Efficiency assessment of SMR development as a non-carbon energy source in the Russian electricity and district heat supply systems

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Russia towards to the carbon neutrality.

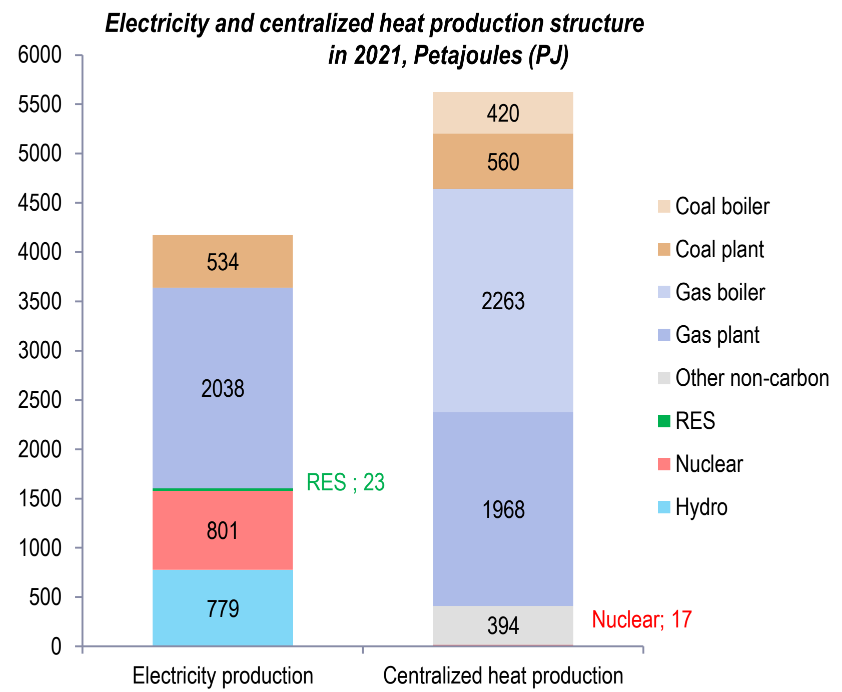
The Climate Doctrine (2022) sets the goal of achieving carbon neutrality by 2060

The National Low GHG Emission Strategy (2021) sets the goal to reduce net emissions by 60% by 2050 (rel. to 2019)

Physical GHG emissions	↓	-13.6% or -0.29 bln t CO_2-eq
Absorption of GHG by ecosystems	↑	+125% or +0.66 bln t CO_2-eq
Net GHG emissions	↓	-60% or -0.95 bln t CO_2-eq

Source: RF Strategy for the Development of Russia with Low GHG Emissions

- Total GHG emissions associated with electricity and heat production amount to about 0.78 billion tons of CO2-eq.
- Currently, more than 60% of electricity and 92% of district heat is produced using fossil fuels, mainly natural gas.
- Nuclear plants provides near 19% of electricity and 0.3% of heat production

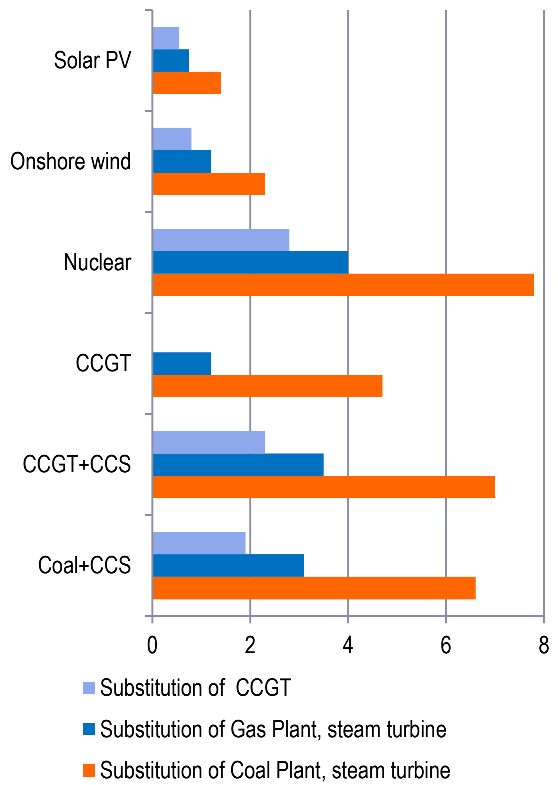


Source: ERI RAS analysis based on Rosstat data

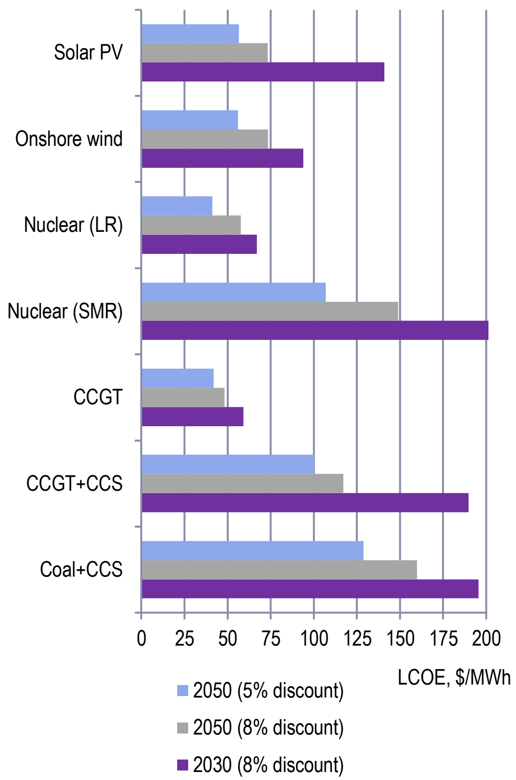
Nuclear plants as an efficient technology for decarbonization

- In Russia, due to the integrated cycle of local production of equipment, design and construction of nuclear power plants, local capital cost of LR (1200+ MW) NPP units are about 1.5-2 times lower than the global average.
- The national market regulator set LR NPP CAPEX based on the cost of the first VVER-1200 units at about $2,700/kW (in 2021 prices).
- Technological learning can reduce these costs by another 10-15% for NOAK units
- It is also expected that CAPEX of new 1200+ MW fast reactors will not exceed VVER level (NOAK to NOAK)
- As a result, LR NPP turn out to be the cheapest carbon-free technology and a priority for solving the problem of decarbonization of electricity production

Annual impact of low- and non-carbon technologies on reducing of CO_2 emissions from thermal plants, per 1 GW



Changes in LCOE from 2025 to 2040 due to technological factors and discount rate, Y2023 USD/MWh

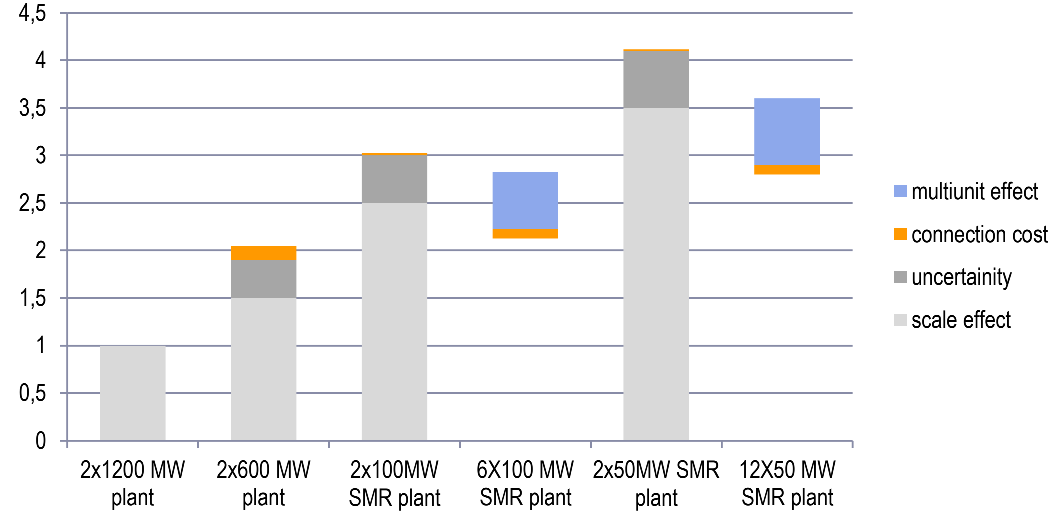


Source: ERI RAS estimations

Competitiveness of SMR vs LR nuclear units

- Due to the economies of scale effect, SMR NPP will have noticeably higher CAPEX than LR NPP (with same type of technologyPWR)
- The gap between LR and SMR CAPEX may (to a certain extent) become lower due to the impact of several factors, such as:
  - modularity and high integrity of production,
  - optimization and simplification of design, as well as regulatory procedures and requirements,
  - more intensive technological learning due to the mass serial production and construction
- 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 (up to 8-12) on one site
- Multiunit (400-600 MW) plant with SMR on the basis of RITM reactors (8-12x55MW) may have comparable (but still higher) higher CAPEX than 2x600MW VVER plant

Difference in the CAPEX of LR NPP and SMR and an impact of multiunit effect, times to 1200 MW unit CAPEX



Source: ERI RAS estimations

- In the large power systems SMR are usually economically inferior to LR NPPs
- But SMR are considered as carbon-free and secure supply option in the remote isolated small systems where 10-100 MW units are required, rather than 1000MW units (and fuel prices are much higher)
- Also 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 CHP and alternative electricity and heat supply technologies based in levelised cost approach

- One-product electric power plant

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

- Heat supply source (boiler/electric boiler)

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

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

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

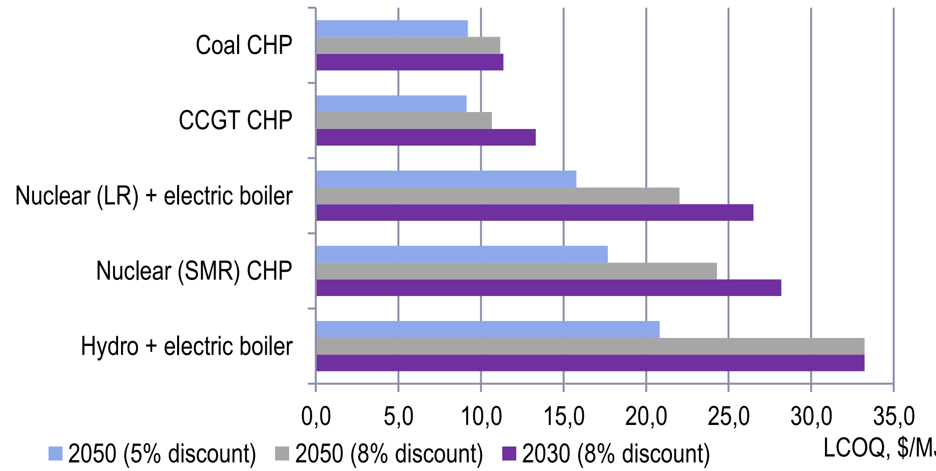
- Alternative electricity and supply combination of one-product power plant and boiler/electric boiler

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

Estimation of nuclear CHP competitiveness based on the screening analysis

- 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
- At the same time, nuclear technologies in heat supply on average win the competition from a combination of electric boilers and hydroelectric power plants
- Lower discount rate will improve the situation to a certain extent, especially for a combination of electric boiler and LR NPP
- 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 electric boilers will require more and more LR NPP capacities. The upper limit on the rates of LR NPP capacity growth (due to sites of plants and industry supplies) should be taken into account.
- As a result, NCHP may complement LR NPP in the scenarios of deep decarbonization of the electricity and heat production

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



- 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		
		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

Source: ERI RAS estimations

Modeling the volumes of LR and SMR nuclear capacities in the national power system

- 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.
- The EPOS model can simulate different decarbonization scenarios with carbon regulation measures like limits on CO_2 emissions from power plants and boilers, or set targets for the carbon intensity of electricity and heat production, as well as carbon prices

Carbon payments

Optimality criterion: the minimum cost of energy supply to the economy (total discounted costs) for the period under review and taking into account the costs of the aftereffect of decisions taken for another 30 years

- capacity balances for an hour of the annual maximum load and for an hour of the minimum load of the winter working day for energy zones, allowing to ensure minimum capacity requirements for the reliable operation of the UES of Russia, including the regulatory level of the reserve and a sufficient level of intraday flexibility of the capacity mix

- annual electricity balances for energy zones with optimization of needs in the volume of own consumption and representation of the level of the distribution network to optimize the effective volumes of distributed generation corresponding to the conditions of network parity, taking into account electricity transmission tariffs

- annual balances of heat supply from power plants and boiler houses in each administrative RF unit, differentiated by groups of heat consumers to optimize the effective scale and directions of heating

- annual fuel supply balances (by fuel types) for power plants and boiler houses, linking production volumes by main fuel deposits, aggregated transport flows (network for gas and radial for coal and fuel oil), consumption volumes optimized in the model at power plants and exogenously set demand forecasts of other domestic consumers and export dynamics

Limits on the annual volume CO_2 emissions from power plants and boilers

Carbon intensity targets for electricity (heat) production

Modeling the volumes of LR and SMR nuclear capacities in the national power system

Changes in the electricity and district heat production structure by 2050 under different scenarios of CO_2 quotas (% of 2019 year) and CO_2 prices

	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, TWh	1159	1482	1610	1821	1532	1669
the same, PJ	4172	5335	5796	6556	5515	6008
Electricity production structure, %, including	100,0	100,0	100,0	100,0	100,0	100,0
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 (gas and coal)	61.4	58.5	23.5	20.3	23.6	19.4
District heat production, PJ	5623	4517	4517	4517	4517	4517
District heat production structure, %, including	100.0	100.0	100.0	100.0	100.0	100.0
CHP	51.1	65.9	42.9	37.9	43.6	36.7
Boilers (gas or coal)	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

Source: ERI RAS estimations (The results were obtained using the EPOS model)

- Together with electric boilers (powered by LR NPP or hydroelectric power plants), nuclear CHP with SMR are perhaps the key technologies for replacing fossil fuels in district heating.
- Such a switch will require the introduction of 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). Model calculations showed that 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

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Thank you for attention!