energy system of Ukraine are shown in Figures XXII-10 and XXII-11.The commissioning of SCWRs is not expected before 2030.

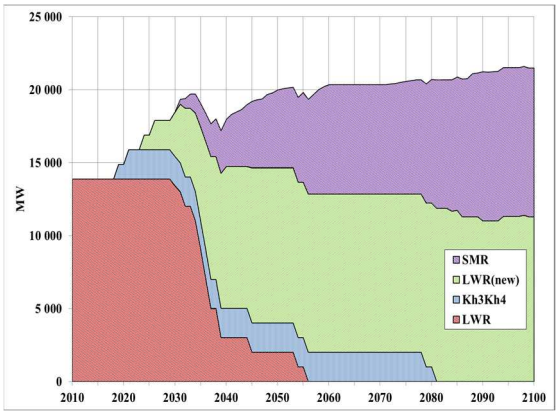

FIG. XXII-7. Total installed capacities

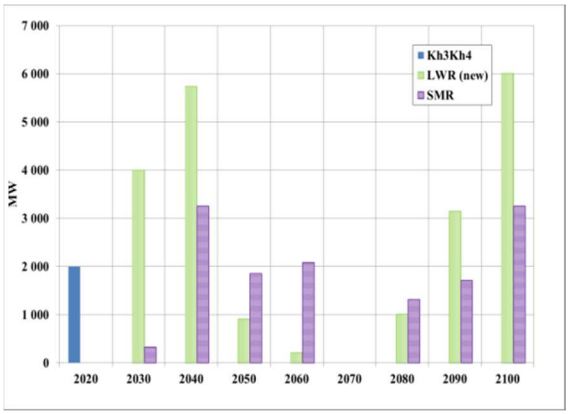

FIG. XXII-8. Schedule of new capacities to be commissioned.

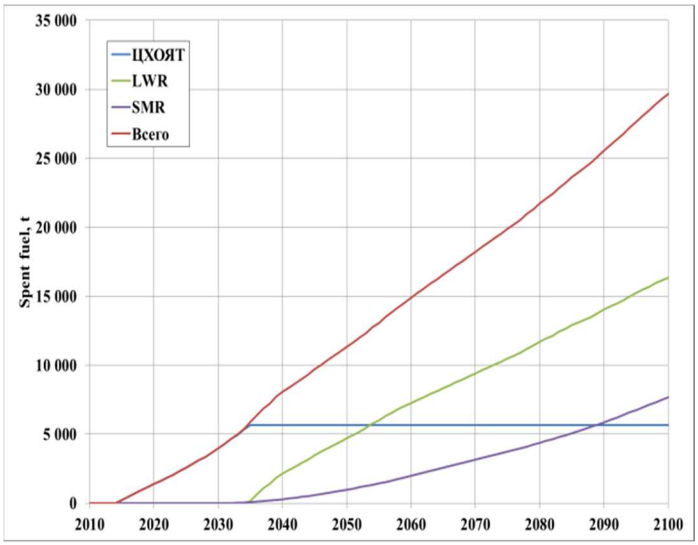

FIG. XXII-9. SNF accumulation.

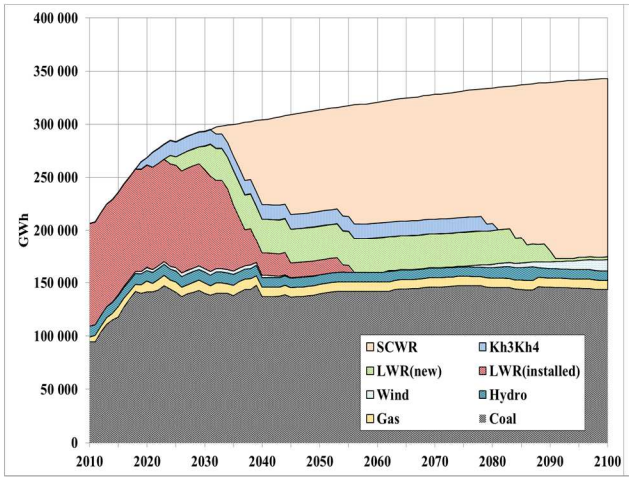

FIG. XXII-10. Electricity generation structure.

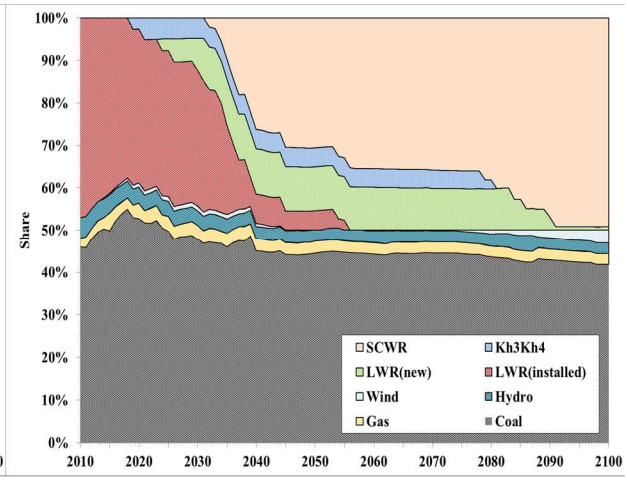

FIG. XXII-11. Generation share.

The total installed capacities and the schedule of new capacities to be commissioned are shown in Figs XXII-12 and XXII-13.

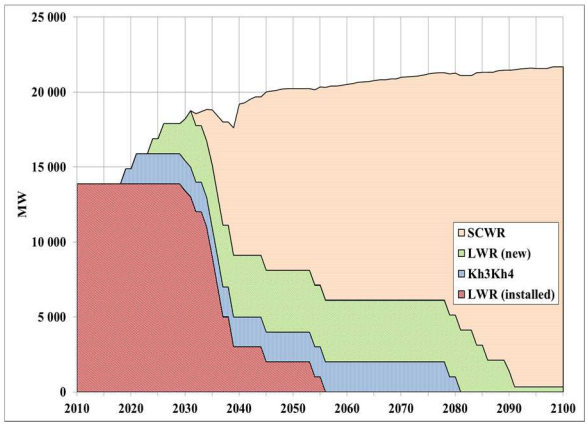

FIG. XXII-12. Total installed capacities.

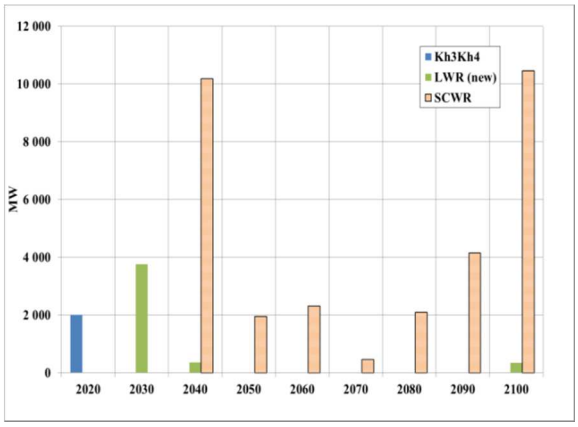

FIG. XXII-13. Schedule of new capacities to be commissioned.

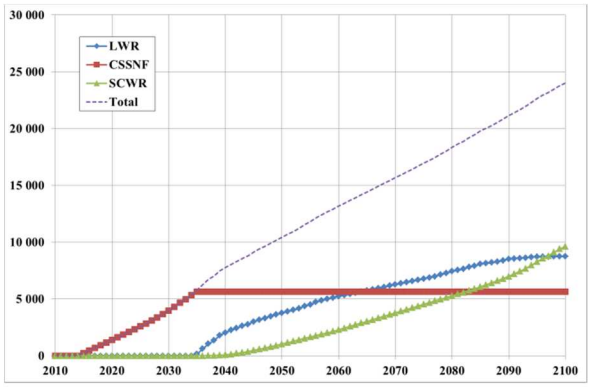

FIG. XXII-14. Spent fuel accumulation.

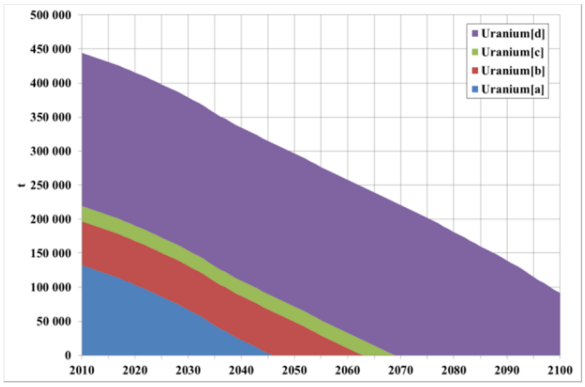

FIG. XXII-15. Uranium resource depletion.

XXII-6. ANALYSIS OF THE RESULTS

XXII-6.1. Replacement of existing heat generation facilities by small nuclear units

The SMRs cannot be implemented in the Ukrainian energy system in a case of sole electricity production.

In case of SMR implementation in energy system for the heat generation, the generation share and structure of NPP increases and by 2050 will make up 50% of total generation share in 2050. Total installed capacities of large-sized reactors are maintained at the level of 15 GW in the long-term. The pace of construction for new nuclear power units should be high enough to maintain a 50% nuclear share in electricity generation. 4 GW of large-sized reactors would be commissioned in 2020-2030 and 6 GW of large-sized reactors would be commissioned from 2030 to 2040, plus an additional 3 GW of small-sized reactors.

In a case that considers heat generation by boiler plants (i.e., CHP and small-sized reactors which operate in the mode of electricity and heat co-generation), the modelling results demonstrate the viability of nuclear power application for electricity and heat co-generation (district heating) purposes. The scenario considers the replacement of some fossil-fueled power plants by nuclear power. Total installed capacity of NPPs would increase up to

20-21 GW. 4 GW of large reactors would be commissioned in 2020-2030, while 5-6 GW would be commissioned during 2040-2050. 3 GW of 300 MW small-sized reactors would be commissioned from 2030 to 2040. 2 GW of small-sized reactors would be commissioned annually from 2050 to 2060. The commissioning of a considerable amount of new nuclear capacities corresponds to the large amount of acting nuclear reactors to be decommissioned in the indicated period. The amount of accumulated SNF will make up about 30 000 tons till 2100.

The analyzed scenario demonstrates the viability of nuclear power application for district heating. The obtained results should be considered as optimistic, because:

- the pace of commissioning nuclear power units is relatively high;
- although the potential of using nuclear reactors for district heating has been demonstrated, it is not always possible to construct NPPs near large consumers;
- more intensive operation of nuclear reactors means more SNF accumulation. The scenarios assume a once-through NFC with SNF disposal, but the construction of storage facilities was not considered.

XXII-6.2. Wide deployment of SCWRs

Increased capital construction costs for Generation III and III+ nuclear reactors (over previous generation reactors) as a result of more complicated safety systems, increased time required for commissioning, construction delays, and periodical changes in exchange rates, may make fossil-fuelled power plants more attractive from an economic perspective. However, increased costs and technical parameters have also increased capital construction costs for fossil-fuel generation.

A possible solution is the construction and operation of supercritical water reactors (SCWRs). The first commissioning of SCWRs is not expected before 2030, but due to the high technical specifications of SCWRs, the capacity of new SCWRs that could be commissioned in 2030-2040 could reach up to 10 GW. This would allow the share of nuclear power in all electricity generation to remain at 50%, in line with the policy requirements for the energy system of Ukraine. This fact is considered as an attractive feature of SCWRs in comparison with approaches involving the generation of energy other than electricity. By 2100, the total installed capacity of ALWRs and SCWRs would be 22 GW.

With utilization of SCWRs, a total of 25 000 t(HM) of SNF would be accumulated by 2100. This amount of SNF is similar to that accumulated in the option based on partially-closed and closed nuclear fuel cycles (NFCs), but is much less than in the option based on a once-through NFC (up to 30 000 t(HM)). This is notable since reprocessing and infrastructure development for minor actinides and plutonium storage would not be required.

In spite of better nuclear fuel utilization in the scenario based on SCWR, natural uranium reserves will only be sufficient till 2020, an unfavorable result compared to scenarios based on a closed NFC.

The levelized cost of electricity for the SCWR is 14.18 USD/MWh (in case of open NFC – 14.12 USD/MWh), and is a result of commissioning period and dependence on time factor.

XXII-7. CONCLUSIONS

XXII-7.1. Replacement of existing heat generation facilities by small nuclear units

Small reactors feature a number of advantages that could be decisive when building an innovative system:

- small size allows for a significantly shorter construction period and, hence, reduced investment risks;
- capability for different applications in addition to electricity generation, e.g. production of industrial heat, water desalination and cleaning, operating in co-generation mode, central heating;
- compactness of the design makes it an advantage in case the construction of large-sized units is not feasible (e.g., due high population density, poor cooling water resources).

Small-sized reactors are technically feasible for co-generation of electricity and heat. If the price for hydrocarbon fuel is high, it could be attractive to use nuclear reactors intensively for heat generation needs (as per input data accepted and model built). However, the use of small-sized reactors for base-scale electricity generation is a less feasible solution for Ukraine due to high capital costs. Small-sized reactors are more attractive if they are deployed for industrial and civil heat generation purposes, as a means to strengthen security of supply in the Ukrainian energy system. However, the system would accumulate a large amount of SNF (30 000 t(HM)) as compared to a basic power generation scenario based on the once-through fuel cycle.

XXII-7.2. Wide deployment of SCWRs

Supercritical reactors are considered to be feasible and attractive. SCWRs can produce a significant share of electricity in the energy system as a result of their higher technical parameters (increased values of capacity factor, efficiency, and fuel burn-up rate). Taking into account the technical and economic characteristics applied in this study, the introduction of SCWRs would significantly increase the share of nuclear generation in Ukraine.

The results show the economic attractiveness of deploying SCWRs after 2030 in comparison to advanced LWRs. SCWR application would allow for a decrease in SNF accumulation, and is the only feasible approach to maintain a 50% share of nuclear generation in the Ukraine energy system.

Development of a SCWR fleet is a reasonable approach to consider as a component of a once-through NFC. In this case, international cooperation in the NFC field will be required only for enrichment of uranium hexafluoride and fuel pellet sintering (until implemented at the domestic nuclear fuel fabrication plant). As for the NFC back end, it may be reasonable to address the capability of establishing a regional complex for long-term SNF storage, so as to optimize economic expenditures and minimize deployment of dry SNF storage facilities at each NPP.

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APPENDIX I. INPUT DATA

I.1. NUCLEAR GENERATION AND NUCLEAR FUEL CYCLE

I.1.1. Front-end

I.1.1.1. Uranium

For the purpose of energy system modelling, natural uranium resources of Ukraine amount to 477 thousand tons. NPP uranium demands are covered by domestic reserves [XXII-3][1].

TABLE I-1. PRICE RANGES OF URANIUM RESOURCES IN UKRAINE

Price range, USD/kg	Resources, thousand tons
80	135
100	64.5
120	22.5
150	255

I.1.1.2. Uranium conversion and enrichment

For the modelling purposes the cost of conversion services in 2013 equals 10 USD/kg(HM) [XXII-4]. The uranium conversion phase is considered to be a service along with uranium enrichment that costs 130 USD/SWU and is purchased at the global market, which is assumed to be unlimited [XXII-4].

I.1.2. Fresh fuel fabrication

I.1.2.1. Fresh nuclear fuel fabrication for LWR

Fresh fuel fabrication is considered to be a service that is purchased at 300 USD/kg(HM). In 2008, the average PWR nuclear fuel fabrication costs reached 250 USD/kg(HM). MOX-fuel fabrication for LWR is considered to be a service purchased at 1500 USD/kg.

I.2. NUCLEAR REACTORS

Technical and economic parameters of the reactors used in the modelling are shown in Table I-2.

TABLE I-2. TECHNICAL AND ECONOMIC PARAMETERS OF THE REACTORS

Reactor/ Parameter	LWR(3)	ALWR (VVER-1200)	SCWR [XXII-5]
Thermal capacity, MW(t)	3000	3200	3575
Electric capacity, MW(e)	1000	1120	1600
Efficiency factor, %	33	35	44.8

[1] Here and after, see the list of references to Annex XXII.

TABLE I-2. TECHNICAL AND ECONOMICAL PARAMETERS OF THE REACTORS (cont.)

Parameter	LWR(3)	ALWR (VVER-1200)	SCWR [XXII-6]
Capacity factor, %	78	90	90
Fuel enrichment, %	4.7	4.7	10
Average burn-up in fuel assembly, GWday/t	60	60	70
First load, t (HM)	72.844(1)	72.844(1)	83.8 (4)
Annual reload, t (HM)	16.088(2)	16.088(2)	16.7 (4)
Construction costs, USD/kW	3400 - Kh3Kh4	5000	5000
Fixed costs, USD/kW [XXII-7]	69.3	69.3	69.3
Variable costs, USD/MWh [XXII-6]	0.50	0.50	0.50
Operation lifetime, years	50	60	50
Construction period, years	6	6	6
Fresh nuclear fuel fabrication, USD/kg	300 [XXII-8 and XXII-9]	300 [XXII-7 and XXII-8]	300
SNF disposal costs, USD/kW	600 [XXII-7, XXII-10, XXII-11, and XXII-12]	600 [XXII-7, XXII-9, XXII-10 and XXII-11]	600 [XXII-7, XXII-9, XXII-10 and XXII-11]
Reprocessing costs, USD/kg	2000 [XXII-8, XXII-13, XXII-14]	2000 [XXII-8, XXII-9, XXII-13]	
Disposal costs of the products derived from SNF reprocessing (MA, FP), USD/kg	10 000 [XXII-15]	10 000 [XXII-20]	10 000 [XXII-20]

(1) 163 fuel assemblies x 545 kg x 0.85 = 72 844 kg
(2) 36 fuel assemblies x 545 kg x 0.85 = 16 088 kg
(3) 25% MOX-fuel is loaded into the core
(4) Calculated

The specifications of small reactors used in modelling are given in Table I-3.

TABLE I-3. SMALL REACTOR SPECIFICATIONS

Parameter	Value [XXII-16, XXII-17]
Thermal capacity, MW	912
Electric capacity without heat output, MW	325
Electric capacity with heat output, MW	302
Heat output, GCal/h	150 (≈174.45 MW)
Burn-up rate, GW/dayt	60
Full load, t*	22.2144
Reloading, t/year*	4.44
Capacity factor, %	80
Fuel enrichment, %	5
Construction costs, USD/kW	5500

* obtained by calculations

I.3. SPENT NUCLEAR FUEL MANAGEMENT

The centralized spent nuclear fuel (SNF) storage facility may be used as a temporary one (until postponed decision is implemented) [XXII-18]. The cost will make up 350 USD/kg(HM) and includes capital, O&M and decommissioning costs. The commissioning of centralized SNF storage facility with capacity of 5 650 t is planned in 2018.

I.4. ELECTRICITY AND HEAT PRODUCTION AND CONSUMPTION

The projected electricity consumption in Ukraine till 2100 is shown in Fig. I-1.

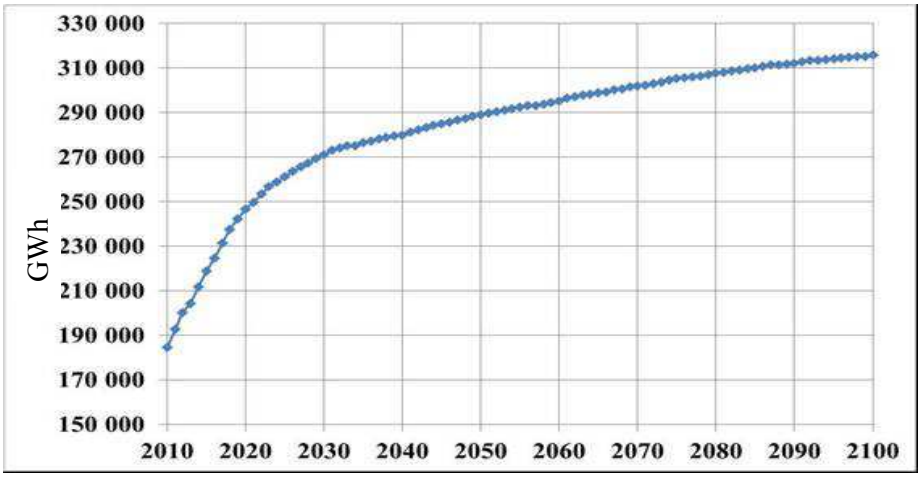

FIG 1-1. Projected electricity consumption in Ukraine till 2100

The installed capacities structure as of 31 December 2011 [XXII-19] and the generation structure [XXII-20] in Ukraine are presented in Tables I-4 and I-5. Coal-fuelled power plants have the biggest share in the installed capacities – about 50%, nuclear power plants cover about 25%. The shares of solar and wind power plants makes up 0.25% and 0.23% respectively.

It should be noted that the majority of thermal power plants were commissioned from 1960 to 1980 [XXII-19] and their modernization should be started in the coming years. The commissioning of nuclear power plants occurred in 1980-1990s. Nowadays the activities on lifetime extension of nuclear power units are carried out.

TABLE I-4. INSTALLED CAPACITIES STRUCTURE IN UKRAINE

Generation type	Capacity, MW	Share, %
NPP	13 835	25.95
Thermal power plants TPP (coal)	27 272	51.16
Combined heat and power plants CHP and other TPP	6 429.8	12.05
Hydro power plants HPP	5 465	10.26
Solar power plants	187.5	0.35
Wind farms	121.1	0.23

Most electricity is generated at nuclear power plants (45-47%); fossil fuel burning power plants produce 43-49% of electricity, and hydro power plants amount to 6-7%.

Heat consumption in Ukraine is presented by Table I-6 and Fig. I-2.

TABLE I-5. ELECTRICITY GENERATION STRUCTURE IN UKRAINE

Type	2010		2011		2012	
	bln. kWh	%	bln. kWh	%	bln. kWh	%
NPP	89.2	47	90.2	46	90.1	45
TPP	86.5	46	93.6	48	97.1	49
HPP	13.2	7	10.9	6	11.0	6
Total	188.8	100	194.9	100	198.9	100

TABLE I-6. HEAT CONSUMPTION IN UKRAINE*

Year	Updated strategy, mln. GCal	Updated strategy, bln. kWh
2000	226	262.836
2001	216	251.208
2002	216	251.208
2003	233	270.979
2004	237	275.631
2005	241	280.283
2006	244	283.772
2007	223	259.349
2008	233	270.979
2030	290	337.270

* Heat consumption is measured in GCal in the "Updated Energy Strategy". In order to compare it with electricity consumption, an additional column was added to the table in which heat consumption is measured in bln. kWh.

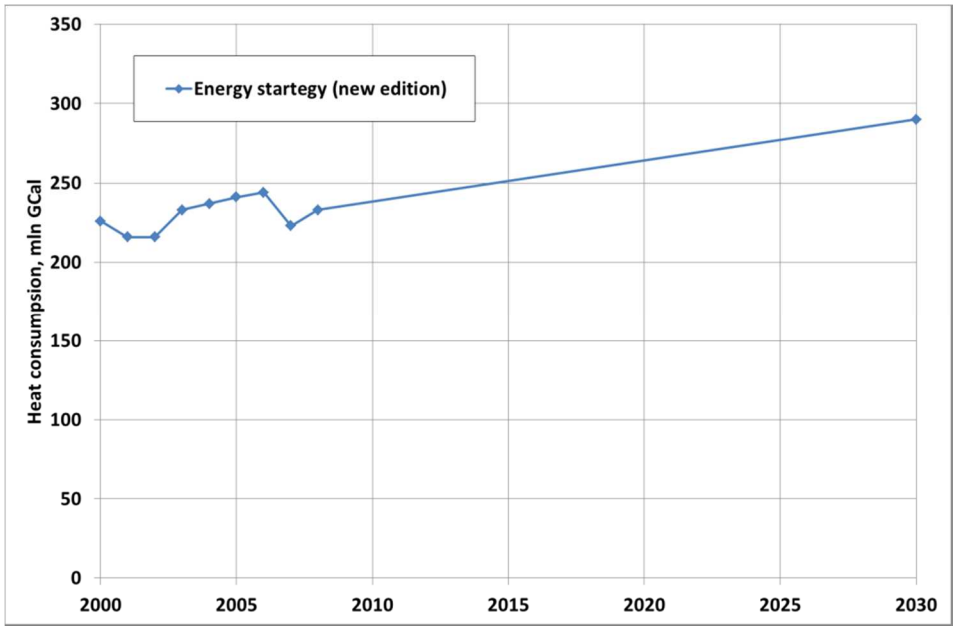

FIG. I-2. Heat consumption in Ukraine.

I.5. BOILERS AND COMBINED HEAT AND POWER PLANTS

Total capacity of boiler plants made up 117.8 thousand GCal/year in the end of 2012 [XXII-6]. Heat output to population to cover communal domestic needs with losses consideration is presented in Table I-7 and Fig. I-3, see reference [XXII-21].

TABLE I-7. HEAT OUTPUT BY BOILER-PLANTS, MLN. GCAL

Year	Heat output	To population	Communal domestic needs	Losses
2005	117.8	62.3	25.4	13.1
2006	114.6	60.7	26.1	13.4
2007	103.0	55.0	23.7	12.4
2008	96.1	51.8	23.6	12.4
2009	90.7	52.1	22.2	12.3
2010	97.8	54.7	23.1	13.6
2011	97.6	54.7	22.6	13.5
2012	96.0	55.0	21.9	13.8

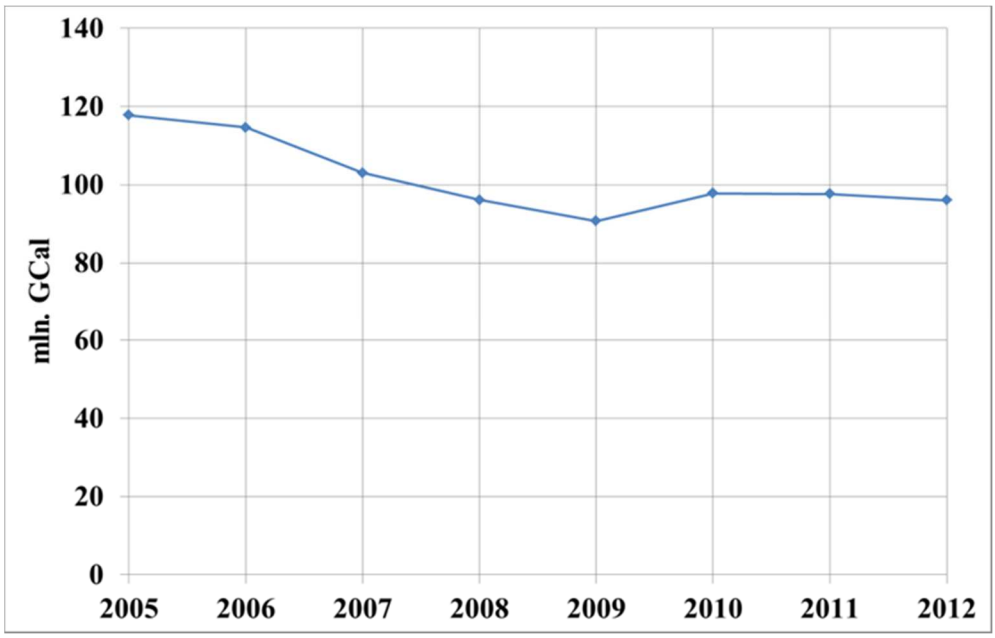

FIG. I-3. Heat output by boiler plants.

Table I-8 presents specifications of the combined heat and power plants (CHP) operating in Ukraine. Table I-9 gives the parameters of CHP and boiler plants used for modelling. CHPs were presented in the model as one technology with averaged parameters, see Table I-9.

TABLE I-8. SPECIFICATIONS OF CHP OPERATING IN UKRAINE

CHP	Year of commissioning	Electrical capacity, MW	Thermal capacity output, GCal/h
Bila Zerkva	1971	120	315
Mironovka	1953	275	
Dneprodzerzhinsk	1932	61.6	
Kalushs	1967	200	590
Kyiv CHP 5	1971	700	1875 GCal
Kyiv CHP 6	1981	500	1740 GCal
Nikolayev	1976	40	475.8
Odessa	1988	68	505
Kremenchuck	1972	255	1131
Severodonetsk	1960	260	600
Kharkiv CHP-5	1979	120	175
	1980	120	175
	1990	300	350
Kherson CHP	1956	80	734
Cherkassy	1961	230	430
Chernigiv	1973	210	625

TABLE I-9. PARAMETERS OF CHP AND BOILER PLANTS FOR MODELLING

Parameter	CHP	Boiler plant
Electrical capacity	300	
Thermal effectiveness (total)	0.75	0.9
Electrical	0.20	-
Efficiency of related (heat) output	0.55	-
Construction costs USD/kW	2000	100
Operation lifetime	6000	60
Construction period	3	1
Capacity factor	0.85	90

I.6. COAL FUELLED POWER PLANTS

Since 2000 the coal consumption for electricity generation was 40-50 mln. tons of standard fuel that corresponds to the mining capabilities of Ukraine. However, the coal reserves in Ukraine are difficult to access, and a lot of investments is required for new technologies deployment that could make the coal mining less expensive.

Coal fuelled power plants were presented in the model as a technology with the following parameters:

- capacity factor – about 55%;
- capital construction costs – 1600 USD/kW;
- construction period – 4 years;
- fixed costs – about 57 USD/kW of installed capacity per year;
- variable costs – about 4.5 USD/kWh of generated electricity at specific coal price correlated with generated energy and estimated at 107 USD/kWyear (100

USD/t);
- construction and modernization pace of coal-fuelled power plants does not exceed 2000 MW per year.

I.7. GAS FUELLED POWER PLANTS

Natural gas application for commercial generation is restricted by its limited reserves and considerable increase of import prices. Taking into account that gas fuelled power plants are the most suitable for responding to peak loads, capacity factor is assumed to be about 32% (gas fuelled power plants are supposed to be highly-maneuverable facilities capable to respond to the peak loads). Some other economic parameters include:

- capital construction costs – 1300 USD/ kW;
- construction period – 3 years;
- fixed costs – about 20 USD/kW of installed capacity per year;
- variable costs – about 15 USD/kWh of generated electricity. The gas price is about 350 USD/kWyear (corresponds to the purchase price of 400 USD/thousand m^3).

I.8. HYDRO POWER

The energy potential of large rivers makes up 7.0 mln. tons of standard fuel per year and is almost exhausted. The energy potential of small rivers is low and amounts to 1.4 mln. tons of standard fuel/year and therefore cannot be considered as a significant factor for base-load generation. Hydro power plants have high energy potential in regulating peak loads and when it is necessary to reimburse the collapse of energy consumption.

The main economic parameters of hydro power used in the model are listed below:

- capacity factor – about 25%;
- capital construction costs – 2200 USD/kW;
- construction period – 10 years;
- fixed costs – about 14 USD/kW of installed capacity per year;
- variable costs – about 2.4 USD/kWh of generated electricity.

I.9. WIND ENERGY

The following parameters of wind power were used in the model of the energy system of Ukraine:

- capacity factor – 26%;
- capital construction costs – 1900 USD/kW;
- construction period – 1 year;
- fixed costs – about 31 USD/kW of installed capacity per year.

I.10. SOLAR ENERGY

The following parameters of solar energy were used in the model of the energy system of Ukraine:

- capacity factor – 16%;
- capital construction costs – 5000 USD/kW;
- construction period – 1 year;

– fixed costs – about 15 USD/kW of installed capacity per year.