Market opportunities of SMR in the regional energy systems of Russia

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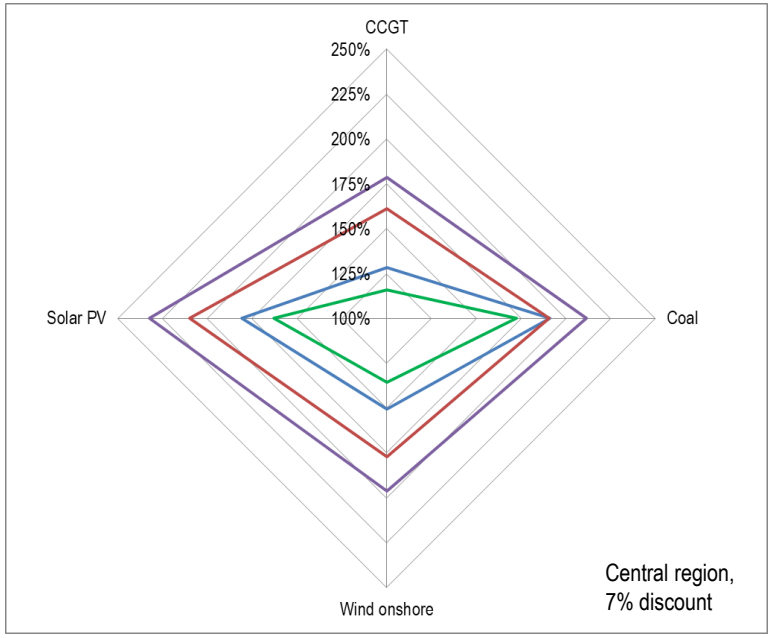
Competitiveness of nuclear power in Russia

- Nuclear plants provide 12% of total installed capacity and 19% total electricity production in the national power system (UPS)
- Russia has well-developed domestic industry providing the full cycle of equipment production and construction of nuclear power plants as well as their fuel supply. It results to:
  - low capital costs of large-scale 1200 MW units with VVER-type reactors (near 2000 USD/kW for NOAK units)
  - expected 15% decrease of capital costs for NOAK units with VVER-TOI type reactors after 2030
  - serial construction of units with fast reactors after 2040 and further 15% decrease of capital costs
  - different SMR concepts (8-300 MW unit capacity); Bilibino SMR was commissioned in 1974. New floating SMR was commissioned in 2020.

Electricity production structure in UPS of Russia, TWh

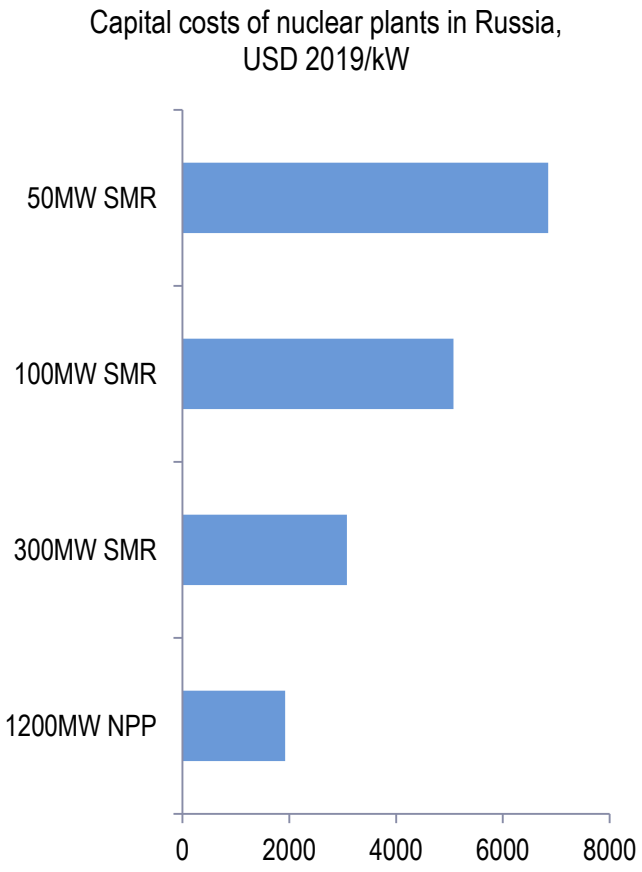
	2010	2019	2040 (Strategy)	2040 (Least cost plan)
Total UPS	1004,7	1080,6	1481,1	1481,1
- Nuclear	*170,2*	*208,8*	*281,9*	*399,0*
- Hydro	158,9	190,3	227,1	227,8
- RES	0,0	1,6	17,6	13,8
- Thermal fossil	675,5	679,9	954,5	840,6
NPP share, %	*16,9%*	*19,3%*	*19,0%*	*26,9%*

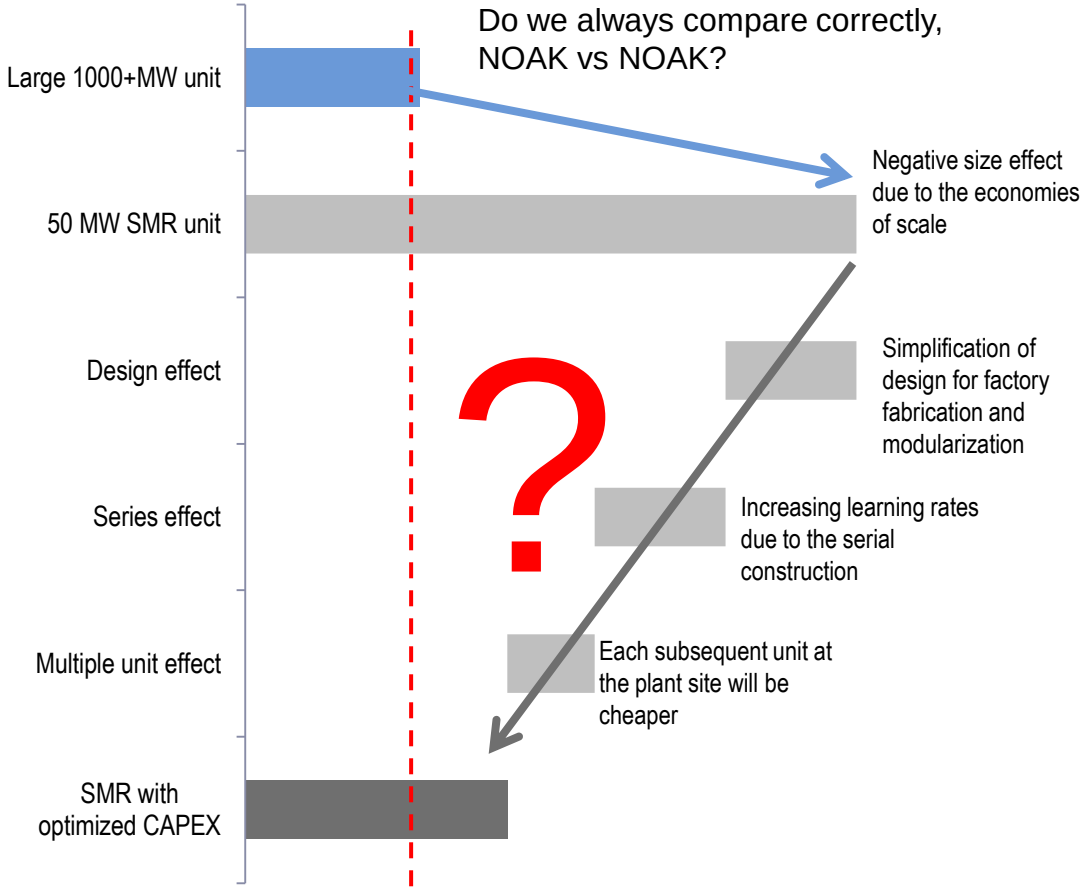
Competitiveness of large-scale NPPs vs alternative types of plants estimated as a ratio of their LCOE



- New nuclear plants are competitive with conventional fossil power plants and they are the least cost option for the non-carbon electricity production
- The role of NPPs will increase. Actual adopted strategy assumes moderate growth of nuclear generation. According to the least-cost development plan, the optimal volumes of NPP generation may me 1,5 times higher

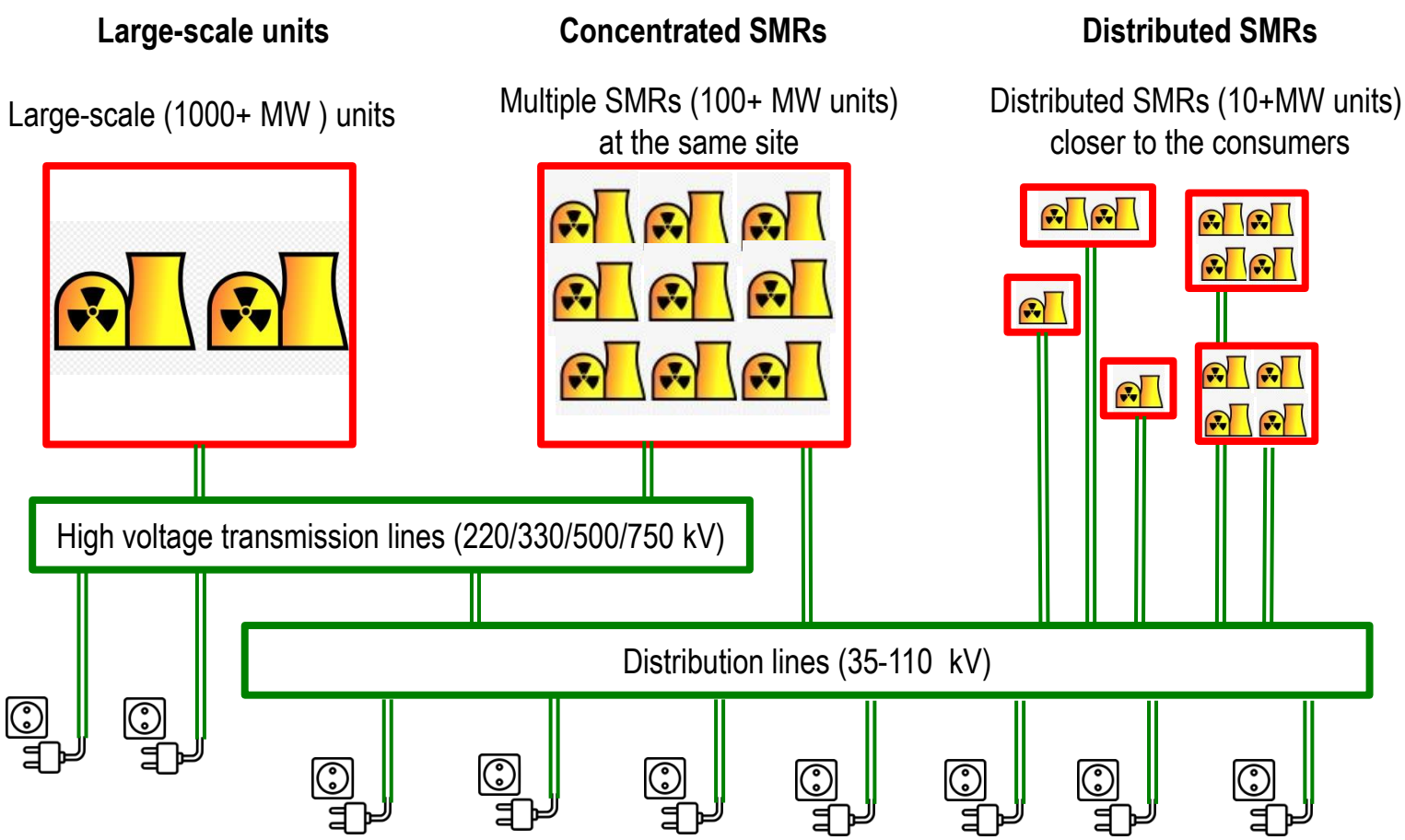
Will SMR always too expensive? Reduction of the overnight costs





- As expected, SMR CAPEX may be reduced due to the impact of some factors. It may remain higher, but by a percentage, not by several times.
  - If we compare costs of NOAK large NPP and SMR units, some of these factors must be already included into CAPEX of SMR
    - As expected, to be a competitive technology, SMRs should became a mass product as …aircrafts… or space launch vehicles?

Alternative nuclear projects by unit size and location



Can SMR produce additional system effects (and cost savings)?

System effects may further compensate the cost difference between LR and SMR

	Large 1000+MW unit	50 MW SMR
Reserve requirements	• 1000+MW (= NPP unit) of existing or new capacity must be available in the power system	• Reserve requirements (and related costs) are limited by 50 MW of available capacity
Required grid development	• New HV lines are required for the capacity output as well as the reinforcement of existing transmission grid in the 300-400 km area around new plant	• Lower voltage for the SMR capacity output • Lower volumes of grid construction due to the shorter distance between the plants and load centers • Reinforcement of distribution grid may be required due to the increase in the number of generating plants
Load-following capability	• High must-run capacity and low ramp rates • Additional measures are required to match high NPP's capacity factor and system's load factor (peaking plants, storage plants, additional grid capacity, load shifting at the demand side)	• Units can follow the load, but their flexibility may be not enough to react on the rapid changes of VRE generation – additional storage capacity is required • Lower NPP's capacity factor will negatively affect on the project's profitability or will require higher prices.

- These system effects are the most pronounced in the mid-scale power systems (10-50 GW)
  - In the large-scale power systems (50+ GW) large NPP units may be integrated with lower system cost
    - In the small-scale power systems (up to 10 GW) SMR (available at the NOAK stage) are the most promising

SMR projects – additional business opportunities

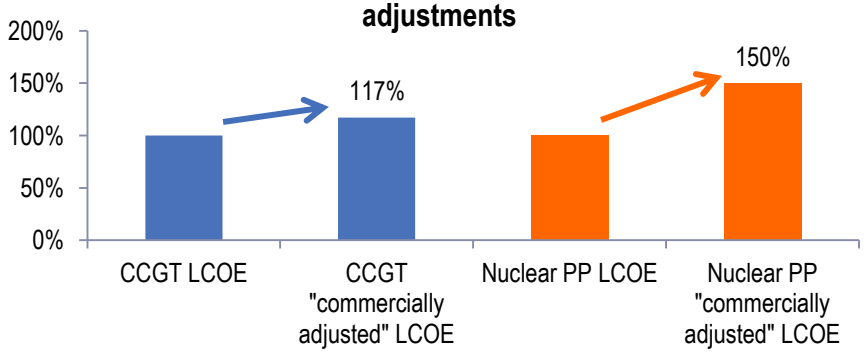
Investments in distributed generation (incl. SMR) has some features improving the commercial parameters of the projects compared with the investments in the large-scale power plants.

- Investments and risks can be distributed among several projects
- Reduced time and costs for licensing (site, construction, etc) of SMR projects using serial and mass produced equipment
- Projects can be implemented by different investors and may have different funding structure
- Projects can have different sales strategy in the market and consumer structure
- Projects have lower construction times that large reactor projects and begin generate money earlier. Investor may avoid the risks of stranded costs or overinvestment
- Production may be well adjusted to the change in demand because of the relatively small unit capacity. Units may be commissioned faster or slower, additional units may be constructed due to the demand requirements

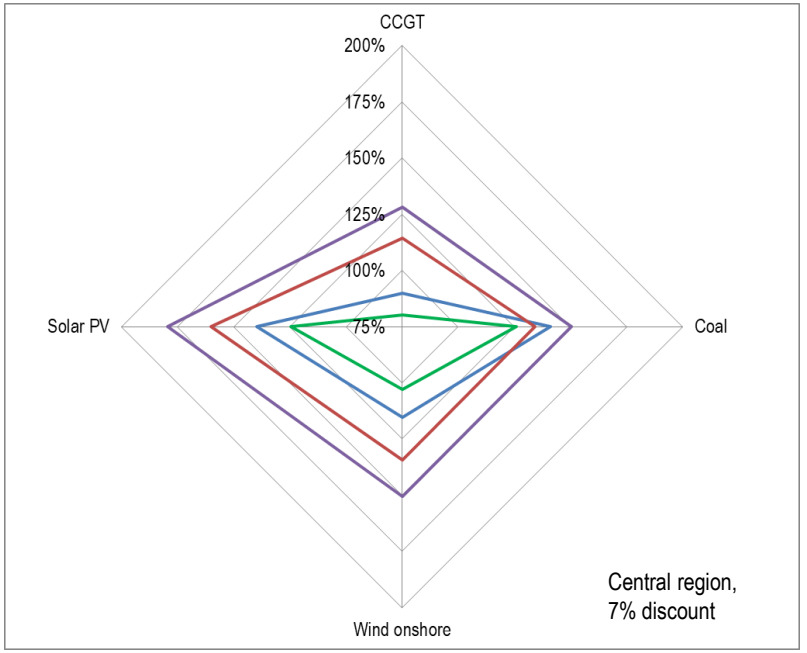
Commercial view on the LCOE

- Traditionally, LCOE analysis is used to compare the investment alternatives from the economy's point of view. IEA, IRENA, IAEA and others estimate LCOE based on the discounted sum of the material and capital resources
- Alternative, the business-oriented approach is also widely used (EIA, EPRI, Bloomberg, etc.). At this financial options are also taken into account:
  - WACC
  - Property, profit and other taxes as well as a tax shield (depreciation)
  - Payback period instead of life cycle
- As a result, LCOE adjusted to the "commercial" factors (LCOE-C) in higher that "traditional", especially for the technologies with the high capital costs, like NPPs

Increase of LCOE value due to the "commercial" adjustments



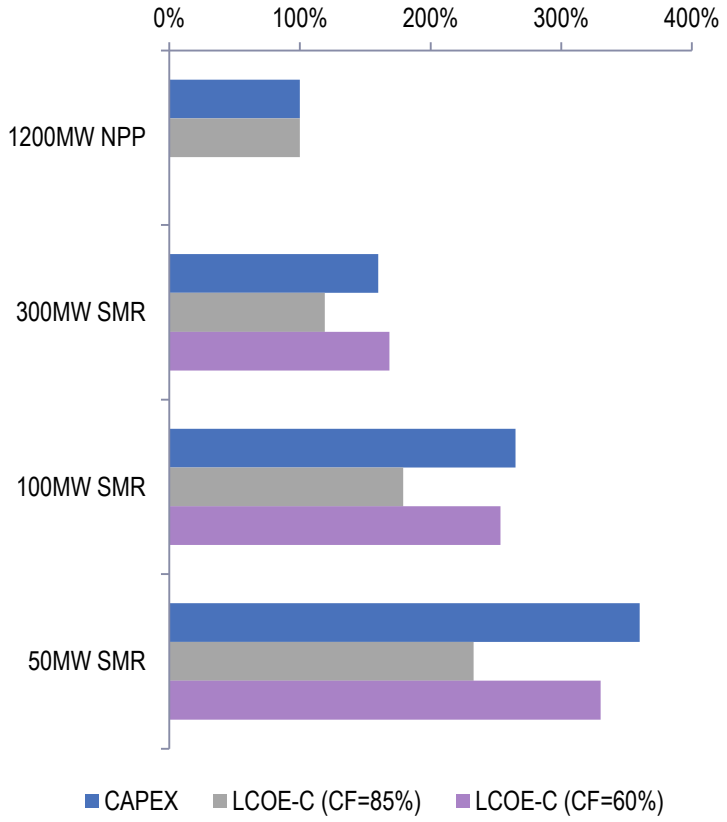
Competitiveness of large-scale NPPs vs alternative types of plants estimated as a ratio of their LCOE adjusted to the "commercial" factors (LCOE-C)



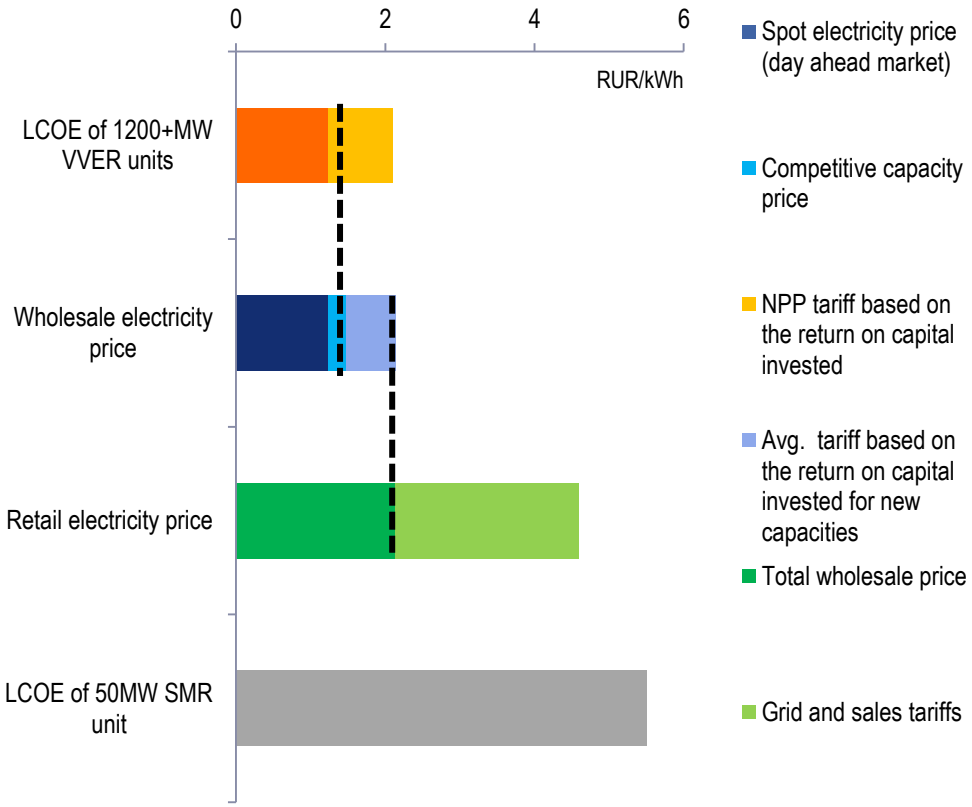
- With adjusted LCOE (LCOE-C) nuclear plants remain also the most effective non-carbon source of electricity
- But the competition with new gas generation plants (CCGT) becomes very strong (it the carbon costs are not taken into account)

Opportunities for SMR at the wholesale and retail markets

Economic parameters of SMR relative to 1000+MW NPP units



Competitiveness of SMR at the wholesale and retail markets



- At the wholesale market competitive electricity and capacity prices do not cover the LCOE of large unit NPP
- Special capacity tariffs are introduced for new NPP (as well as for RES) to guarantee the return on capital invested
- SMRs with much higher LCOE at the wholesale market will require unacceptable capacity tariffs
- But LCOE of SMRs is comparable with retail electricity prices that are twice higher than wholesale due to the T&D grid tariff

How SMR can be profitable at the retail markets?

Cost of supply with SMR

Alternative cost of supply

SMR LCOE-C

Additional grid costs of SMR's integration into power system may be required

SMR LCOE-C

Additional costs for capacity reserves may be required

Power system

Existing consumer(s) — On-grid purchase at retail price

New consumer — On-grid purchase at retail price; Connection charge rate

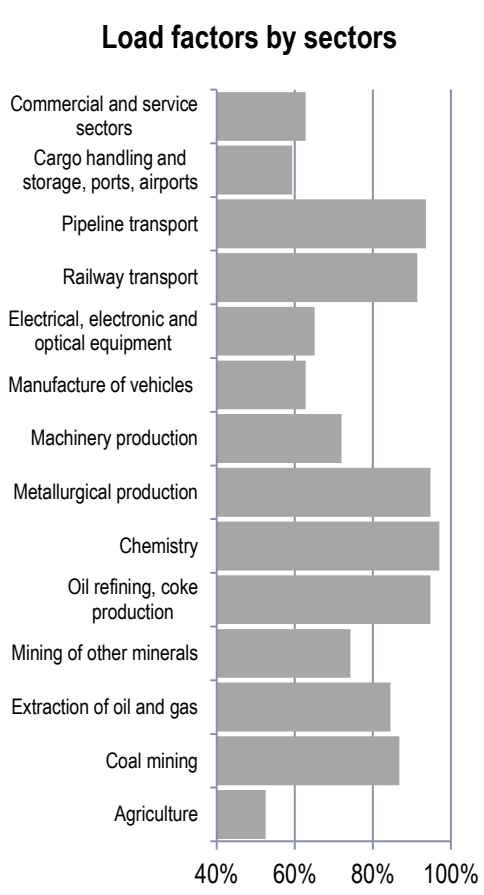
Decentralized area

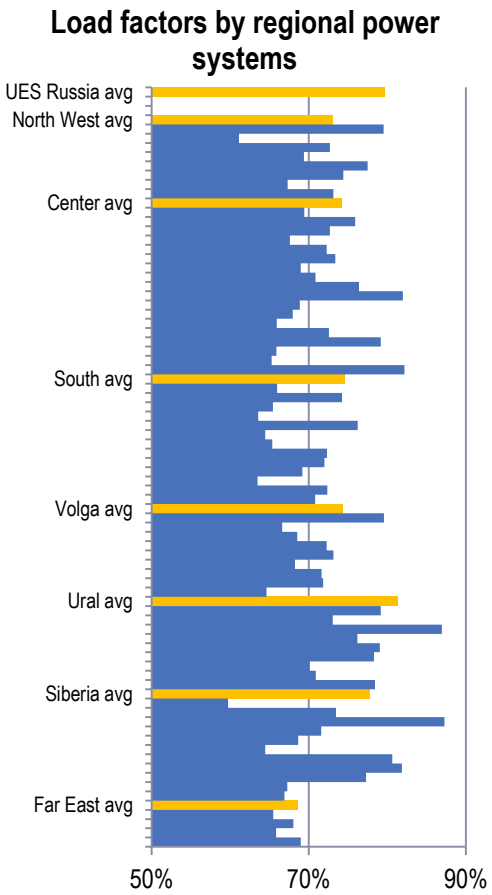
Existing consumer(s) — Existing cost of supply from diesel units

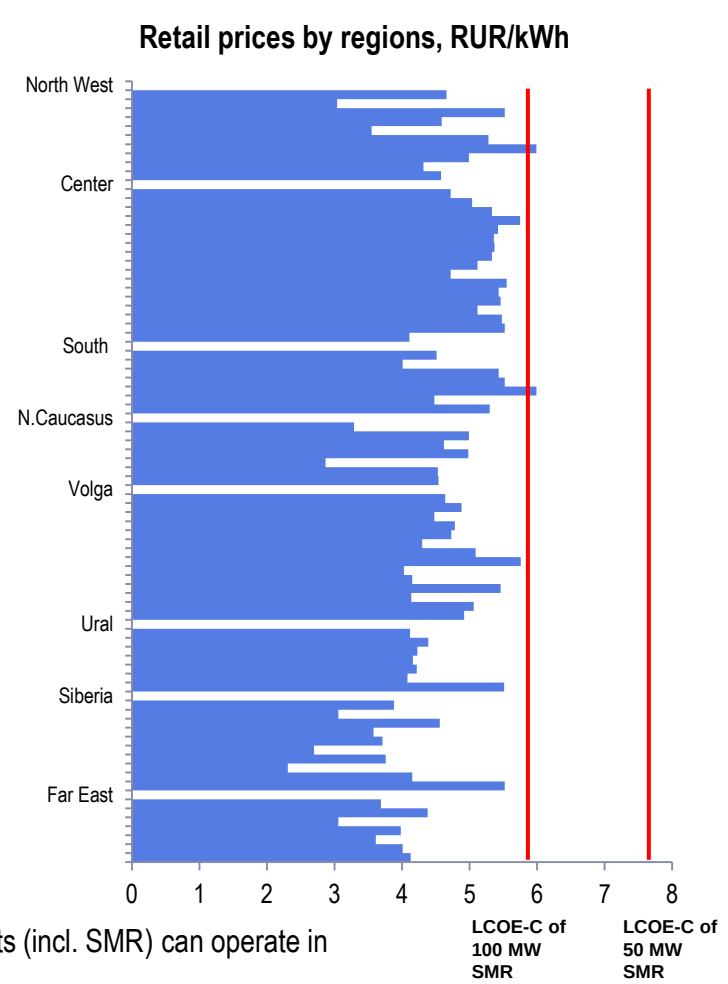
New consumer — Cost of supply from new sources (diesel, LNG, biomass, RES, etc)

- All 25+MW generators are obliged to sell electricity to the wholesale market, except the self-producers.
- Special penalty for maintaining the grid reserve may be introduced for consumers
- High capacity factor for SMR is highly important for the profitability of the SMR project:
  - Consumer's load (in MW) must be comparable to the SMR capacity
  - Consumer's load factor must be close to the SMR optimal CF

How SMR can be profitable at the retail markets?





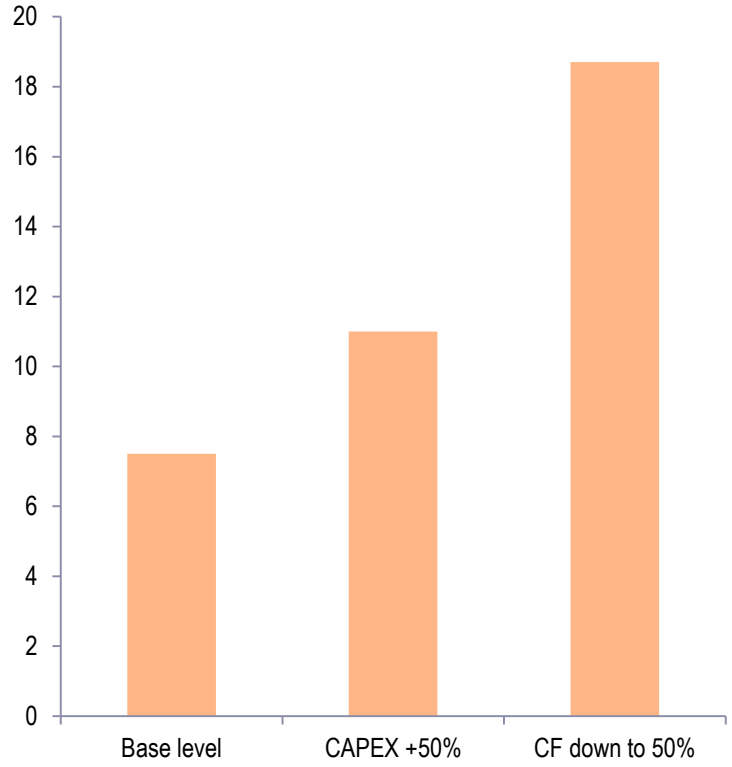


- In the centralized electricity supply area (national Unified Power System) nuclear plants (incl. SMR) can operate in the most effective baseload mode with CF 85% and more
- But at the actual retail price levels they are not competitive with on-grid electricity supply as well as other DG sources using natural gas
- The possible option for SMR projects is integration with industrial consumer to meet its energy needs

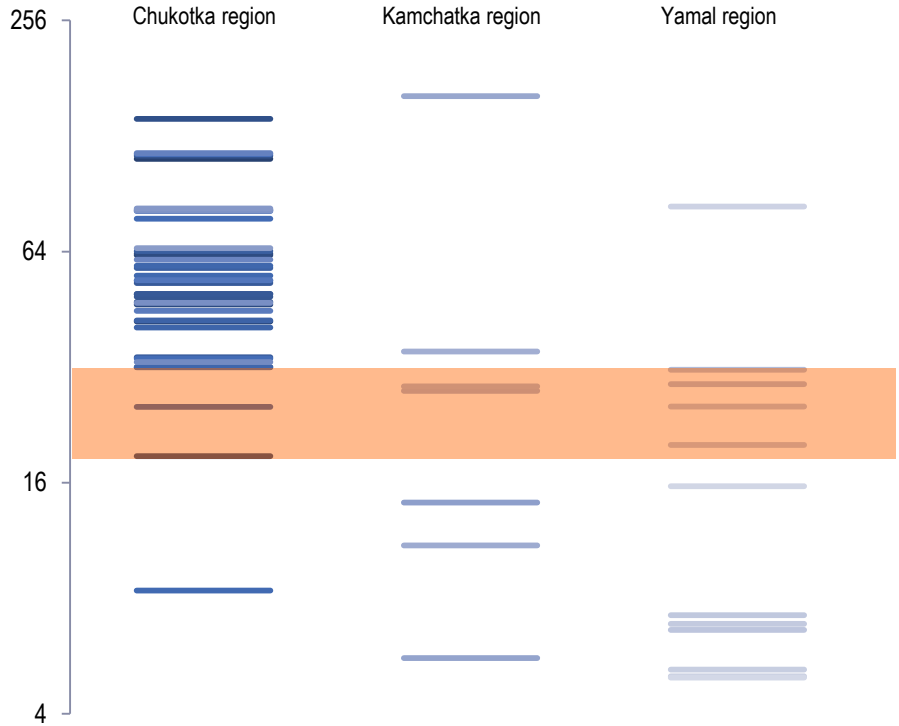
How SMR can be profitable at the retail markets?

- In the decentralized electricity supply (Arctic, North Siberian and Far East regions) area SMRs must operate a an autonomous source in the load following mode with lower CF
- Due to the remoteness and severe climate conditions capital costs will be also higher than in the central part of the country
- It will led to the doubling of LCOE-C of SMRs, but the actual electricity supply costs there may be even much higher

LCOE-C of 50MW SMR, RUR/kWh



Cost of electricity supply in the settlements out of UPS, RUR/kWh



Can SMR be profitable as CHP?

Specific features of the heat market in Russia	
Opportunities for SMR-based CHP	**Risks for SMR-based CHP**

• 90GW of CHPs in the UES of Russia – 55% of total thermal plants and near 45% of total centralized heat supply
• All NPPs supply heat for the neighboring settlements
• Encouragement of CHP as a strategic priority in the national energy policy
• 50%+ share of boilers in the structure of heat supply
• High degree of deterioration of boilers, huge potential for the reconstruction or substitution
• Marginal pricing mechanism for heat based on the cost of new boiler is defined by a law and is being tested in pilot projects
	• Very slow heat demand growth
	• Deconcentrating of heat loads:
	  • Decreasing share of the industrial (concentrated) heat loads
	  • New heat loads are related with the residential sector (distributed load)
	• Seasonal heterogeneity of heat demand due to the heating requirements in 5-7 month
	• Heat prices are regulated by regional authorities, cross-subsidies is the common practice
	• CHPs operate simultaneously at the competitive (electricity) and regulated (heat) markets

Strong technological competition in heat supply for SMRs in Russia:

- Large gas-fired CHPs
- Distributed co-generation plants using gas, biogas and biomass
- Reconstruction of boilers to small CHPs
- Energy (electricity and heat) supply from different sources:
  - CCGT or large NPP + new efficient modular boilers using gas, biogas and biomass
  - Large NPP + electric boilers

Specific approach for screening analysis of the technologies:

- Integrated levelized cost of electricity and heat supply (LCOQ) must be considered instead of LCOE calculation
- Local, even not regional specific (concentration and profile of electricity and heat loads) is highly important
- Costs of the heat distribution network construction or upgrade should be assessed for each alternative technology
- In a case of new generating source appearing locally costs of electricity distribution grid upgrade must be also taken into account

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Thank you for attention!