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Power Market Formation for Clean Energy Production as the Prerequisite for the Country's Energy Security

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Abstract: The paper analyzes the main issues of power market development for clean energy production within the broader framework of ensuring the country's energy security. In addition, special attention is paid to the technologies aimed at reducing emissions of toxic substances and greenhouse gases by the fossil-fired power plants. Even though the future electricity markets would most likely depend on the high shares of renewable energy sources (RES) in the electricity system, energy efficiency such as the one based on the near-zero emission technologies might also play a crucial role in the transition to the carbon-free energy future. In particular, there are the oxy-fuel combustion technologies that might help to reduce the proportion of unburned fuel and increase the efficiency of the power plant while reducing the emissions of flue gases. Our paper focuses on the role and the place of the near-zero emission technologies in the production of clean energy. We applied economic and mathematical models for assessing the prospects for applying oxy-fuel combustion technology in thermal power plants, taking into account the system of emission quotas and changes in the fuel cost. Our results demonstrate that at the current fuel prices, it is advisable to use economical combined cycle gas turbines (CCGT). At the same time, when quotas for greenhouse gas emissions are introduced and fuel costs increase by 1.3 times, it becomes economically feasible to use the oxy-fuel combustion technology which possesses significant economic advantages over CCGT with respect to the capture and storage of greenhouse gases.

Keywords: energy security; power market; near-zero emission technologies; oxy-fuel combustion cycles; emission rights sales mechanism; economic assessment

1. Introduction

The energy sector plays a key role in any country's economy in terms of maintaining its sustainability and ensuring its energy security. Moreover, it is the level of energy efficiency and reliability that defines the country's national security [1–4]. The development of the energy sector should take place at a faster pace than the development of other sectors of the economy which is explained by the need for satisfying the ever-growing demand of the economy for the electric energy.

Our analysis of the available data [5–7] on the construction of generating facilities of all possible types from various countries around the world allows us to conclude that there has been a significant increase in electricity consumption over the past 30 years. At the same time, despite the growth that was achieved over the past decade in the installed capacity of alternative and renewable energy sources, the consumption of classical fuel and energy resources (oil, gas, coal) is growing, and the role of traditional thermal power industry based on the chemical conversion of organic fuel still remains crucial [3,4].

The generating unit of the traditional thermal power industry is a thermal power plant (TPP). In Russia, TPPs account for more than 57% of the country's total electricity generation and 37% of heat production intended for the consumers' needs. At the same time, thermal power plants consume 38% of the extracted fossil fuel. The conversion of this fuel into energy becomes the main source of environmental pollution (forming about 57% of emissions among all processing industries).

The active use of fossil fuels at thermal power plants that is intended to meet the demand for electricity while this resource is limited is one of the main factors in the development of effective energy conversion technologies. Figure 1 presents a graph reflecting a gradual increase in efficiency on the example of coal TPP in countries with the most developed energy sector [6–10]. As it can be observed from the example of countries with the highest deficit of fossil fuels, the development of effective power generation technologies is faster.

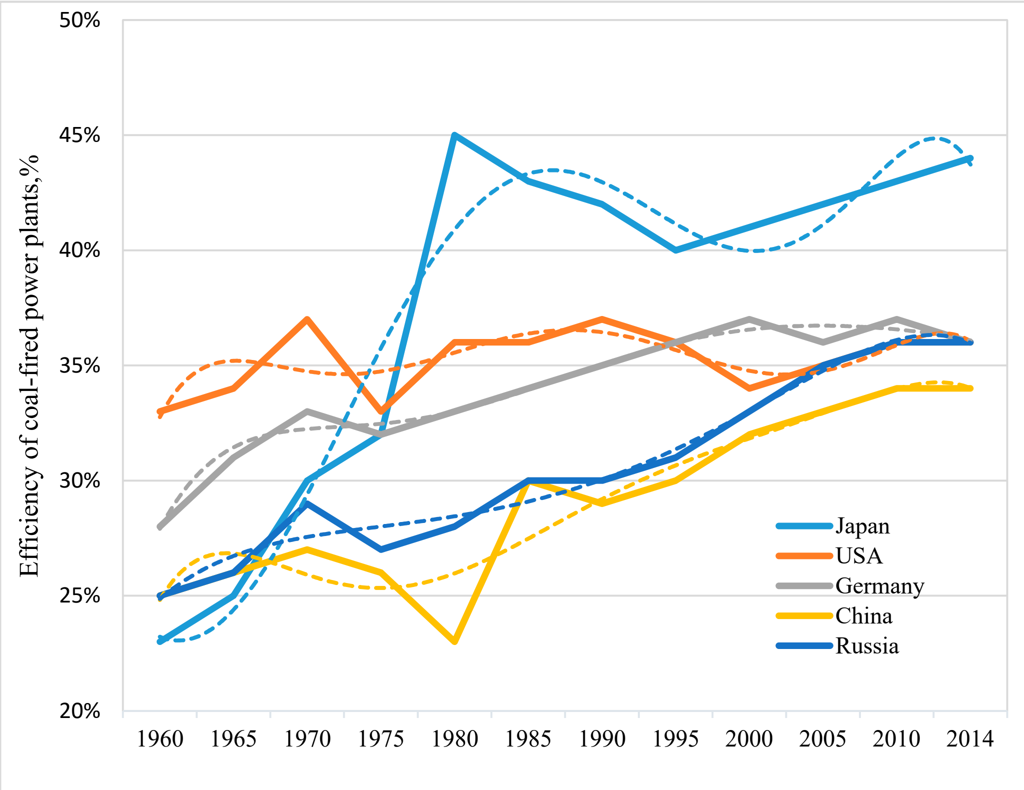

Figure 1. Development of coal thermal power plants (TPPs) in countries with the most developed energy sector.

Nowadays, the development of technologies for the production of energy products is moving towards the increase of the initial parameters of steam-pressure P_0 and temperature t_0. From a thermodynamic point of view, this is the only possible way to significantly increase the efficiency of turbine units and, hence, the efficiency of a power plant by surging its environmental friendliness in general. The most significant effect on the efficiency of a power unit is a change in the initial temperature of the steam t_0 in the combustion chamber. Thus, an increase in t_0 by 1% leads to an increase in the efficiency of thermal power plants by an average of 0.13% with a simultaneous increase in pressure P_0 by 0.0086% [11,12].

The existing modern technologies used for increasing the initial temperature of fuel combustion are based on its oxygen combustion which is a process when oxygen is served as the oxidizer instead of atmospheric air in the combustion chamber. In turn, oxygen is produced at a power plant or purchased from an external supplier. The increased oxygen content leads to an increase in the combustion temperature and the amount of heat transferred to the technological process. Thus, the share of unburned fuel is reduced and the efficiency of the power unit of the TPP is increased while the nitrogen oxide emissions are reduced (NO_x) [2,13–16].

Since the atmospheric air contains 80% of nitrogen, the use of the oxygen combustion leads to a significant reduction in flue gas consumption. At the same time, an increased concentration of greenhouse gases is formed in the volume of exhaust gases which creates favorable conditions for capture and storage CO_2 [16–19]. Therefore, in the research literature, this technology is typically characterized as a near-zero emission technology [20–22].

The implementation and dissemination of the near-zero emission technologies for the production of electricity in power plants is largely due to their economic efficiency which in this case is determined by the environmental policy pursued by the state, namely, the established standards for the maximum permissible concentration of harmful substances in the atmospheric air and the market mechanisms for emissions trading [22–24]. The paper studies the issue of near-zero emission technologies and draws conclusions about the prospects for the application of these technologies in Russia under various scenarios of tightening the norms of the maximum permissible concentration of harmful substances in the air and developing the market for flue gas emission quotas.

2. Analysis of the Oxy-Fuel Combustion Technology and Its Environmental Benefits

Nowadays, most of the energy produced in TPPs is produced by the combustion of fossil fuels. The oxygen contained in the atmospheric air is usually used as the oxidizing agent. The combustion products contain greenhouse gases and toxic substances such as the nitrogen oxides. A significant reduction in the emissions of these substances into the atmosphere is cumbersome for technical and economic reasons. In particular, the emission of carbon dioxide from flue gases is inefficient due to its low partial pressure. Moreover, the insufficient combustion temperature leads to the formation of unburned fuel and its emission into the atmosphere along with the flue gases [25–27]. With regard to the above, oxygen-fuel technologies for energy production have a special meaning. They allow to almost completely reduce emissions of harmful substances into the atmosphere.

According to the technology of oxy-fuel combustion, three flows enter the combustion chamber:

- fuel (gaseous, including based on coal gasification),
- oxygen,
- carbon dioxide flow limiting the maximum temperature in the combustion chamber.

As a result of the combustion reaction, a mixture of carbon dioxide and water steam is formed. The predominantly two-component medium at a temperature of 1000 to 1700 °C is sent to a cooled turbine, expands in it, and then enters a surface heat exchanger which can be a waste heat boiler or regenerative heat exchanger. Having given off most of the thermal energy, the flow is directed to a cooler-separator. There, the cooling of the working medium is accompanied by the formation of condensate of water steam removed from the cycle. After that, a stream rich in carbon dioxide is sent to the compressor, increases its pressure and is fed to the combustion chamber for recycling. Thus, the thermodynamic cycle is reserved [27–29].

In order to replenish the material balance, part of the working environment is removed for further burial. The storage tanks for carbon dioxide can be both natural and artificial.

The schematic diagram of the oxygen-fuel energy complex is shown in Figure 2 that follows.

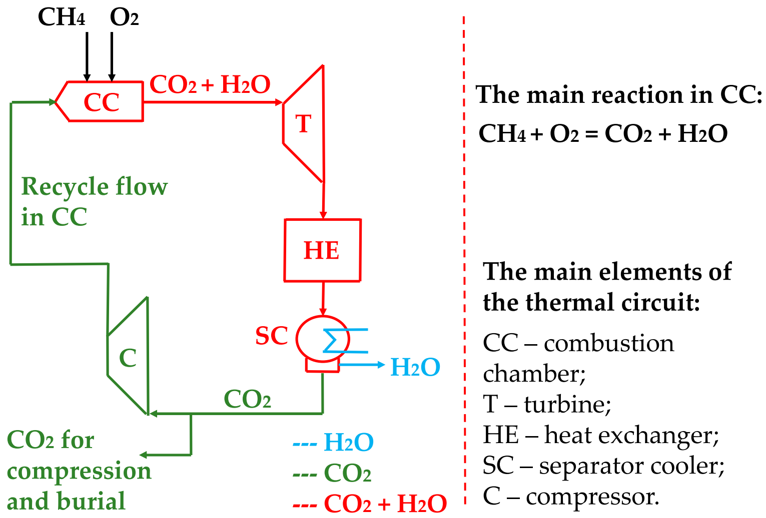

Figure 2. Schematic diagram of the oxygen-fuel energy complex.

The competitive technology for oxy-fuel combustion is the thermodynamic cycles used in the combined cycle power plants which are characterized by high efficiency and can significantly reduce thermal emissions into the atmosphere due to the long stay of the fuel–air mixture at high temperatures [30–33]. Unlike a combined cycle power plant, the oxygen-fuel energy complex is semi-closed. Most of the working medium circulates in a circle, and its mass and chemical composition only changes in the combustion chambers and cooler-separators. The maximum and minimum temperatures of the working medium are approximately at the same level as those of a combined-cycle power plant, and the maximum pressure is much higher: from 2 to 30 MPa, depending on the cycle [25,26].

These features of oxygen-fuel cycles lead to a number of advantages in comparison with the traditional combined-cycle power plants using air as an oxidizing agent:

1. Due to the lack of nitrogen among the components of the combustion reactions, the formation of high temperature nitrogen oxides is prevented. This allows to shift the main emphasis in the development of the combustion chamber to achieve high rates of efficiency and combustion stability.
2. The two-component composition of the working medium makes it possible to organize the simplest principle of thermodynamic separation of carbon dioxide and water steam in a cooler-separator by condensing the latter. As a result, there are no additional costs associated with respect to the capture of carbon dioxide from the flue gases.
3. Carbon dioxide is an inert gas that does not corrode power equipment, both at high and low temperatures.

The disadvantages of oxygen-fuel cycles include:

1. In order to avoid high energy costs for the production of oxygen, it must be supplied to the combustion chamber with a small excess coefficient relative to the stoichiometric ratio. The occurrence of the combustion reaction in the combustion chamber with a stoichiometric ratio of fuel to oxidizing agent necessitates the prevention of burning the fuel.
2. The need for high purity oxygen production causes higher costs of energy own use.

Table 1, which follows, shows a comparative analysis of the technical, economic, and environmental characteristics of oxygen combustion technologies and combined steam-gas cycle [25,34–41].

Table 1. Technical and economic characteristics of oxy-fuel combustion technologies and combined steam-gas cycles.

Oxy-Fuel Combustion Cycles	Fuel	Oxidizer	Net Efficiency, %	Specific Amount of Produced CO_2, g/kWh	CO_2 Capture Rate, %	Specific Amount of Captured CO_2, g/kWh	Specific Amount of CO_2 Emitted to the Atmosphere, g/kWh
				oxy-fuel combustion cycle			
SCOC-CC	CH_4	O_2	47.7	406	98.9	402	4
MATIANT	CH_4	O_2	43	451	98.9	446	5
E-MATIANT	CH_4	O_2	44	440	98.9	436	5
CC-MATIANT	CH_4	O_2	46	421	98.9	417	5
Allam cycle	CH_4	O_2	56.5	343	98.9	339	4
S-Graz cycle	CH_4	O_2	54	359	98.9	355	4
CES cycle	CH_4	O_2	48	404	98.9	399	4
AZEP	CH_4	O_2	50	388	98.9	383	4
ZEITMOP	CH_4	O_2	51	380	98.9	376	4
				combined steam-gas cycle			
Combined cycle gas turbine with CCS	CH_4	Air	48	404	89	359	44
Combined cycle gas turbine without CCS	CH_4	Air	60	323	0	0	323

As one can see from Table 1, the oxygen-fuel cycles have significant environmental advantages in comparison with the combined steam-gas cycle (in particular, expressed in the reduction of greenhouse gas emissions) with comparable values of the efficiency of power units. To date, the use of oxy-fuel combustion is restrained in the first place by the economic factors. However, due to the tightening of standards for emissions of harmful substances and the development of trade with quotas for greenhouse gas emissions, oxygen-fuel cycles of electricity production can become quite attractive.

3. Analysis of the Market Formation for Emissions Quotas of the Harmful Substances

The industrial and economic activities of thermal power plants are associated with direct environmental impacts in the form of emissions of the harmful substances. The criterion of environmental cleanliness of the generating facility is the condition that the concentration of harmful substances does not exceed the threshold value of the maximum permissible concentration (MPC). Current values of MPC of pollutants in the air are presented in the state regulations of countries. Some excerpts from the state standard of Russia GN 2.1.6.1338-03 are shown in Table 2 below [42].

Table 2. Maximum permissible concentrations of harmful substances in the air.

No.	Substance	Hazard Class	One-Time MPC, mg/m^3	Daily Average MPC, mg/m^3
1	Carbonic oxide	4	5	3
2	Nitrogen dioxide	2	0.2	0.04
3	Nitrogen oxide	3	0.4	0.06
4	Sulfur dioxide	3	0.5	0.05
5	Ammonia	4	0.2	0.04
6	Hydrogen sulfide	2	0.008	-

From Table 2, it becomes apparent that the existing system for regulating the amount of harmful substances used in Russia is rather soft and does not stimulate the development and implementation of the new and more environmentally friendly technologies for the production of electricity, in particular, oxygen combustion technology [43–46].

The above situation can be corrected by the development of the market mechanisms for the sale of emissions of harmful substances by the power plants [47–49]. Based on this market, the initially allocated quotas for pollutants and greenhouse gases will be redistributed from a position of minimizing total costs. In this case, the market will act as an optimizer and better cope with the task of reducing emissions than the introduction of a pollution tax [48,50]. The fact is that the determination of the required tax rate by regulatory authorities is very difficult, while the market usually copes with the optimization task much better.

The emissions trading scheme is shown in Figure 3.

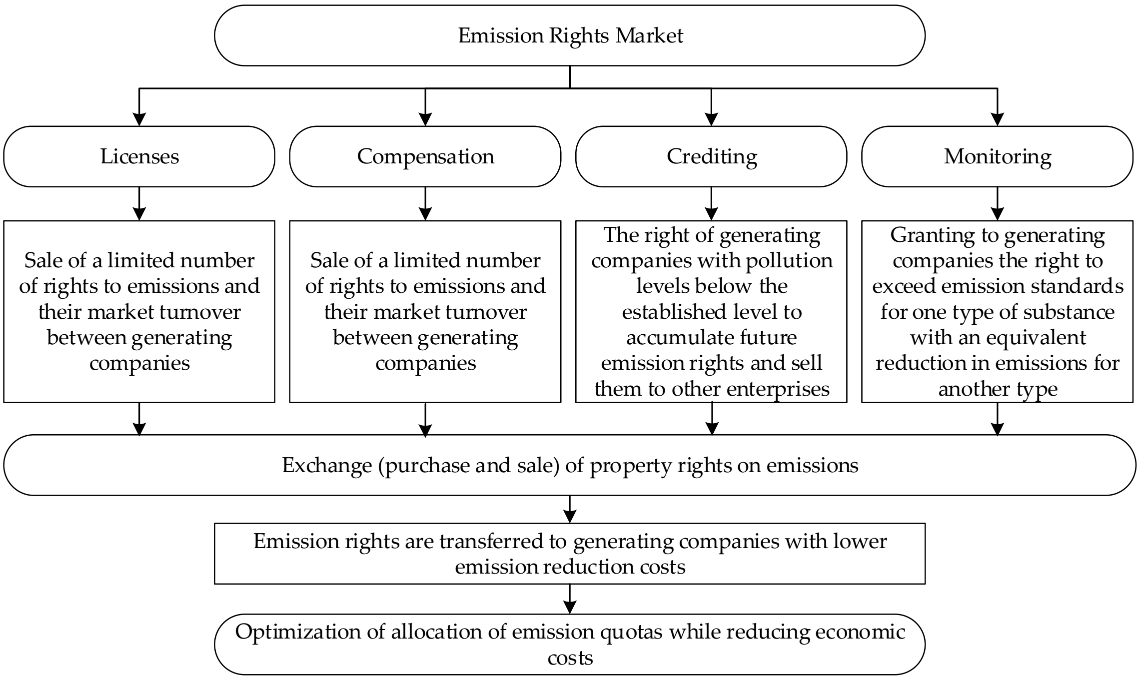

Figure 3. The emissions trading scheme of harmful substances.

A limit on a certain amount of pollutant emissions is introduced within a limited area. Emission permits are distributed among individual generating companies. The generating company is required to either meet the limits by investing in the appropriate technology, or, if this appears to be too expensive, purchase permits for additional emissions from those companies that are more profitable to reduce their emissions above the established limits [51,52].

A special role is played by the creation of a market mechanism for the sale of pollution rights at the global level [53,54]. The existing carbon tax creates a lot of problems for the industries of the developed countries which have almost exhausted all cheap ways for reducing their emissions. In these conditions, Russia can make itself significantly better off. The country possesses more than 75% of the world's carbon reserves. The creation of the international transfer mechanisms for offsetting the carbon balance is going to bring significant benefits and attract additional foreign investment.

In 2010, Russia transferred quotas for the emission of harmful substances and greenhouse gases into the atmosphere to the foreign companies for the first time. Japanese enterprises Mitsubishi and Nippon Oil bought quotas for the emission of 290,000 t of greenhouse gases from a Russian company PJSC Gazprom Neft. The cost of emissions is estimated to be at a total of 3.3 million euros. The transfer of quotas was carried out as part of joint implementation projects (JIP), the mechanism of which is prescribed in the Kyoto Protocol. The Kyoto Protocol obliges developed countries and transition countries to reduce or stabilize greenhouse gas emissions [55–57]. As a result of the JIP implementation, Russian enterprises received foreign investment in energy-efficient technologies, harmful emissions into the atmosphere were reduced, and the emission reduction volume could be implemented on the market.

In the case of the introduction of stringent standards for maximum permissible concentrations of harmful substances in the air and tax rates for flue gas emissions, one can expect the widespread usage of pollution rights sold for market purposes between different countries in the world. This will be conducive to environmental protection at the global level as well as the introduction of environmentally friendly technologies for the production of energy products in developing countries, in particular, based on oxy-fuel combustion, due to the influx of financial resources from developed countries, where the control of harmful substances is much more expensive.

At the local level, the development of the market for the emission quotas is facilitated by the development of the distributed electricity generation which complements the existing organization of energy supply to consumers on the basis of the centralized energy system of the country. The distributed power supply system is based on the idea of involving small distributed generation and consumer resources in the management of electric power systems with the achievement of the effect of increasing the total efficiency of work.

At the same time, there are many transaction costs and barriers arising on the way to the development of distributed energy such as the large number of participants in the system and economic relations between them, the costs of their information integration into control loops, as well as the costs of integrating their equipment into electrical networks which would prevent the power system from losing in reliability and stability of functioning. In order to remove these costs, it is necessary to develop a new system architecture that allows to support numerous fast transactions between participants and provides flexible connection to the electric networks of producers and consumers. These requirements are met by the architecture of the Internet of Energy (IoE) which represents a decentralized electric power system implementing an intelligent distributed control based on the energy transactions between its users [58,59]. The formation of the Internet of Energy will facilitate the transition of small generation to environmentally friendly energy supply to consumers based on the market principles.

4. Development of Economic Effect Assessing Model for the Application of the Oxygen Combustion Technology, Taking into Account the Environmental Aspect

The oxygen-fuel cycles increase the initial parameters of steam power plants which are currently one of the main ways to increase the efficiency and environmental friendliness of thermal power plants. Let us consider the social and environmental effectiveness of the use of oxy-fuel combustion from the perspective of economic criteria.

As an economic criterion which reflects the social significance of technology, we chose the minimum specific cost of electricity production. A reduction in the operating costs for electricity production will limit the increase in the electricity tariffs. The transition from the technology of one generation to a more efficient one should occur when the specific cost of electricity production using a more advanced technology becomes lower than the technology already used in the generation of energy. In many ways, the change in the cost of electricity production is determined by the change in the price of fossil fuels which grows as the available resource is exhausted.

In order to assess the level of specific costs for the production of electric energy for various generation technologies, we composed the following mathematical expression:

$$C = C_f + C_w + C_d + C_r + C_o \tag{1}$$

where C—annual cost of the electricity production; C_f—fuel costs of TPP; C_w—labor costs; C_r—repair costs; C_o—other expenses.

The most significant component is the fuel costs. The amount of the fuel costs depends on many factors. Among them, there are price of fuel, the efficiency of electric energy generation, determined by the level of generation technology, and the installed capacity utilization factor (ICUF), which sets the load on the generating facility during the year.

The fuel costs can be represented as the following mathematical expression:

$$C_f = N_p \cdot T_y \cdot K_{cf} \frac{1}{\eta \cdot Q_f} P_f \tag{2}$$

where N_p—installed capacity of TPP, kw; T_y—number of hours of operation of the power plant in a year, h; K_{cf}—installed capacity utilization factor; η—TPPs efficiency of the electricity production; Q_f—fuel calorific value, kJ/kg; P_f—fossil fuel price.

Labor costs can be estimated according to the following expression:

$$C_w = n\overline{W}(1+\alpha) \tag{3}$$

where n—number of personnel at TPP, determined in accordance with the standard depending on the installed capacity of power units of the power plant; $\overline{W}$—industry average wage; α—the share of the mandatory insurance contributions.

The number of personnel is determined by the installed capacity of the power plant and the number of power units. In order to ensure the comparability of simulation results for each individual technology, we will calculate for one power unit. In this case, the electric power of the power unit will vary depending on the level of technology.

Depreciation can be calculated linearly. Then the share of depreciation charges can be determined by the life of the TPP power unit. For units at different steam parameters, let us assume the service life to last 30 years. Although the increase of the initial steam parameters is accompanied by the technological difficulties such as metal deformation and high temperature corrosion, the design life is maintained due to economic reasons, such as maintaining the investment attractiveness of power plant construction projects.

Repair costs are estimated in fractions of the amount of capital costs. The higher the steam parameters, the more expensive the steels and alloys used to create power units; therefore, repairs will cost more. The repair costs can be determined according to the following expression:

$$C_r = \beta \cdot I_s \cdot N_p \tag{4}$$

where β—share of contributions to the repair fund; I_s—specific investment, \$/kW; N_p—installed power capacity.

By other costs, we mean those costs that are not included in the above calculation, in particular, general expenses. Other costs depend on the power of the unit and can be estimated as part of the fixed costs:

$$C_o = \gamma(C_r + C_w + C_d) \tag{5}$$

where γ—share of other expenses.

The compiled functional model (1) allows us to calculate the specific cost of electricity production for technologies with different initial parameters of steam (including supercritical parameters achieved by oxygen combustion of fuel) at different prices for fossil fuels. Thus, it is possible to determine the cost of fossil fuels at which the use of oxygen-fuel cycles becomes economically feasible.

The introduction of a market-based mechanism for trading in CO_2 emissions quotas leads to an environmental factor affecting the cost of electricity production. In this case, the technology of oxygen combustion of fuel receives additional economic benefits. Incorporating environmental considerations leads to the following changes in the cost of electricity production model:

$$C = C_f + C_w + C_d + C_r + C_o + C_e \tag{6}$$

where C_e—costs for payment of quotas for CO_2 emissions.

In 2018–2019, CO_2 quotas were traded on the London Stock Exchange ICE Futures Europe at an average price of 20.4 €/t [60]. In this case, the price of quotas is set not by a decision of the authority, but by market mechanisms; therefore, the indicated value can also be used in calculating the economic efficiency of oxy-fuel combustion technology for Russian power plants.

5. Results and Discussions

The initial data for calculating the specific cost of production of energy products at various prices for fossil fuels and the formation of quotas for greenhouse gas emissions are provided in Table 3, which follows. The table contains model parameters of the existing and future environmentally friendly power generation plants at thermal power plants: gas turbine plants (GTU TPP without CO_2 capture) [61], combined cycle plants (CCGTU TPP without CO_2 capture and storage) [62], combined cycle plants with CO_2 capture and storage (CCGTU TPP with CO_2 capture and storage) [63], and oxygen-fuel plants (TPP with the oxygen-fuel cycle) (which are discussed in this paper).

Table 3. The calculated parameters of the model for determining the cost of electricity at different costs of fossil fuels and the availability of quotas for greenhouse gas emissions.

Model Parameter	GTU TPP Without CO_2 Capture	CCGTU TPP Without CO_2 Capture and Storage	CCGTU TPP with CO_2 Capture and Storage	TPP with Oxygen-Fuel Cycle
Installed capacity, MW	100	300	300	300
Net efficiency for the generation of electric energy, %	40	58	48	50
Specific CO_2 emissions, g/kWh	485	323	44	4
Specific capital investment, $/kW	1200	1700	2200	1900
Period of operation, years	30	30	30	30
Installed capacity utilization factor	0.7	0.7	0.7	0.7
Calorific value, kJ/m^3	36,000	36,000	36,000	36,000
The number of staff, persons	120	250	250	250
Average salary level in the industry, rubles	47,000	47,000	47,000	47,000
The coefficient of social contributions, %	30.2	30.2	30.2	30.2
The coefficient of contributions to the repair fund, %	5	5	5	5
The ratio of other costs, %	25	25	25	25

According to the functional model (1), the dependences of the unit cost of the electricity production on the price of fossil fuels (coal gasification) were obtained with an increase in the initial steam parameters by supplying the purified oxygen to the combustion chamber. The simulation results are presented in Figure 4.

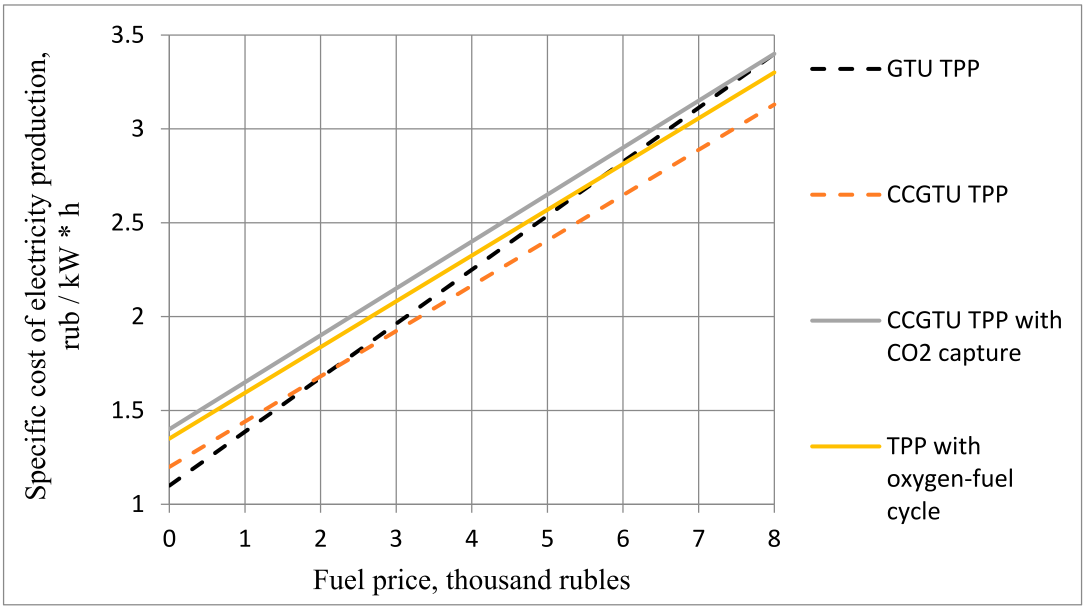

Figure 4. The dependence of the unit cost of electricity production on the price of fuel during the conventional and oxygen combustion.

In 2019, the average price of gasified fuel in Russia amounted to 2600 rubles/ton. At this level of fuel prices, according to the results of thermal power plants, CCGTU TPP units provide the lowest specific cost (1.78 rubles/kWh) of electricity production, which explains the increased interest of generating companies in their construction and commissioning. It also helps to reduce the burden on the environment.

The use of oxy-fuel combustion at TPPs will be economically feasible at a gasified fuel price of 5700 rubles/ton, which is 2.2 times the current cost of fuel. While maintaining the current dynamics of coal price growth, it will be economically feasible to build TPPs with oxygen-fuel cycles after 30 years.

Consider the simulation results obtained using model (2). This model of the specific cost of electricity production includes a quota system that provides for the purchase of rights for carbon dioxide emissions by generating companies. Accounting for the costs of ensuring environmental standards leads to a decrease in the threshold value of the fuel cost, which determines the economic feasibility of switching to the oxygen-fuel cycles. This is explained by the environmental benefits of TPPs operating at higher steam parameters and the possibility of almost complete capture of greenhouse gases during oxygen combustion of fuel. The simulation results are shown in Figure 5.

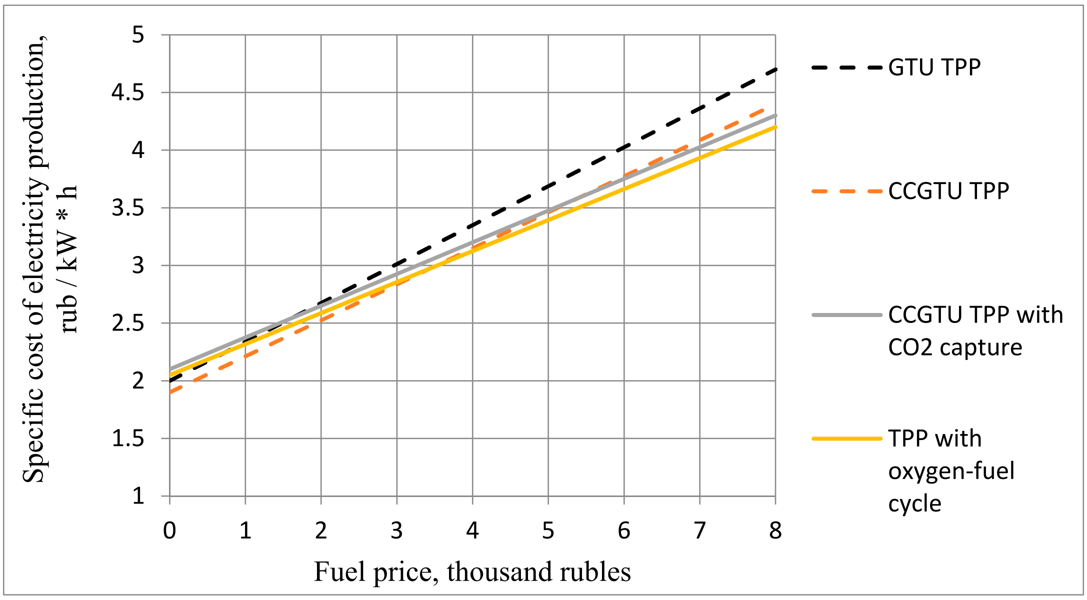

Figure 5. Dependence of the unit cost of electricity production on the price of fuel for the conventional and oxygen combustion, taking into account quotas for the greenhouse gas emissions.

From the analysis of the results presented in Figure 5, it is possible to determine the new threshold values of the fuel price at which it is economically feasible to build TPPs using oxy-fuel combustion technology. Table 4 presents the results of comparing threshold values for coal cost, which determines the economic feasibility of using oxy-fuel combustion technology without taking into account (model (1)) and taking into account (model (2)) the system of quotas for the greenhouse gas emissions.

Table 4. Comparison of threshold values for gasified coal prices that determine the economic feasibility of using oxy-fuel combustion technology.

Electricity Production Technology	Fuel Price Range Providing a Minimum of Unit Cost of Electricity Production, Rub/t	
	Without Emission Quota	With Emission Quotas
GTU TPP	0–1910	-
CCGTU TPP	>1910	0–3461
CCGTU TPP with CO_2 capture	-	-
TPP with the oxygen-fuel cycle	-	>3461

The results presented in Table 4 allow us to conclude that the introduction of a system of quotas for the greenhouse gas emissions would lead to the formation of market signals for owners of TPPs that determine the commissioning of the more advanced technologies for the fuel combustion and power units. The introduction of the oxy-fuel combustion technology provides a reduction in emissions of harmful substances into the atmosphere and also allows for the more careful use of limited fossil fuels which creates the basis for the sustainable development of the national economy.

It is worth noting that the introduction of quotas for the CO_2 emissions would inevitably lead to the increase of production costs and electricity prices for end consumers. However, a one-time increase in the prices for energy products in order to build a mechanism for the functioning of the energy industry that meets the principles of sustainable development appears to be an acceptable measure.

6. Conclusions

Our paper analyzed the prospects for the oxy-fuel combustion technologies from the position of ensuring the sustainable economic development of the country. Moreover, in our analysis, we also took into account the introduction of quotas for the greenhouse gas emissions.

Currently, the development of the technologies aimed at the production of electricity at traditional TPPs is associated with an increase in the temperature of fuel combustion in the combustion chamber and the beneficial use of flue gases. Thus, the initial steam parameters at the turbine inlet are significantly increased, which leads to an increase in the efficiency and environmental friendliness of the power plant due to a decrease in the formation of unburned fuel and its emission into the atmosphere. At the same time, capital costs are rising and have an impact on the cost of electricity through depreciation.

In connection with the tightening of quotas for emissions of harmful substances, oxygen-fuel technologies for energy production which allow to reduce emissions of harmful substances into the atmosphere almost completely, are of particular relevance. At the same time, their widespread use is hampered by the spread in the industry of competitive technology for energy production based on CCGT TPPs, the thermodynamic cycle of which is characterized by high efficiency and can significantly reduce thermal emissions into the atmosphere in comparison with the classical steam-powered power units.

The economic and mathematical model which was developed in this paper made it possible to formulate the dependences of the specific cost of electricity production on the price of gasified coal for the various levels of electricity production technologies, taking into account the possibility of the CO_2 capture and storage at CCGT and oxygen-fuel combustion. It is shown that at the current fuel prices it is advisable to use typical CCGT. At the same time, when quotas for greenhouse gas emissions are introduced and the cost of fuel rises by 1.3 times, it becomes economically feasible to apply the oxy-fuel combustion technology which has significant economic advantages over CCGT units with respect to the capture and storage of greenhouse gases.

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