Electricity grid development in the decarbonization scenarios of the Russian power and district heating sectors

Andrey Khorshev

The Energy Research Institute
of the Russian Academy of Sciences

Regional Workshop on the Role of Electricity Grid in the Decarbonization Efforts

Ankara, Türkiye, 20-24 May 2024

ИНЭИ
РАН

Current Situation in Russian power sector

Kolskaya Wind Farm. Largest wind farm above the Arctic circle (202 MW)

Russian Unified Power System (UPS)

75 regional power systems spanning over 6000 km and 8 time zones

7 integrated power systems (IPS)

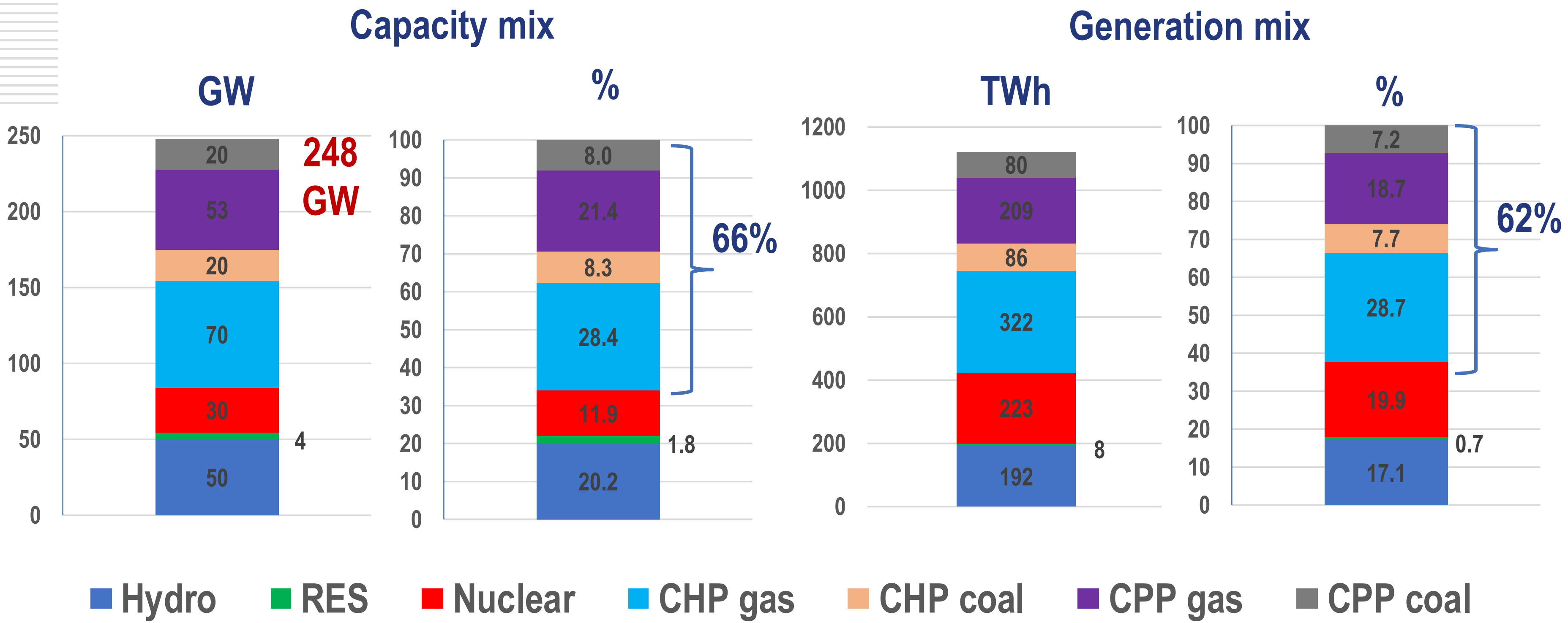
> 600 power plants with installed capacity of around 250 GW

> 3 200 000 km of power lines, of which 500 000 km of HV (110kV and higher) transmission lines

> 1 000 000 MVA of transformers capacity

Source: https://www.so-ups.ru/

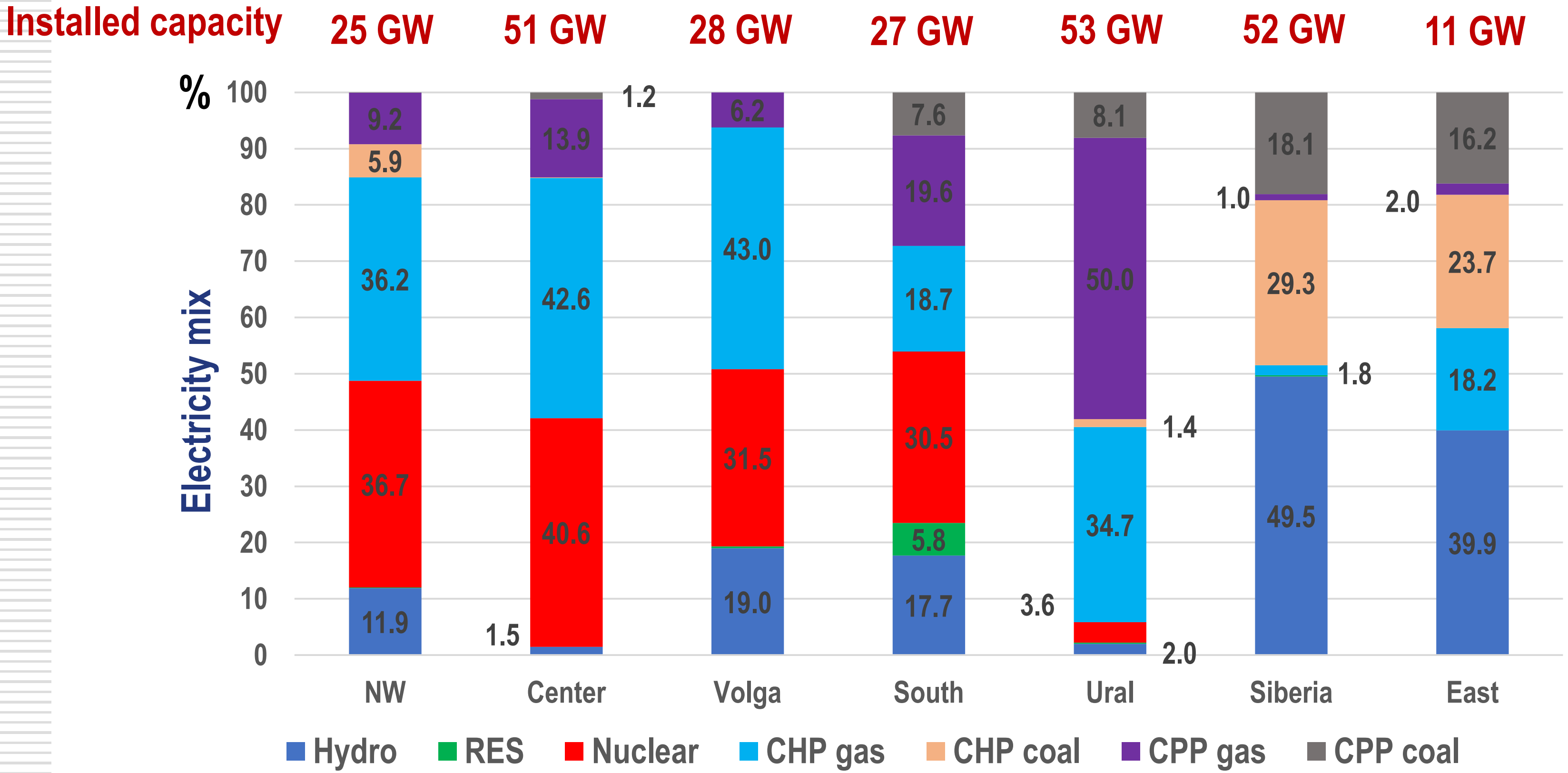
Capacity and generation mix in Russian UPS in 2022



Source: *https://www.so-ups.ru/*

Maximum load – 159 GW. Electricity consumption – 1122 TWh

Generation mix differs greatly over the regions

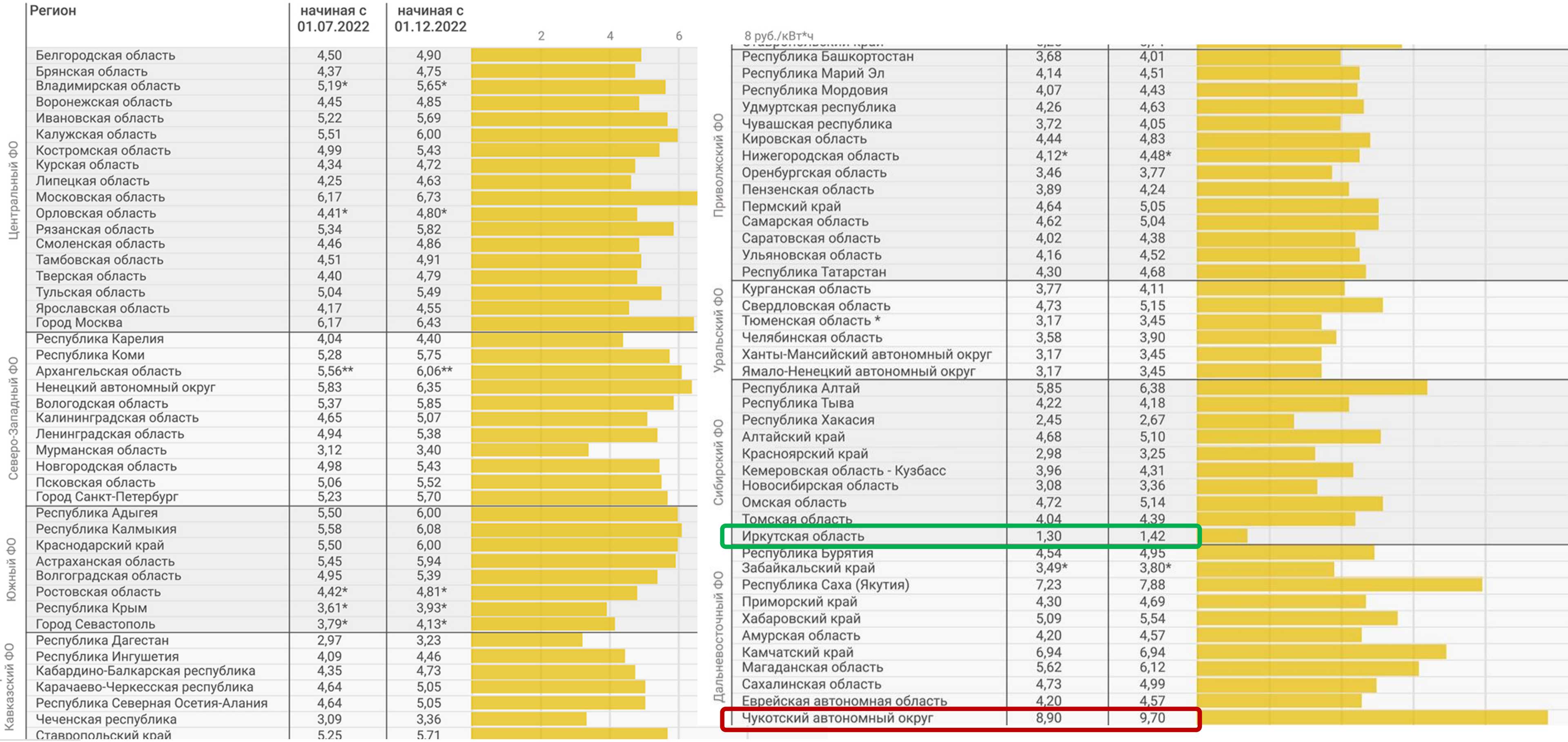


Source: *https://www.so-ups.ru/*

Average prices at the day-ahead market in 2023, RUB/kWh

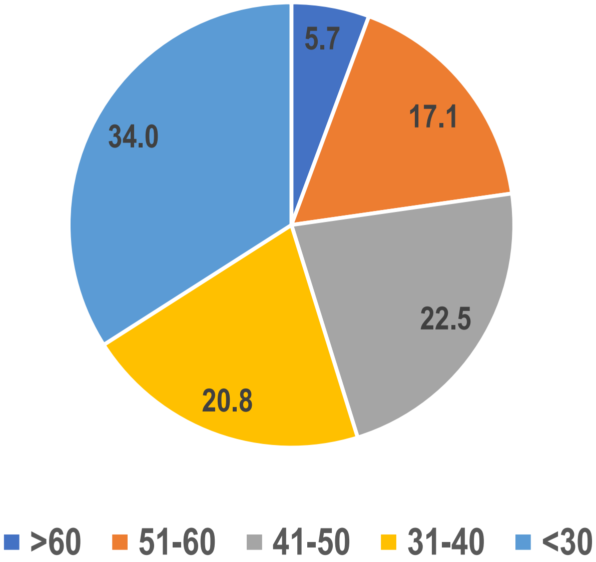
Source: *https://www.so-ups.ru/*

Retail price for households with gas stoves in 2023, RUB/kWh



	Регион	начиная с 01.07.2022	начиная с 01.12.2022
Центральный ФО	Белгородская область	4,50	4,90
	Брянская область	4,37	4,75
	Владимирская область	5,19*	5,65*
	Воронежская область	4,45	4,85
	Ивановская область	5,22	5,69
	Калужская область	5,51	6,00
	Костромская область	4,99	5,43
	Курская область	4,34	4,72
	Липецкая область	4,25	4,63
	Московская область	6,17	6,73
	Орловская область	4,41*	4,80*
	Рязанская область	5,34	5,82
	Смоленская область	4,46	4,86
	Тамбовская область	4,51	4,91
	Тверская область	4,40	4,79
	Тульская область	5,04	5,49
	Ярославская область	4,17	4,55
	Город Москва	6,17	6,43
Северо-Западный ФО	Республика Карелия	4,04	4,40
	Республика Коми	5,28	5,75
	Архангельская область	5,56**	6,06**
	Ненецкий автономный округ	5,83	6,35
	Вологодская область	5,37	5,85
	Калининградская область	4,65	5,07
	Ленинградская область	4,94	5,38
	Мурманская область	3,12	3,40
	Новгородская область	4,98	5,43
	Псковская область	5,06	5,52
	Город Санкт-Петербург	5,23	5,70
Южный ФО	Республика Адыгея	5,50	6,00
	Республика Калмыкия	5,58	6,08
	Краснодарский край	5,50	6,00
	Астраханская область	5,45	5,94
	Волгоградская область	4,95	5,39
	Ростовская область	4,42*	4,81*
	Республика Крым	3,61*	3,93*
	Город Севастополь	3,79*	4,13*
Кавказский ФО	Республика Дагестан	2,97	3,23
	Республика Ингушетия	4,09	4,46
	Кабардино-Балкарская республика	4,35	4,73
	Карачаево-Черкесская республика	4,64	5,05
	Республика Северная Осетия-Алания	4,64	5,05
	Чеченская республика	3,09	3,36
	Ставропольский край	5,25	5,71
Приволжский ФО	Республика Башкортостан	3,68	4,01
	Республика Марий Эл	4,14	4,51
	Республика Мордовия	4,07	4,43
	Удмуртская республика	4,26	4,63
	Чувашская республика	3,72	4,05
	Кировская область	4,44	4,83
	Нижегородская область	4,12*	4,48*
	Оренбургская область	3,46	3,77
	Пензенская область	3,89	4,24
	Пермский край	4,64	5,05
	Самарская область	4,62	5,04
	Саратовская область	4,02	4,38
	Ульяновская область	4,16	4,52
	Республика Татарстан	4,30	4,68
Уральский ФО	Курганская область	3,77	4,11
	Свердловская область	4,73	5,15
	Тюменская область *	3,17	3,45
	Челябинская область	3,58	3,90
	Ханты-Мансийский автономный округ	3,17	3,45
	Ямало-Ненецкий автономный округ	3,17	3,45
Сибирский ФО	Республика Алтай	5,85	6,38
	Республика Тыва	4,22	4,18
	Республика Хакасия	2,45	2,67
	Алтайский край	4,68	5,10
	Красноярский край	2,98	3,25
	Кемеровская область - Кузбасс	3,96	4,31
	Новосибирская область	3,08	3,36
	Омская область	4,72	5,14
	Томская область	4,04	4,39
	Иркутская область	1,30	1,42
Дальневосточный ФО	Республика Бурятия	4,54	4,95
	Забайкальский край	3,49*	3,80*
	Республика Саха (Якутия)	7,23	7,88
	Приморский край	4,30	4,69
	Хабаровский край	5,09	5,54
	Амурская область	4,20	4,57
	Камчатский край	6,94	6,94
	Магаданская область	5,62	6,12
	Сахалинская область	4,73	4,99
	Еврейская автономная область	4,20	4,57
	Чукотский автономный округ	8,90	9,70

Ageing generation capacities

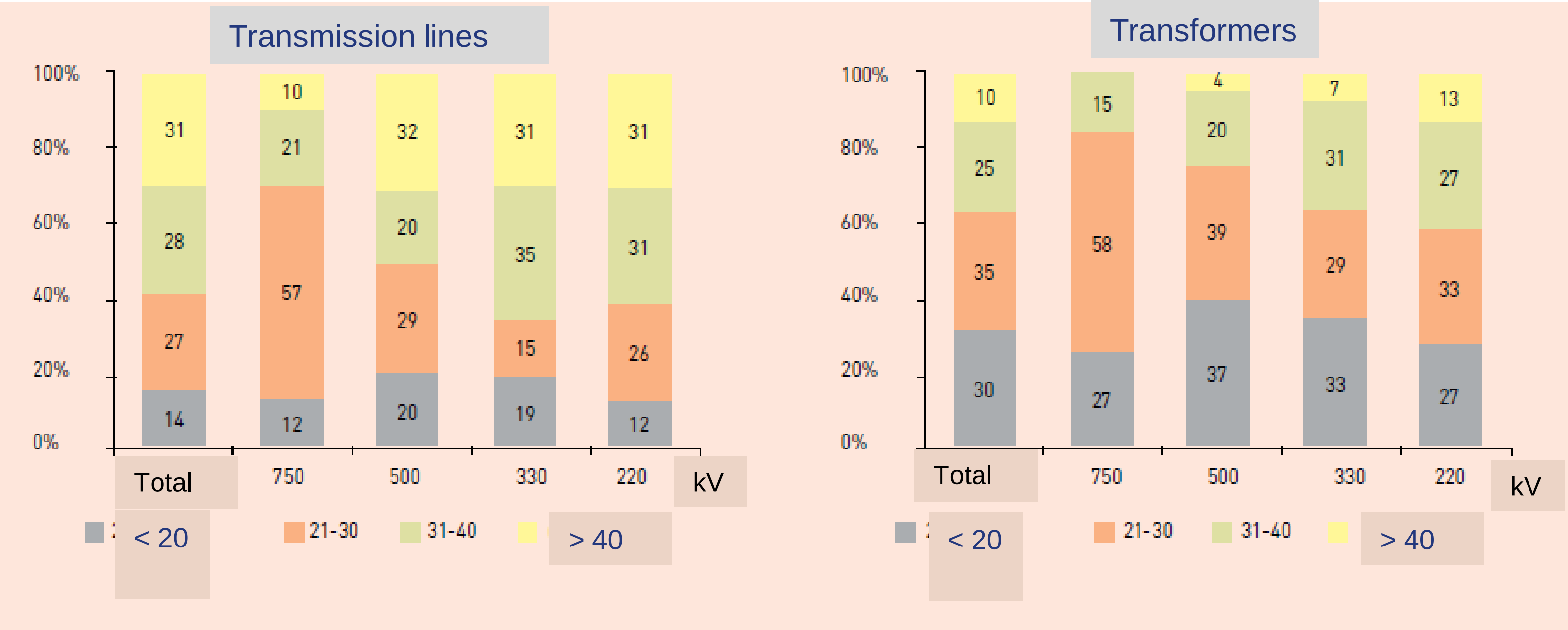


GES-1 in Moscow. Built in 1897

Only 34 % of the power plants are younger than 30 years. And only 55% – younger than 40.

Source: https://www.so-ups.ru/

Ageing grid infrastructure



- Despite recent large investments in grid renovation about 1/3 of transmission lines and 10% of transformers are still in operation for more than 40 years.
- Situation in distribution grid is much worse

Key challenges for power sector development in Russia

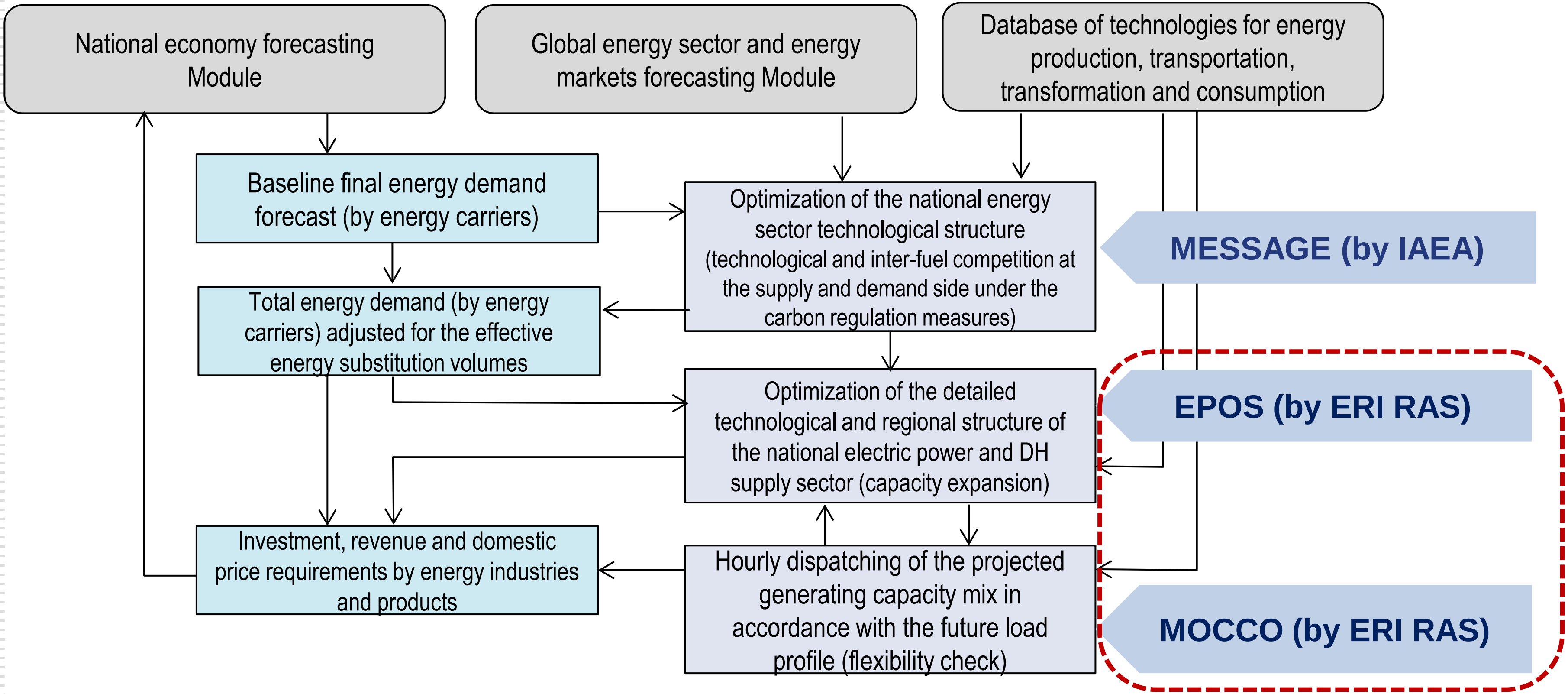
GHG mitigation

- According to the National Climate Doctrine (2023), Russian economy should become carbon-neutral by 2060
- According to the National Strategy for Development with Low Level of GHG Emissions (2021) by 2050:
  - Net emissions should be reduced by 60% compared to 2019 level, mainly due to the doubling of GHG absorption by LULUCF sector
  - At the same time, GHG emissions related to energy and industry should be only 13,6% lower than in 2019
  - If the absorption ability of LULUCF doesn’t change, real GHG emissions in 2050 should be 45% lower than in 2019

Energy support of GDP growth

- According to the long-term Forecast of economic development, GDP should grow about 2,7-3% per year
  - It requires an increase in electricity production by 1,0-1,1% per year
- Geopolitical, technological, market challenges require much more intensive growth of the national economy, and GDP can grow by 3,5-4,5% per year
  - It requires an increase in electricity production by 1,6-2,0% per year

Forecasting module of the National energy sector decarbonization scenarios



National economy forecasting Module

Global energy sector and energy markets forecasting Module

Database of technologies for energy production, transportation, transformation and consumption

Baseline final energy demand forecast (by energy carriers)

Optimization of the national energy sector technological structure (technological and inter-fuel competition at the supply and demand side under the carbon regulation measures)

MESSAGE (by IAEA)

Total energy demand (by energy carriers) adjusted for the effective energy substitution volumes

Optimization of the detailed technological and regional structure of the national electric power and DH supply sector (capacity expansion)

EPOS (by ERI RAS)

Investment, revenue and domestic price requirements by energy industries and products

Hourly dispatching of the projected generating capacity mix in accordance with the future load profile (flexibility check)

MOCCO (by ERI RAS)

Source: ERI RAS analysis

Long-term Modelling (Capacity Expansion Model)

Main features of EPOS model

EPOS optimization model is the least-cost multi-year, multi-regional modeling tool for the power sector strategic planning:

- 2050 planning horizon (now extended to 2070)
- >400 major existing and planned power plants + >50 types of new generating technologies
- capacity (incl. reserve) and wholesale electricity balances by 42 nodes
- heat and retail electricity balances by 80 regions
- only basic flexibility check – rated capacity balances for min/max load hours of representative winter day by 7 integrated power systems

The Energy Research Institute of the Russian Academy of Sciences
The Energy Centre, Moscow School of Management SKOLKOVO

GLOBAL AND RUSSIAN ENERGY OUTLOOK 2019

Moscow 2019

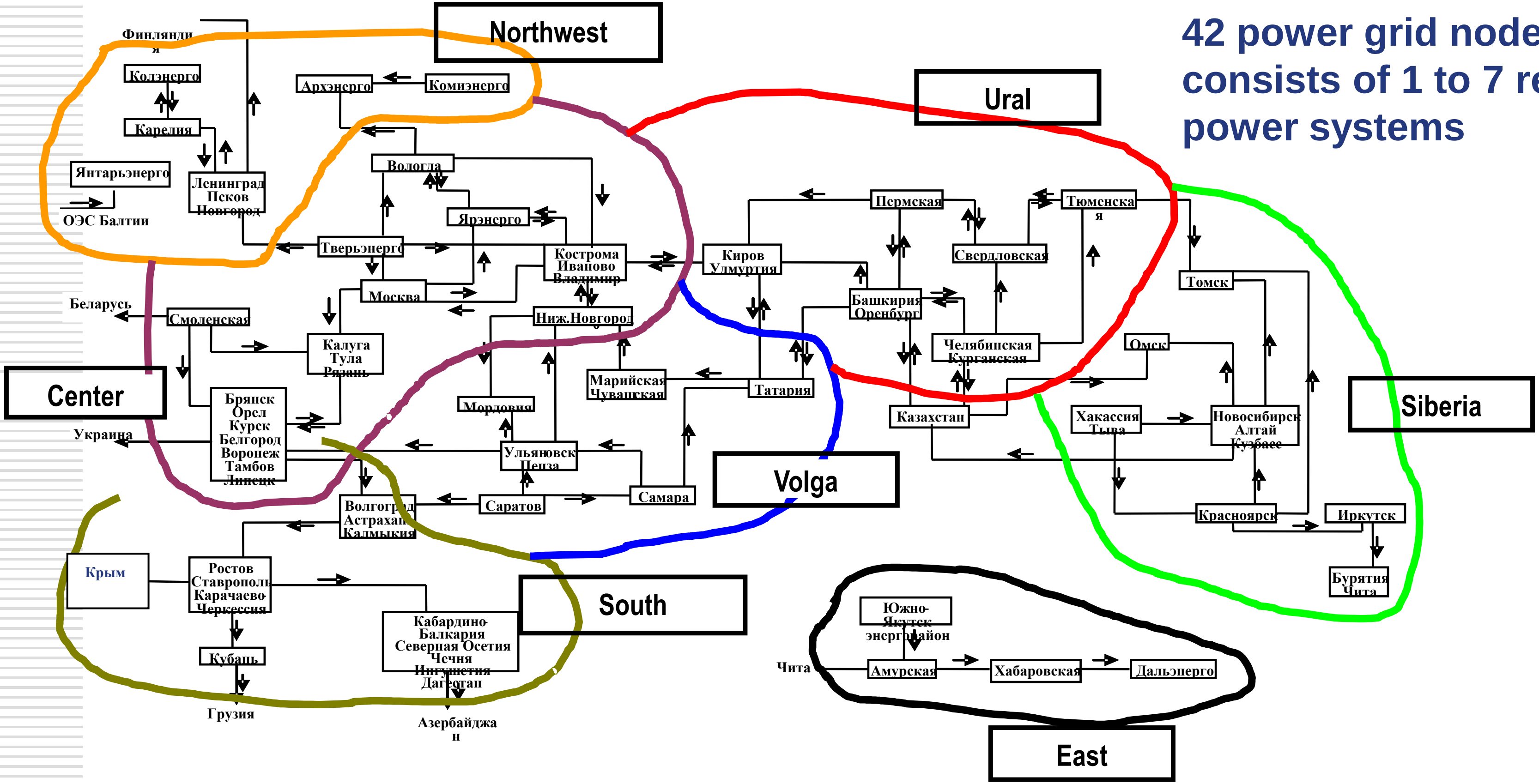
SCANER

modelling and information complex

The Energy Research Institute of the Russian Academy of Sciences (ERI RAS)

Russian Unified Power System – Example of 2012

Russian Unified Power System – Representation in the EPOS Model



42 power grid nodes, each consists of 1 to 7 regional power systems

Electrical grid representation in EPOS model

- Simplified representation of power grid (energy flows with losses and costs)
- Only inter-regional power lines (220 kV and higher) with constraints on power and annual energy flows
- New builds of inter-regional power lines are allowed
- 42 power grid nodes, each consists of 1 to 7 regional power systems
- No congestions, only losses inside the node (copper plate)
- Distribution lines are not modelled
- Grid connections of the new power plants are taken into account only as additional investments (fixed amount for each type of power plant)

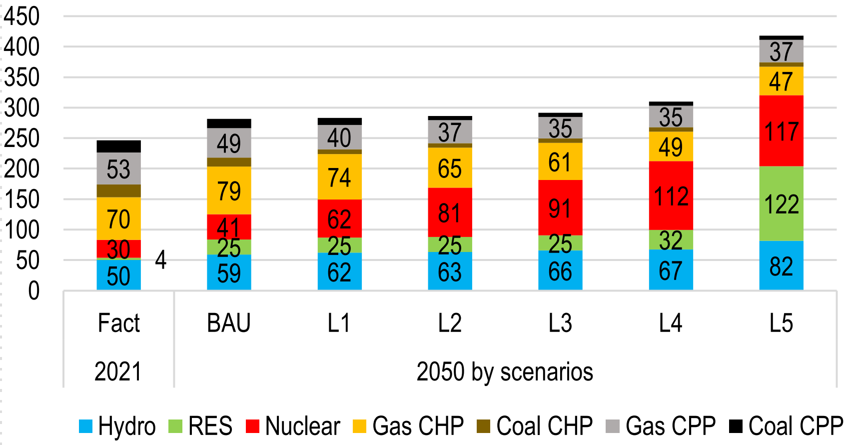
Scenarios with CO2 emission quotas in power and DH sectors

Scenarios	CO2 emission quota, % to 2019			
	2035	2040	2045	2050
Base (BAU) - no limits on emissions	108	105	103	103
L1	-	100	94	86
L2	-	95	86	75
L3	99	93	83	70
L4	97	90	76	60
L5	96	85	70	50

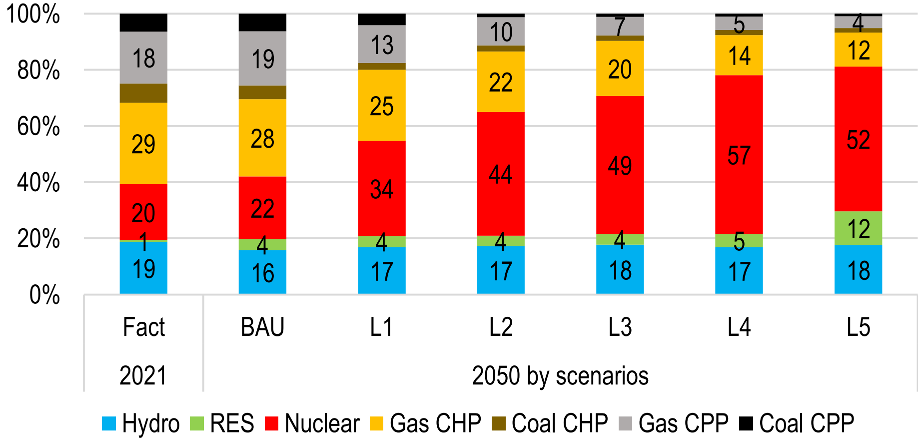
Source: ERI RAS forecast

Scenarios with CO2 emission quotas in power and DH sectors – Power sector

Capacity mix, GW



Electricity production mix, %

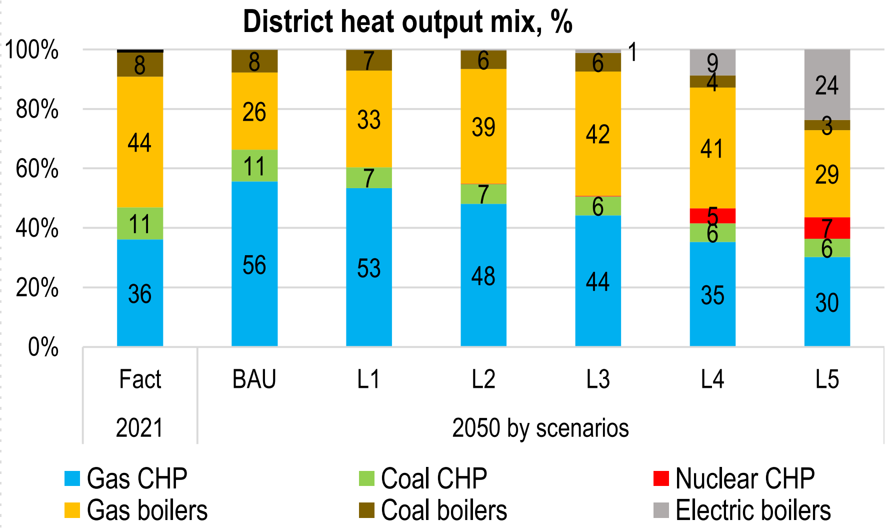


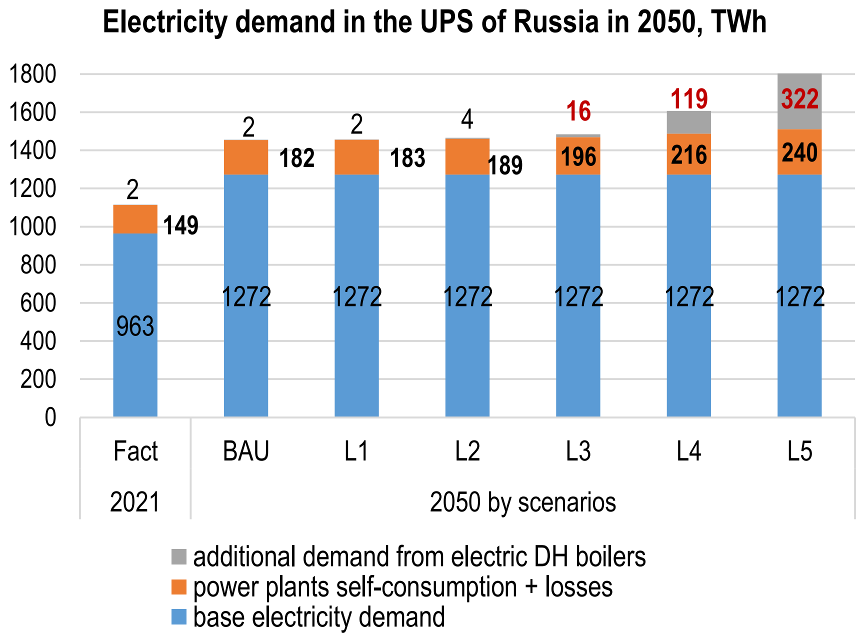
GW	2021	2050 by scenarios					
	Fact	BAU	L1	L2	L3	L4	L5
Total installed capacity	246	281	283	286	291	310	418
Nuclear CHP (SMR)	-	-	-	-	-	10	15
RES with batteries	-	-	-	-	-	-	49
CCS	-	-	-	-	-	0.6	9.0

	2021	2050 by scenarios					
	Fact	BAU	L1	L2	L3	L4	L5
Share of non-carbon	39.3	42.0	54.7	65.0	70.7	78.1	81.2
Share of coal	13.2	11.1	6.5	3.4	3.1	2.8	2.5
Share of gas	47.5	46.8	38.8	31.6	26.2	19.1	16.4
Share of CCS	-	-	-	-	-	0.2	2.6

Source: ERI RAS modelling

Scenarios with CO2 emission quotas in power and DH sectors – DH sector


District heat output mix, %

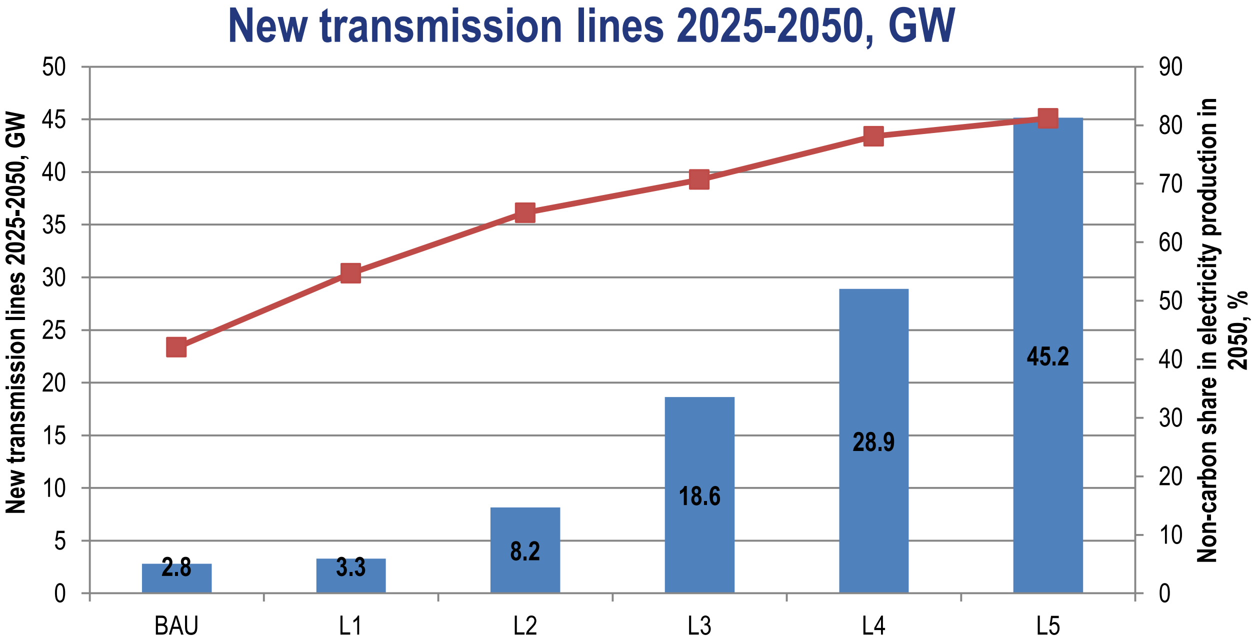

Electricity demand in the UPS of Russia in 2050, TWh

%	2021	2050 by scenarios					
	Fact	BAU	L1	L2	L3	L4	L5
Share of non-carbon	0.1	0.1	0.1	0.4	1.4	13.7	30.9
Share of coal	19.1	18.4	14.0	12.9	12.6	10.4	9.7
Share of gas	80.9	81.5	85.9	86.7	86.0	75.9	59.4

Electricity losses are growing. Not only because of the increase of the demand. But also due to an increase of the non-carbon production

Source: ERI RAS modelling

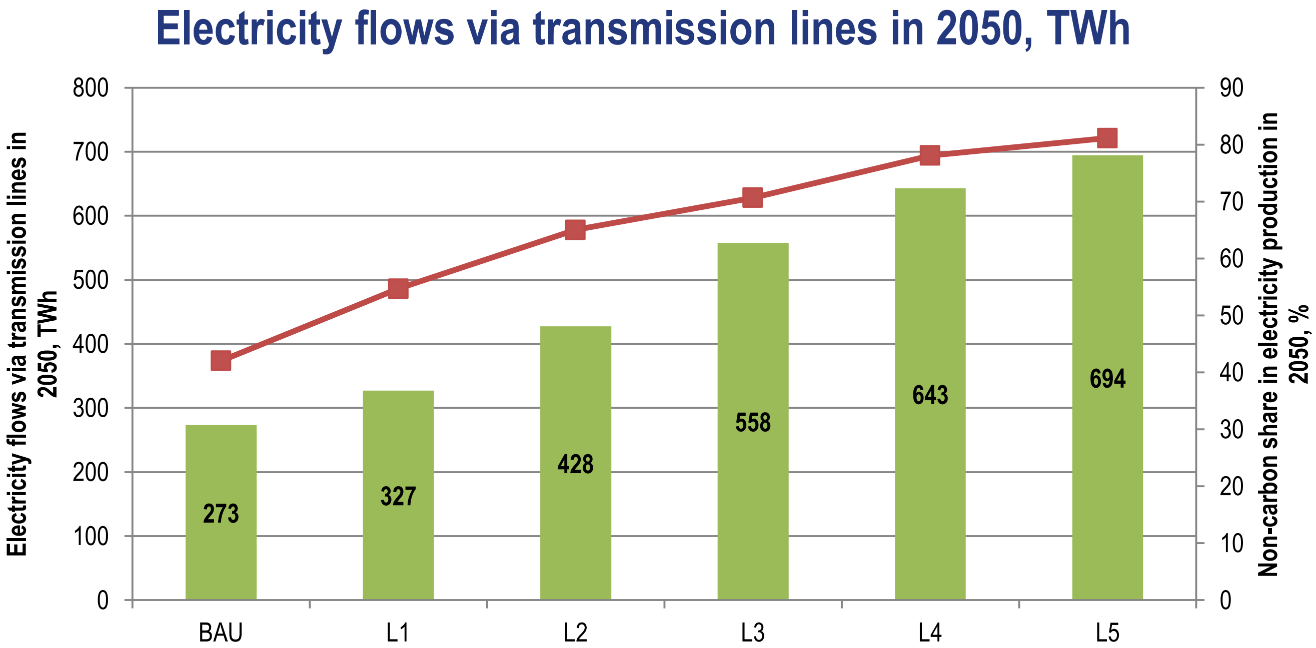
Scenarios with CO2 emission quotas in power and DH sectors – Grid development



Fast development of new transmission lines is needed to accommodate growing capacity of non-carbon sources

Source: ERI RAS modelling

Scenarios with CO2 emission quotas in power and DH sectors – Grid development


Electricity flows via transmission lines in 2050, TWh

Electricity flows over transmission lines grow with an increase of non-carbon share but not so fast as a capacity of new transmission lines

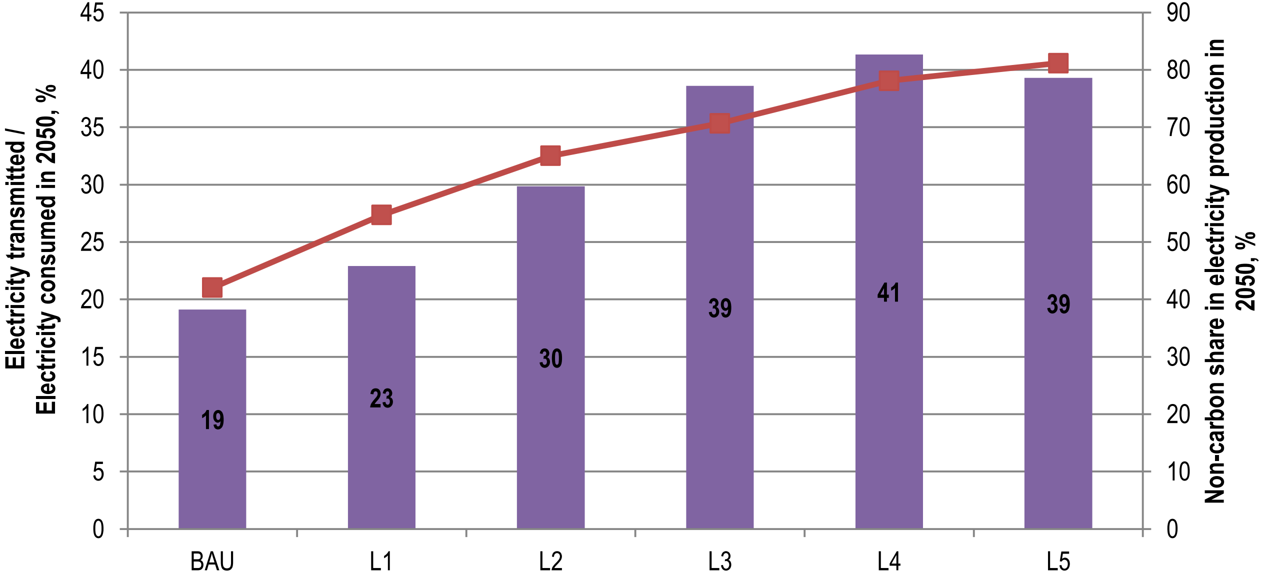
Source: ERI RAS modelling

Net annual electricity flows in 2050 – BAU Scenario, TWh

Net annual electricity flows in 2050 – L5 Scenario, TWh

Scenarios with CO2 emission quotas in power and DH sectors – Grid development

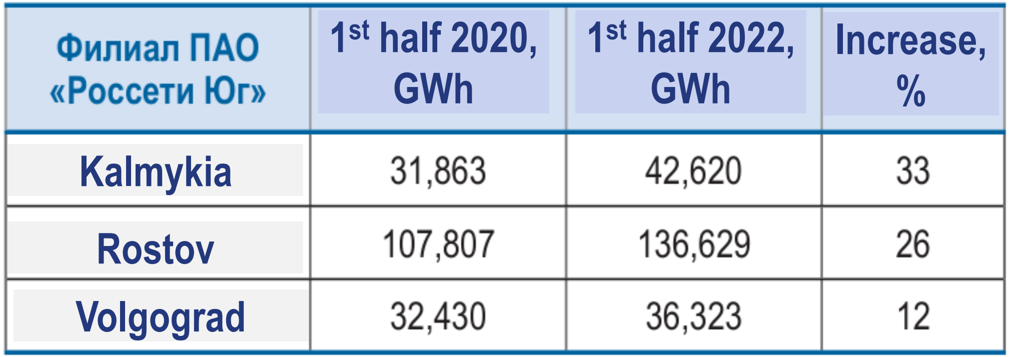
Electricity transmitted / Electricity consumed in 2050, %



In decarbonizing scenarios almost 40% of consumed electricity is transmitted over the inter-regional power lines

All of this means that non-carbon power plants are not evenly distributed over the face of the Earth due to various reasons

The volume of losses after RES connection: Real-life example from Russia



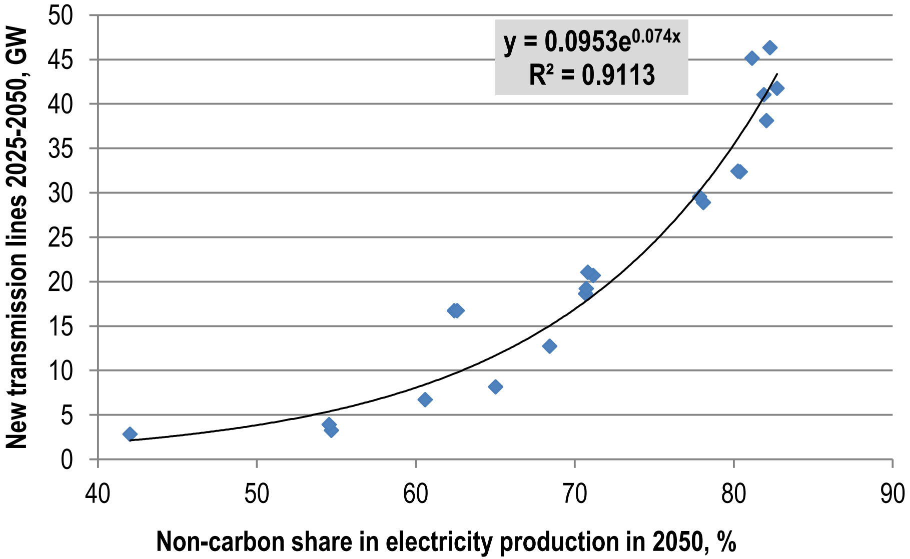
Филиал ПАО «Россети Юг»	1st half 2020, GWh	1st half 2022, GWh	Increase, %
Kalmykia	31,863	42,620	33
Rostov	107,807	136,629	26
Volgograd	32,430	36,323	12

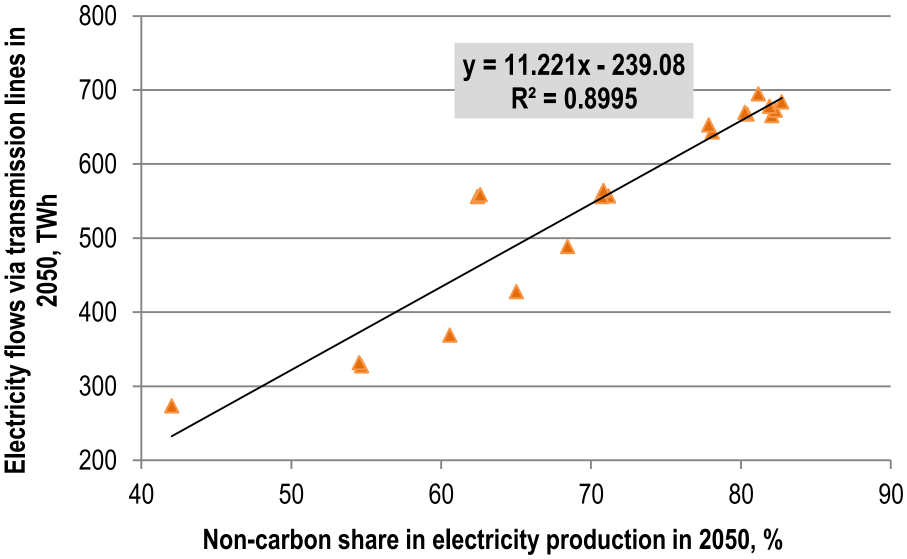
According to DSO “Rosseti South” it happens because “the generated electricity is not consumed locally due to the lack of consumers, but it is transmitted over long distances”

Source: ERI RAS forecast

Scenarios with CO2 emission quotas in power and DH sectors – Grid development

Correlation between grid development and share of non-carbon sources in electricity production mix





Obviously the investments into transmission grid will grow while decarbonization deepens, but I’m not sure about their share in total investments in power sector.
The distribution grid could be another story depending on the type of dominating non-carbon source and the depth of electrification of final demand

Intra-Year Modelling (Dispatch Model)

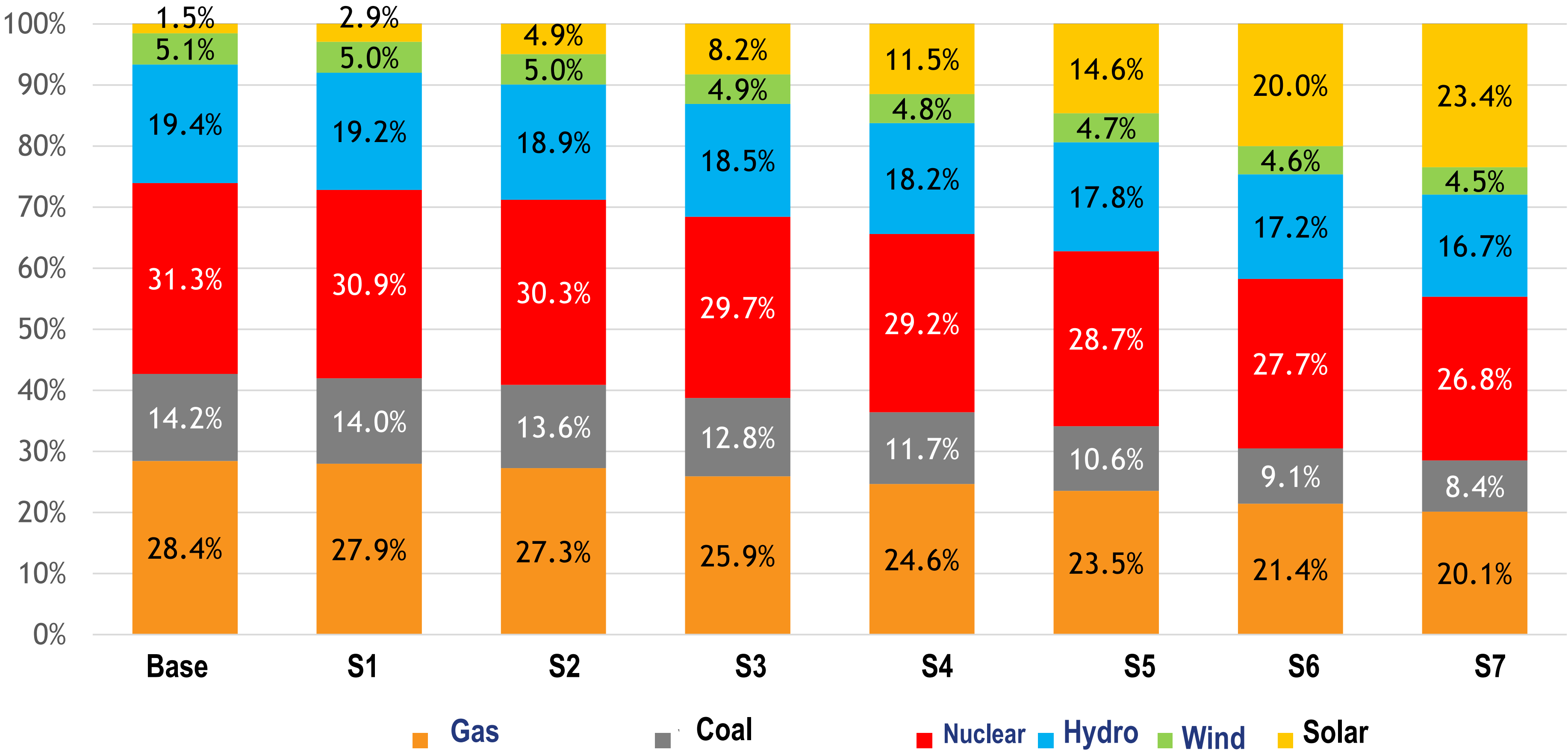
Representation of Russian power sector in MOCCO

- MOCCO is a simplified dispatch model optimizing commitment and load of every power plant on hour-to-hour basis
- Very simplified representation of the electricity grid (limit on transmission capacity)
- Instead of 42 power nodes, for the sake of optimization time, balances were modelled only for integrated power systems (IPS)
- 20 aggregated generating technologies in each IPS were modelled; Optimal capacity and aggregated characteristics are obtained from EPOS model;
- Historical data of hourly generation curves for wind and solar plants as well as a load curves in each IPS were used;

Modelled scenarios

- Only 3 IPS were modelled with an special emphasize on a IPS South with most promising solar power resources
- Idea of the study – to evaluate the change in the functioning of the power system with the increasing share of solar PV generation
- 7 scenarios with growing share of solar PVs were modelled
- hour-by-hour optimization for the whole year was performed

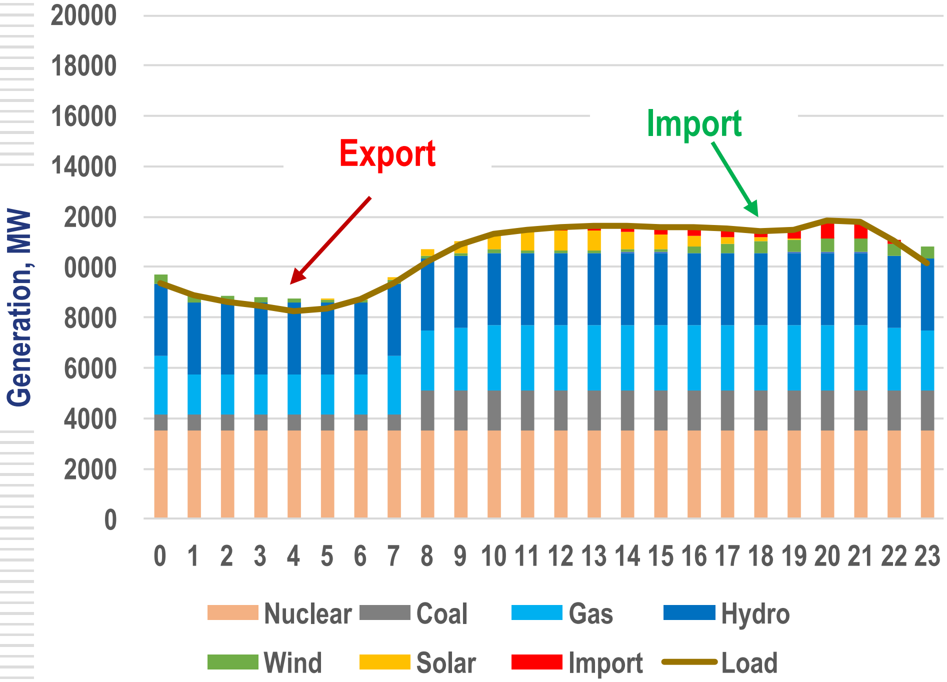
Modelled scenarios – Annual electricity mix



	Base	S1	S2	S3	S4	S5	S6	S7
Solar	1.5%	2.9%	4.9%	8.2%	11.5%	14.6%	20.0%	23.4%
Wind	5.1%	5.0%	5.0%	4.9%	4.8%	4.7%	4.6%	4.5%
Hydro	19.4%	19.2%	18.9%	18.5%	18.2%	17.8%	17.2%	16.7%
Nuclear	31.3%	30.9%	30.3%	29.7%	29.2%	28.7%	27.7%	26.8%
Coal	14.2%	14.0%	13.6%	12.8%	11.7%	10.6%	9.1%	8.4%
Gas	28.4%	27.9%	27.3%	25.9%	24.6%	23.5%	21.4%	20.1%

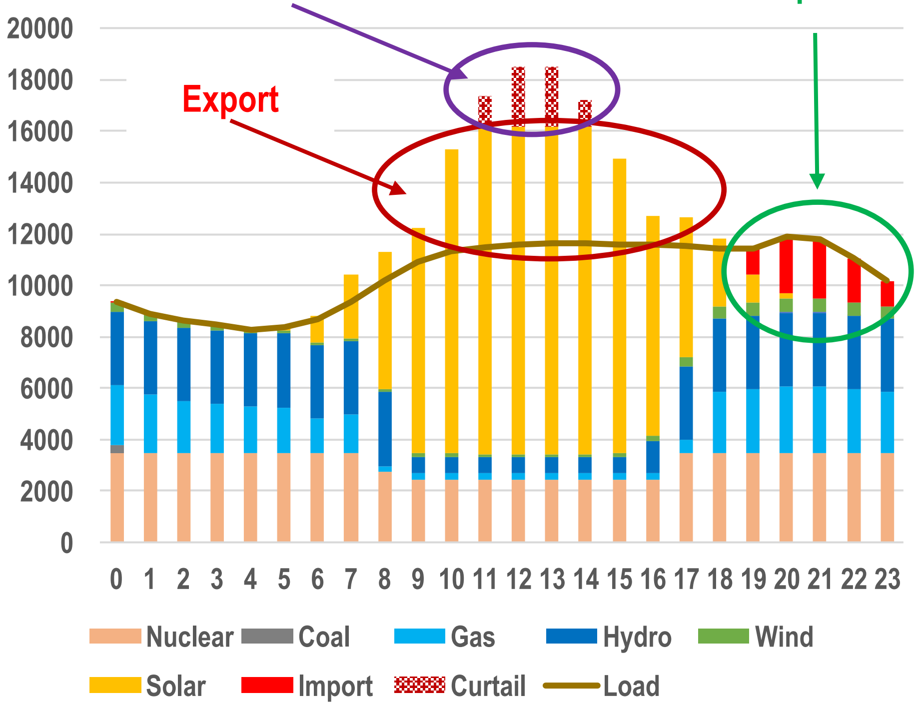
Hourly dispatch (example)

Base scenario, July 12



Curtailment due to transmission capacity limit

, July 12



Transmission capacity utilization

Scenario	Annual export/ import balance, TWh	Utilization of transmission capacity, % of the year					
		Total	South to Volga	Volga to South	Total	South to Center	Center to South
Base	-7,5	62	10	51	25	3	22
S1	-6,3	59	13	46	23	4	19
S2	-4,6	61	20	42	23	9	14
S3	-2,4	68	32	36	29	18	11
S4	-0,9	72	41	32	37	27	10
S5	0,1	76	46	30	44	35	9
S6	1,2	85	53	32	52	41	11
S7	1,8	89	56	33	59	45	14

- Utilization of the grid capacity increases with the grow of RES development. Especially, at the beginning, when the most favorable areas for RES placement are developed, which could be situated far from consumers.

- The grid allow not only to transfer excess electricity from renewable energy sources, but also to provide additional flexibility

Takeaways

- As decarbonization progresses, the importance of networks will eventually grow.
- The grid allows not only to transfer excess electricity from renewable energy sources, but also to provide additional flexibility
- It may be necessary to include more detailed descriptions of load nodes and networks in capacity expansion models, or check their solutions on more complex power flow models.

The Energy Research Institute of the Russian Academy of Sciences

www.eriras.ru

Andrey Khorshev,
PhD, Head of the Center for Energy Modeling
epos@eriras.ru

Thank You for Attention!