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Prospects of using new technologies in Russia's electric power industry to comply with international commitments to reduce CO_2 emissions

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Abstract. This study addresses the methodology of projecting the electric power industry developments, taking into account environmental constraints. I obtained quantitative assessments of long-term electric power industry development in a Russian region, determined the emission of greenhouse gases from fuel combustion at thermal power plants (TPPs), and the efficiency of technologies to reduce greenhouse gas emissions in the electric power industry.

1 Introduction

Presently, when planning and programming economy development of the countries and regions, the global climate change problem related to emissions of greenhouse gases – carbon dioxide, CO2 being the main among the latter – at fuel combustion is regarded the most acute [1]. The constraints on its emission imposed by the Paris Agreement, in fact, define the boundaries impeding the power engineering development, and, consequently, they restrain the economy development, especially in developing countries. At present, it is difficult to estimate how much these constraints are justified, because investigations into the anthropogenous emission effect on the climate and its change have not been completed yet, with the preliminary conclusions being ambiguous and even contradictory [2].

In Russia, a number of Federal Laws, according to which greenhouse gas emissions should be reduced to 75% of the 1990 level by 2020, and to 70% by 2030 [3], have been passed.

There is no real alternative to fossil hydrocarbon fuel as a primary energy carrier over a long perspective. Reducing the carbon dioxide emissions into the atmosphere may be achieved by:

- active promotion of energy-saving technologies;
- increase in electric power production efficiency through improving thermodynamic cycles, equipment, fuel combustion techniques, use of fuel elements, etc.;
- introduction of multi-purpose power technological installations that, besides electric power, produce additional marketable products (for example, through the catalytic synthesis methods, etc.) increasing the fuel usage coefficient as compared with separate production of electric power and those products;
- switching to fuels containing smaller carbon amount (replacing coal with natural gas, or oil motor fuel with hydrogen);
- CO_2 recovery in the power installation cycle with its subsequent durable disposal (sequestering).

2 Modelling long-term development of Russia’s electric power industry

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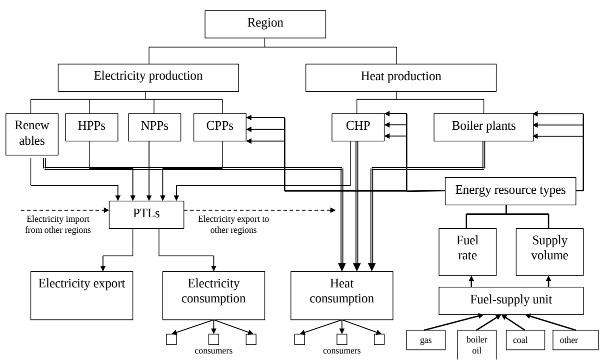

Fig. 1. Structure of the model for production, distribution, and consumption of electric and district heating

As per the above model construction principle, each energy carrier produced at this or that stage is appropriated by the corresponding equation in the model, whereas each power plant is appropriated by a variable:

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$$I^{t}_{e,r} + \sum_{k} R^{t}_{e,k,r} + \sum_{r'} Y^{t}_{e,r'r} + \sum_{p\in r} (p_e \times X^{t}_{p,r}) - \sum_{r'} (b^{t}_{e,r,r'} \times Y^{t}_{e,r,r'}) + \sum_{d} D^{t}_{e,d,r} + Ex^{t}_{e,r} \quad (1)$$

for all: $e \in 1, ..., E; r \in 1, ..., r'..., R; t \in 1, ..., T$,
where: $I^{t}_{e,r}$ is the energy carrier *e* import to the region *r* in year *t*; $R^{t}_{e,k,r}$ is the extraction of the given energy carrier *e* by all plants *k* in the territory of the region *r* $(k \in r)$ in year *t*; $Y^{t}_{e,r'r}$ is possible import of the energy carrier *e* from other regions *r'*; $X^{t}_{p,r}$ is the production capacity of the power plant *p* in the region *r* $(p \in r)$ in year *t*; p_e is the coefficient determining the output (consumption) of the energy carrier *e* at the plant *p* ($p_e = -1/f_p$, if the energy carrier is consumed, $p_e = 1$, if the energy carrier is produced); $Y^{t}_{e,r,r'}$ are possible deliveries of the energy carrier *e* to other regions *r'* considering transport losses $b^{t}_{e,r,r'}$ in year *t*; $D^{t}_{e,d,r}$ is the consumption of the end energy carrier *e* by customers' categories *d* in the region *r* in year *t*; $Ex^{t}_{e,r}$ is the energy carrier *e* export from the region *r* in year *t*.

All the power plants are split into operating $(RESX^{t}_{p,r})_{t=1}$ by the settling period start, and newly-built plants $(X^{t}_{p,r})_{t>1}$. For the operating plants, I specify the dynamics of their possible retirement by stages of the settling period $(RESX^{t+1}_{p,r} \le RESX^{t}_{p,r})$, and creation of new production capacities. Newly-commissioned capacities at each temporal stage may be restrained and should retire as the standard life comes to an end. To consider the dynamics factor, I introduce the capacity transport equations for each power plant by stages *t* of the settling period *T*. For a separate plant *p* in the region *r*, this equation looks like:

$$X^{t}_{p,r} = RESX^{t}_{p,r} + \sum_{b<t} \min(RL^{b,t}_{p} / n_t, 1) \times X^{b}_{p,r} \quad (2)$$

for all $p \in 1,...,P$,
where: $X^{t}_{p,r}$ is the power plant *p* capacity in the region *r* in year *t*; $RESX^{t}_{p,r}$ is the residual capacity of the plant *p* in the region *r* at the stage *t,* that was commissioned by the settling period start; $RL^{b,t}_{p}$ is the number of years, over which the power plant *p* capacity built at the stage *b* persists (proceeding from the standard life) at the stage *t*; n_t is the number of years at the stage *t*; $X^{b}_{p,r}$ is the power plant *p* capacity introduced at the stage *b* in the region *r*;

In general case, the technological aspect of the power plant (technology) is described by the following metrics: coefficients determining the consumption and production of energy carriers by the given plant (technology); power installation efficiency coefficient; operation mode; plant life.

As the economic metrics of power plants, I use: specific constant and variable costs related to maintaining power plant capacities and to producing power resources and energy carriers; specific holdings necessary for building (renovating) power plant capacities, energy-saving technologies and emission reduction technologies.

3 Assessing the efficiency of using new technologies in Russia

Effective (in terms of the CO_2 emission reduction, included) is perfecting the TPP energy production based on [4, 7, 8]:

- introducing coal power-generating units at supercritical (41% eff.) and supercritical (46% eff.) steam parameters;
- introducing steam-gas plants (55-60% eff.);
- using boilers with circulating fluidized bed at low-grade-fuel combustion;
- using fuels with an increased calorific value, and natural gas;
- using technologies of CO_2 recovery and disposal.

To assess the performance of the offered methodical approach, I address two scenarios for the Irkutsk Oblast electric power industry development: optimistic and basic [5, 6].

The power consumption was projected by considering the economy development and the population perspective metrics. Inasmuch as the planned long-term regional major energy-intensive investment projects, the projection for the need in electric power was performed separately for the industries and services (developed for today) and for new industries (projects) [7-10].

Table 1. Projection of the electric power and heat production in Irkutsk Oblast

	1990	2000	2010	2015	2020		2025		2030	
					o.s.	b.s.	o.s.	b.s.	o.s.	b.s.
Electricity production, bil. kW·h	**67,1**	**54,5**	**62,4**	**48,0**	**64,3**	**56,9**	**73**	**57,5**	**77**	**60,6**
Hydro Power Plants	47,5	47,3	49,3	35,9	46,3	46,3	46,3	46,3	48,6	48,6
Thermal Power Plants	19,6	7,2	13,1	12,1	18,0	10,6	26,7	11,2	28,4	12,0
Thermal energy production, mln. GCal	**72,6**	**54,7**	**49,1**	**41,2**	**46**	**44**	**50**	**46**	**59**	**54**

As per the electric power industry development scenarios, we calculated the CO_2 emissions from fuel combustion at TPPs (Table 2).

Table 2. CO_2 emission volume at boiler-furnace fuel (BFF) combustion, mln. tonnes*

	1990	2000	2010	2015	2020		2025		2030	
					o.s.	b.s.	o.s.	b.s.	o.s.	b.s.
Thermal power plants	**35,4**	**22,4**	**22,7**	**20,7**	**26,4**	**23,3**	**36,3**	**33,3**	**32,7**	**30,9**
including coal	32,0	19,6	19,3	17,9	22,9	19,9	32,8	29,8	22,6	21,8
gas	0	0	0	0	0	0	0	0	6,6	5,7
oil	0,6	0,3	0	0	0,09	0,09	0,09	0,09	0,1	0,1
other, etc	2,8	2,52	3,4	2,8	3,4	3,4	3,4	3,4	3,4	3,4

* - *Author's calculations*

The CO_2 emissions from TPP fuel combustion will exceed the 1990 level by 2025, and reach 36,3 and 33,3 mln. t. in the optimistic and basic scenarios, respectively. By 2030, they decrease provided new power stations are commissioned.

However, if one considers further decrease in the CO_2 emissions, it is necessary to change the structure of the consumed fuel (to use natural gas), or to use new technologies of steam-gas plants (integrated gasification combined cycle (IGCC), etc.).

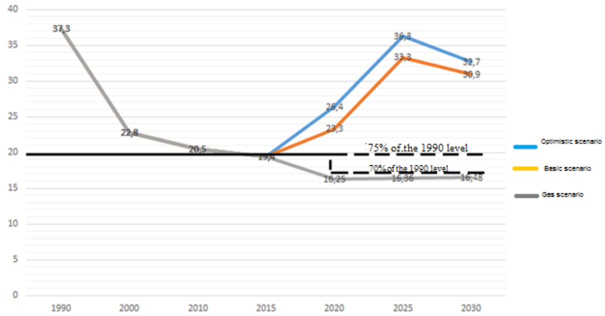

Fig. 2 Projection for the CO_2 emissions from TPP fuel combustion, mln. tonnes

To implement President's Decrees on the CO_2 emission reduction in any scenario for the Irkutsk Oblast electric power industry development, it is necessary to apply additional measures. Considering the capital investments and operational costs, TPP switching to natural gas is the most inexpensive way (of all the above processes) to reduce CO_2 emissions. Herewith, the CO_2 reduction may reach 20-22 mln. tonnes (Figure 2).

4 Conclusion

The proposed methodical approach enables to select an optimal version for Russia's (regions') electric power industry development, considering environmental constraints.

I provided an example of assessing the CO_2 emission reduction technology efficiency in Irkutsk Oblast, and showed the necessity to change the structure of the BFF consumption and TPP switching to natural gas.

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