IAEA-CN-327-29

EFFICIENCY ASSESSMENT OF SMR DEVELOPMENT AS A NON-CARBON ENERGY SOURCE IN THE RUSSIAN ELECTRICITY AND DISTRICT HEAT SUPPLY SYSTEMS

F.V. VESELOV, A.A. KHORSHEV, T.G. PANKRUSHINA, and T.V. NOVIKOVA

Energy Research Institute of the Russian Academy of Sciences, Moscow, Russian Federation, erifedor@mail.ru

ABSTRACT

The paper discusses the economic and technical possibilities and limitations of SMR development in the Russian energy system. The results of an economic comparison of nuclear plants with SMR units and large reactors (LR) are presented. The assessment of SMR capital costs (based on LR cost) takes into account various factors of their reduction, including the technological learning, multiunit effect, the grid connection cost. The SMR competitiveness analysis has been extended to district heating systems. Coal and gas cogeneration plants (CHP), as well as a carbon-free "joint scheme" of energy supply using a combination of electric boilers and LR nuclear power plants or hydroelectric power plants as sources of electricity, are considered as competitors of nuclear CHP with SMR. An analysis of "switching to nuclear" condition has been performed to assess the scale of support measures (for example, carbon prices) that are necessary for the mass implementation of SMR as an option for district heating. Optimization of the low-carbon transformation of Russian electricity and district heating supply systems has made it possible to study the effective scale of SMR development for the period up to 2050. The optimization took into account different levels of carbon emissions quotas. The impact of carbon payments on "switching to nuclear" decisions and the development of nuclear energy sources, including SMR, was also studied.

INTRODUCTION. COST OF LARGE AND SMALL NUCLEAR PLANTS

- Nuclear plants (NPP) provide 19% of electricity production (out of 4.17 EJ in total) and 0.3% of centralized heat production (out of 5.62 EJ in total) in Russia
- Local capital cost (CAPEX) of LR (1200+ MW) NPP units are much lower than the global average - at about $2,700/kW (in 2021 prices) according to the national market regulator
- As a result, LR NPP is the cheapest carbon-free technology and a priority for solving the problem of decarbonization of electricity production in Russia
- Due to the economies of scale effect, SMR NPP will have noticeably higher CAPEX than LR NPP (with the same type of technology). The gap between LR and SMR CAPEX may (to a certain extent) become lower due to the modularity of units, high integrity of their production, optimization and simplification of design, more intensive technological learning as well as optimized regulatory procedures and requirements
- Even with the reduced scale effect CAPEX for 50 and 100 MW SMR units will still remain 3.5 and 2.5 times higher than for 1200 MW units, respectively (for comparable conditions of a two-unit plant).
- An additional (up to 15-20%) reduction in CAPEX is achieved by placing a larger number of units on one site. Multiunit (8-12x55MW) plant with SMR (RITM reactor) may have comparable (but still higher) higher CAPEX than 2x600MW VVER plant (Fig.1)

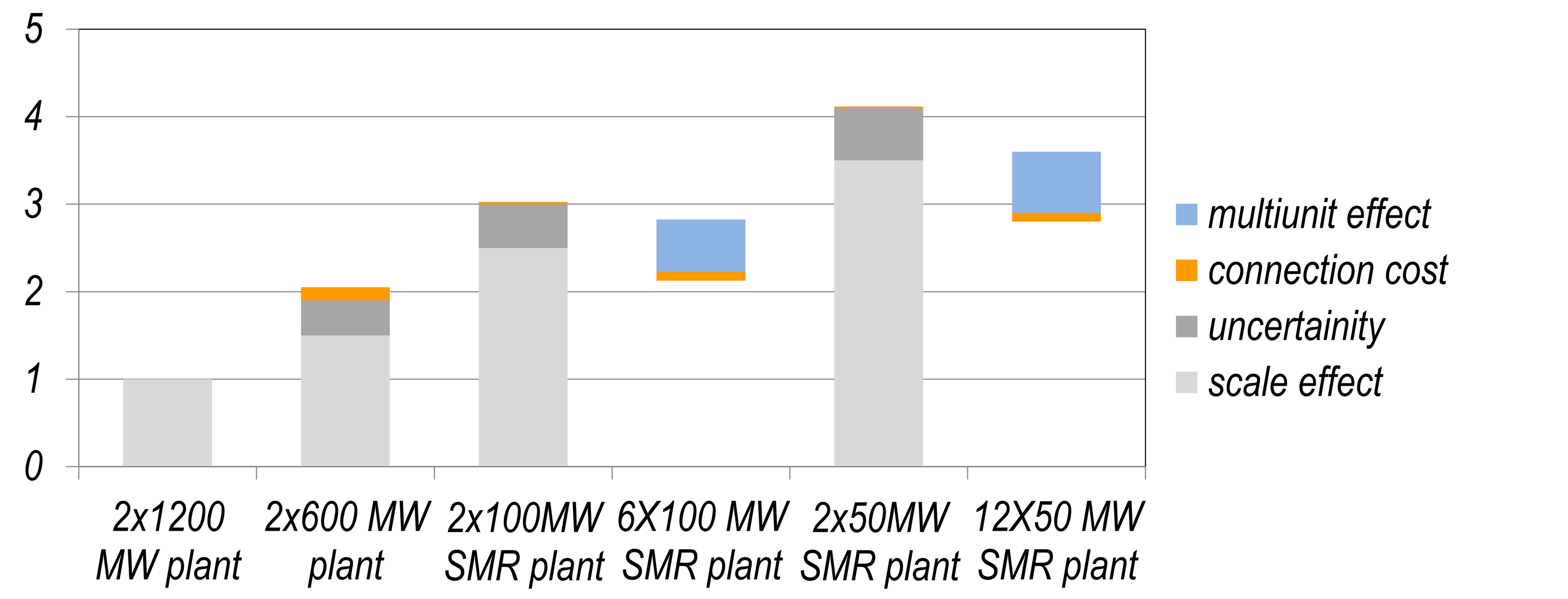

FIG. 1. CAPEX of LR NPP and SMR and an impact of multiunit effect, times to 1200 MW unit CAPEX

In the large power systems SMR are usually economically inferior to LR NPPs as the source of electricity only. But SMR may be considered as an option for decarbonizing heat supply. Here, a nuclear CHP (NCHP) may potentially compete with a combination of LR NPP and gas or electric boilers

SCREENING ANALYSIS OF NUCLEAR CHP AND ALTERNATIVES

Levelised cost approach was used for the economic comparison of various district heating and CHP technologies based on the LCOE, LCOH and LCOQ indicators:

- One-product electric power plant

$$LCOE_i = \frac{\sum_t (CAPEX_{i,t} + Fuel_{i,t} + VarOM_{i,t} + FixedOM_{i,t} + Carbon_{i,t}) \cdot (1+d)^{-t}}{\sum_t (Electr_{i,t}) \cdot (1+d)^{-t}}$$

- Heat supply source (boiler/electric boiler)

$$LCOH_i = \frac{\sum_t (CAPEX_{i,t} + Fuel_{i,t} + VarOM_{i,t} + FixedOM_{i,t} + Carbon_{i,t}) \cdot (1+d)^{-t}}{\sum_t (Heat_{i,t}) \cdot (1+d)^{-t}}$$

- Two-product (combined heat and power) plant or CHP

$$LCOQ_i = \frac{\sum_t (CAPEX_{i,t} + Fuel_{i,t} + VarOM_{i,t} + FixedOM_{i,t} + Carbon_{i,t}) \cdot (1+d)^{-t}}{\sum_t (Electr_{i,t} + Heat_{i,t}) \cdot (1+d)^{-t}}$$

- Alternative combination of one-product power plant and boiler/electric boiler

$$LCOQ = \frac{\sum_t (LCOE_j \cdot Electr_{j,t} + LCOH_k \cdot Heat_{k,t}) \cdot (1+d)^{-t}}{\sum_t (Electr_{j,t} + Heat_{k,t}) \cdot (1+d)^{-t}}$$

Key findings from screening analysis (Fig.2):

- By 2050, coal and gas-fired CHPs will be able to provide approximately twice lower the cost of electricity and heat supply than nuclear alternatives. Lower discount rate will improve the situation just to a certain extent

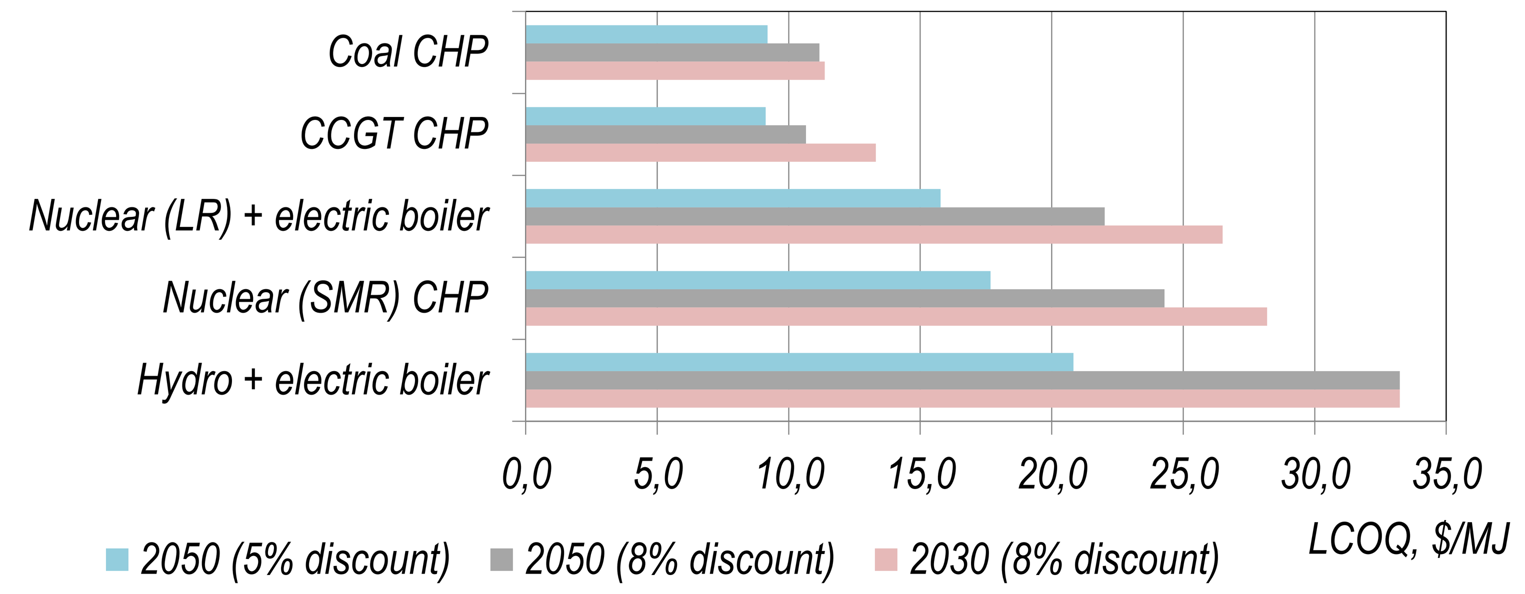

FIG. 2. Changes in LCOQ from 2025 to 2040 due to technological factors and discount rate

- The cost of energy supply from a nuclear CHP will be 10-15% higher than from a combined electric boiler and LR NPP scheme. But larger SMR units (with a capacity of 100 MW) aligns the competitive positions of NCHP and LR NPP with electric boilers
- Nuclear CHP with 50 MW SMR can also lose competition with electric boiler and large reactor nuclear power plants in the heat supply. But NCHP may complement LR NPP in the scenarios of deep decarbonization of the electricity and heat production (because of upper limits on the rates of LR NPP capacity growth – max 100 GW by 2050).

Additional carbon regulation measures are required for "switching to nuclear" in district heating. Carbon prices can help bring the LCOQ values of gas and coal-fired thermal power plants in line with nuclear technologies:

Nuclear technology	*Substituted conventional technology*	*Required CO_2 price, \$/t CO_2*		
		2030, 8% discount	*2050, 8% discount*	*2050, 5% discount*
Nuclear (SMR) CHP	*Coal CHP*	*132*	*103*	*67*
Nuclear (LR) + electric boiler	*Coal CHP*	*113*	*80*	*47*
Nuclear (SMR) CHP	*CCGT-CHP*	*253*	*232*	*145*
Nuclear (LR) + electric boiler	*CCGT-CHP*	*200*	*169*	*94*

MODELING THE VOLUMES OF LR AND SMR NUCLEAR CAPACITIES IN THE NATIONAL POWER SYSTEM. CONCLUSIONS

Modeling of changes in the structure of electricity and district heat production until 2050 was performed using the EPOS long-term capacity planning model developed at the ERI RAS. Different scenarios of CO_2 quotas (% to 2019) and prices by 2050 were considered:

	2021	2050 CO_2 limit at 84,6%	2050 CO_2 limit at 60%	2050 CO_2 limit at 50%	2050 CO_2 price 100\$/t CO_2	2050 CO_2 price 200\$/t CO_2
Electricity production, PJ	4172	5335	5796	6556	5515	6008
Hydro and RES, %	19.5	19.7	21.5	29.4	21.2	25.4
Nuclear, %	19.2	21.8	55.0	50.4	55.0	55.1
Thermal, %	61.4	58.5	23.5	20.3	23.6	19.4
District heat production, PJ	5623	4517	4517	4517	4517	4517
CHP, %	51.1	65.9	42.9	37.9	43.6	36.7
Boilers, %	48.2	33.0	43.6	32.0	49.4	37.8
Electric boilers, %	0.3	0.5	8.6	22.9	3.3	18.5
Nuclear plants, %	0.4	0.6	4.9	7.2	3.7	7.0

Conclusions from system optimization:

- Nuclear CHP with SMR and electric boilers (powered by LR NPP or hydroelectric power plants), are perhaps the key technologies for replacing fossil fuels in district heating.
- Switch to NCHP will require high carbon prices (more than \$100/t CO_2 to replace coal sources and more than \$200/t CO_2 to replace gas heat sources) or strict quotas for CO_2 emissions (40-50% below the 2019 level). Under these conditions, the capacity of NCHP with SMR by 2050 can reach up to 15 GW
- Thus, SMR can really become a mass energy supply technology in the UPS of Russia – 15 GW SMR capacity means 270 units of RITM-200 (55MW) of 190 units of RITM-400 (80 MW) by 2050

ACKNOLEDGEMENTS

The study is supported by Russian Science Foundation grant (project № 21-79-30013).