Energy and world development forecast in XXI century

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Energy and World Development Forecast in XXI century

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Abstract. The revealed patterns of energy development are analyzed. An assessment of their impact on the technological development of the world economy and its sectors is given (using the example of the coal industry).
Keywords: Energy density, caloric equivalent of energy sources used, global energy transition, patterns of energy development, per capita consumption of fuel mass, global energy of the XXI century, average speed of movement of goods and people, large technological "leaps", technological impulses, forecasts of world development, local energy transitions, world industrial revolutions, coal trap.

1. INTRODUCTION

The development of global energy is closely related to the formation of a technological "image" of the economy. Its further transformation as a whole depends on two factors: the speed of the global technological process and the consequences that are expected in the sectors of the economy in connection with its implementation. This process and its consequences are presented on the example of a large-scale sector of the economy - the coal industry. The changes taking place in the global energy sector are subject to a number of laws, the implementation of which is objective in nature, independent of the desires and economic aspirations of many participants in the global, regional and industry markets. Taking these laws into account makes it possible to develop more reliable forecasts of world development.

2. REGULARITY OF INCREASING ENERGY DENSITY

One of the basic patterns observed in the course of world development is the pattern of a constant increase in the energy density of energy sources used in the economy [1, 2].

In this case, the energy density is understood as the amount of energy per unit mass of the fuel used.

Many fuel and energy experts believe that this energy density can be estimated by the caloric equivalent of the fuel used. Energy sources such as firewood, coal, oil, gas, consistently used in the course of the development of civilization, continuously increased the average energy density (caloric equivalent) in the global energy sector (Figure 1).

It should be noted that the further development of global energy, even already in the 21st century, will be associated with the use of energy sources with high and very high levels of caloric equivalents.

3. THE REGULARITY OF THE GLOBAL ENERGY TRANSITION AND ITS FEATURES

Recently, many researchers have been talking about the energy transition, linking it with the use of another new source of energy. This is partly correct, but only partly. The fact is that the energy transition is characterized not only by zones of local manifestation, but also by its global manifestation.

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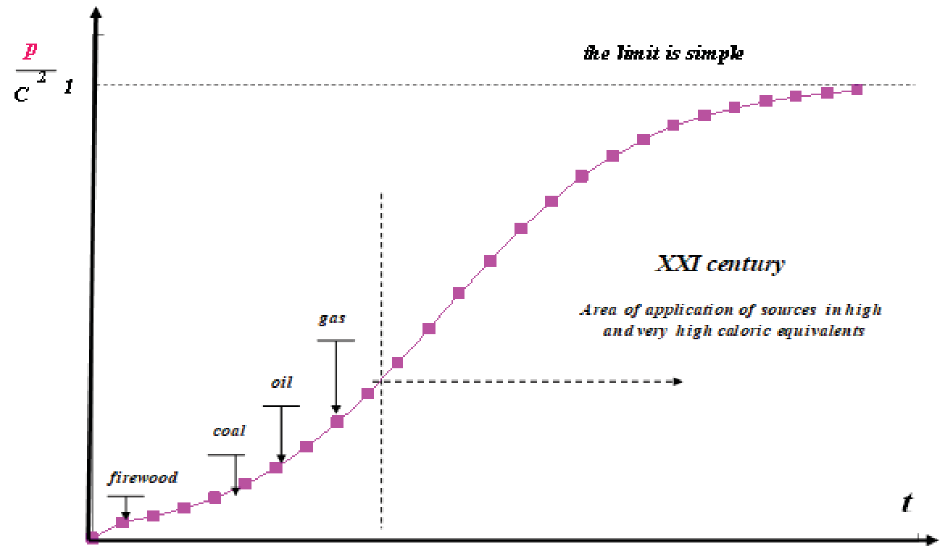

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FIGURE 1. The pattern of increasing energy density (calorie equivalents) of energy sources used

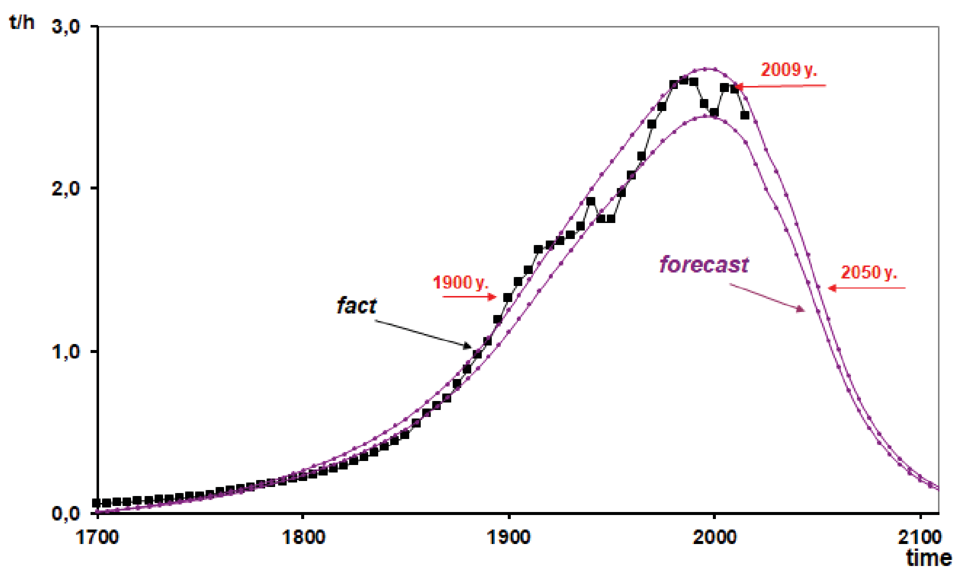

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FIGURE 2. Forecast dynamics of per capita fuel mass consumption

Investigating the dependence of the change in per capita fuel consumption, one can note the achievement of the maximum values of its growth, approximately, in 2008-2009. [1, 2] (Figure 2).

It should be noted that it was during this period that the global financial crisis took place, and the world oil price changed from the trend of constant growth to a downward trend. All this testifies to the fact that changes have taken place in the global energy sector that have significantly influenced the development of the world economy.

The changes that have taken place in the global energy sector are quite dramatic. In fact, they are of a civilizational nature. Indeed, throughout the entire period of development of civilization, there was a constant increase in per capita consumption of fuel mass to the maximum reached in 2008-2009. After this period, the per capita consumption of the mass of fuel began to systematically decrease.

Global energy began to switch to a fundamentally opposite way of development: if earlier the development of civilization was based on the involvement of an increasing amount of fuel mass into economic circulation, then after the period of reaching maximum per capita consumption, its development will be accompanied by savings in the mass of fuel used.

This is a fundamentally different way of developing the global energy and economy. Since this period, the global energy industry has changed the track of its development, in which not the amount of energy involved in the economic turnover, but its efficient use will determine the main vector of the development of the world economy.

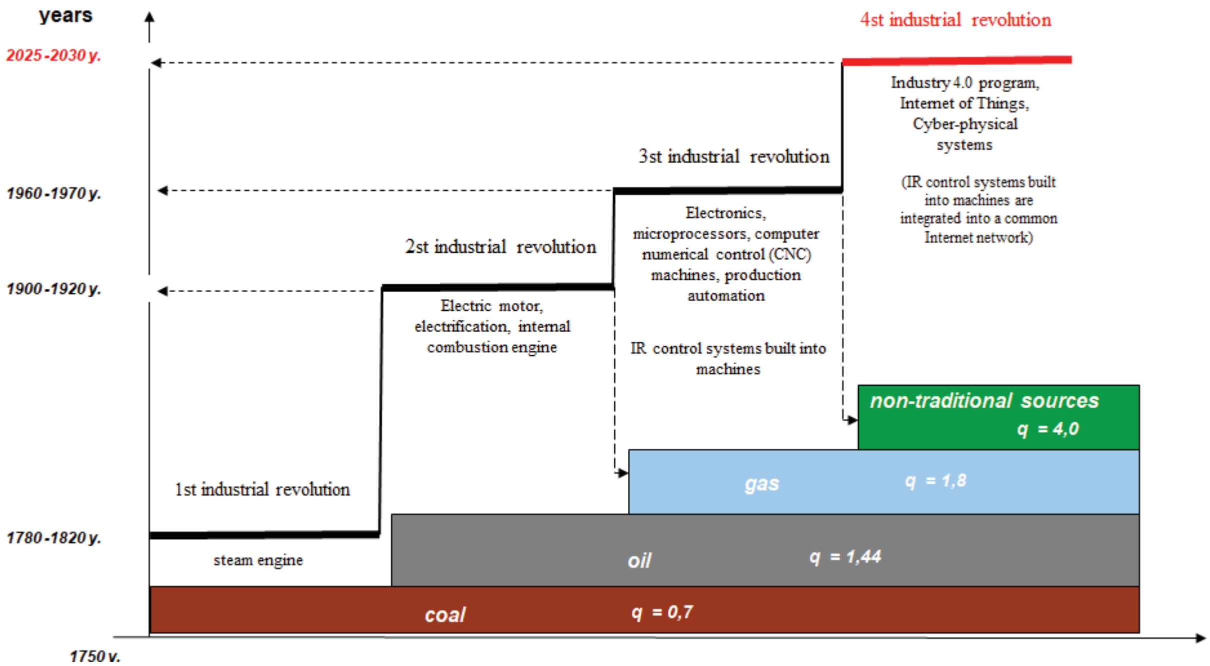
Note that over the past 300 years, per capita energy consumption has increased 6 times, and the calorie equivalent has increased by no more than 2 times. During the past civilization period, Mankind did not really "care" about increasing the caloric equivalent of the fuel used.

The new period of civilizational development, in contrast to the past, will be associated with the use of energy sources with a high level of energy density.

4. LOCAL ENERGY TRANSITIONS AND THEIR IMPACT ON GLOBAL TECHNOLOGICAL DEVELOPMENT

It can be stated that in the world economy, starting from 2008-2009, a global energy transition began, within which local energy transitions will take place, aimed at a gradual increase in the levels of the caloric equivalent of the energy sources used.

Energy, developing in the direction of continuous growth of the energy density (caloric equivalents) of the energy sources used, "pulls" more and more new technologies. In confirmation of this, Figure 3 shows the chronology of the industrial revolutions that have taken place and the world energy stages.



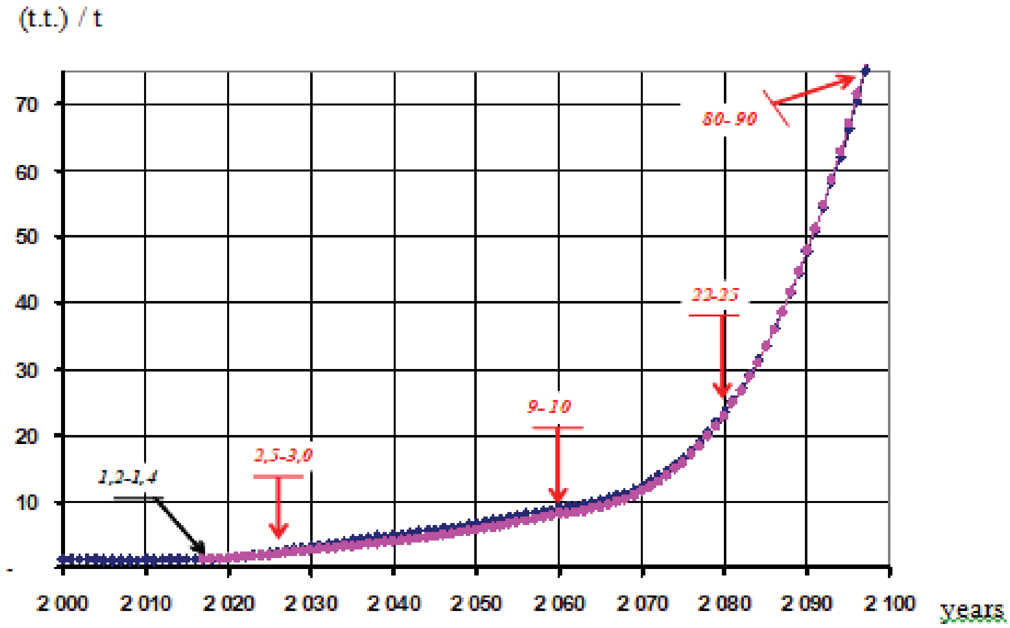
Source: ERI RAS

FIGURE 3. Graph of world industrial revolutions and world energy stages

Each industrial revolution has been accompanied by the preliminary appearance of a new source of energy. So, for example, the 1st industrial revolution was based on the use of coal, the 2nd on the use of oil, and the 3rd is associated with the emergence of a more comfortable source of energy - gas. The 4th industrial revolution, which is based on digitalization, the use of the "Internet of Things", robotic cyber-physical systems, provides for the widespread use of non-traditional energy sources. Moreover, due to the global energy transition, digitalization and robotization began to form a fundamentally different way of technological development of the economy. If earlier there was an increase in labor productivity due to equipping the employee with an increasing number of machines and equipment, that is, labor mechanization was increasing, then the new period is characterized by an increase in the intellectualization of the entire production process due to digitalization and the use of the Internet of Things, turning them into intelligent robotic systems [3].

5. INCREASE IN ENERGY DENSITY AND SPEED OF PRODUCTION PROCESSES

In the course of the study, the author obtained the predicted dynamics of the calorie equivalent in the coming periods of the twenty-first century (Figure 4).



Source: ERI RAS

FIGURE 4. Forecast corridor of the dynamics of energy density (caloric equivalent) in the global energy of the XXI century

At present, the average caloric equivalent in the global energy sector is approximately 1.2 - 1.4 t/t. However, already in 2025-2030. it should increase by 2 times, reaching marks equal to 2.5-3.0 t/t. By 2050-2060 the calorie equivalent is likely to increase by another 3 times in relation to the level of 2025-2030. By the end of the 21st century, however, it can reach levels exceeding 100 t / t.

Returning to the predicted growth of the caloric equivalent in the above periods, it can be noted that neither coal (with its caloric equivalent equal to 0.7 ton / t), nor even oil (with a caloric equivalent of 1.44 ton / t) will be able to provide the stated above increase in energy density (caloric equivalent).

Other energy sources are needed - with a higher energy density [see. 1].

What is the potential energy of the fuel used being realized? The answer is obvious - in the work done by machines and mechanisms used in the economy. The potential energy of the fuel is converted into kinetic energy, providing the required speed of movement and implementation of production operations.

In the process of research, we obtained the dependence of the average speed of movement of goods in the economy on the calorie equivalent of the fuel used:

$$V \approx 93{,}9 * q^2 \text{, km / h} \quad (1)$$

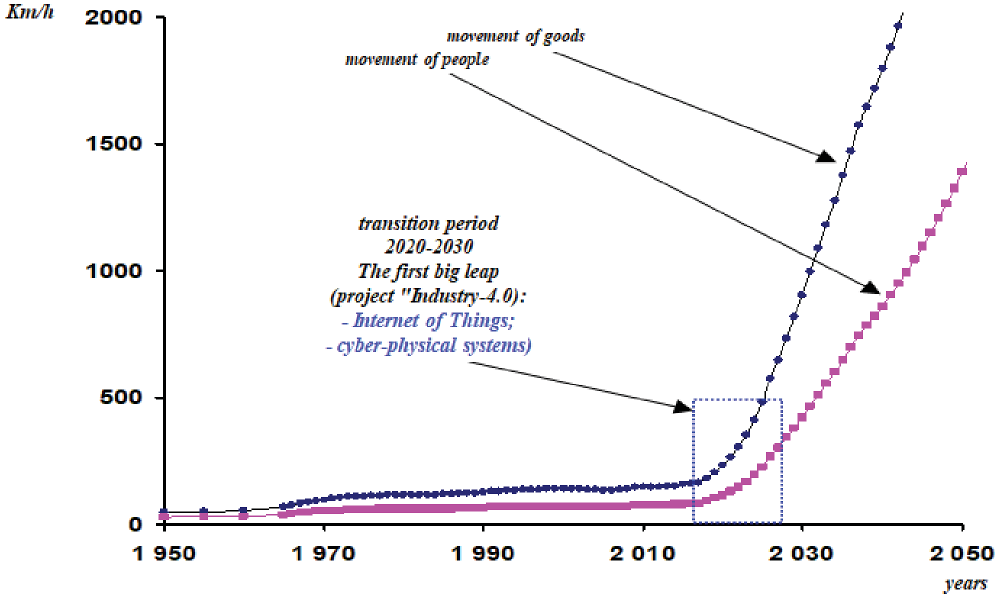
where: q - caloric equivalent, ton / ton.

The presented dependence (1) indicates that it is enough to double the calorie equivalent, and the speed of movement in the economy will increase by almost 4 times. If the intensity of production processes increases by 4 times, then the duration of production operations will be reduced. All this means the possibility of increasing labor productivity by about 3-4 times.

6. GREAT TECHNOLOGICAL "LEAPS" OF THE XXI CENTURY

Estimation of the average speed of movement in the world economy, in fact, makes it possible to assess the level of technological development achieved in the future period.

The above dependence (1) made it possible to estimate the predicted dynamics of the average movement speed achieved in the coming period. Our calculations show that, approximately, in 2025-2030. the average travel speed should sharply increase [see. 1]. This means that during this period a significant increase in labor productivity and the level of technological development should be achieved (Figure 5).



Source: ERI RAS

FIGURE 5. Forecast dynamics of the average speed of movement in the economy for the period up to 2050.

In fact, we are talking about the upcoming technological "leap". Note that many experts associate this period with the 4th industrial revolution, the implementation of which will be accompanied by the implementation of the world project "Industry-4.0" [4, 5]. It is indicative that the leader of the world project "Industry-4.0".

Germany, "realizing" that a technological "leap" cannot be carried out on the basis of the energy density of traditional energy sources, has developed and since July 2020 began to implement an important strategic document "Hydrogen Strategy of the Federal Republic of Germany ".

Note that the use of hydrogen technologies makes it possible to double (in comparison with natural gas) the energy density of the energy sources used.

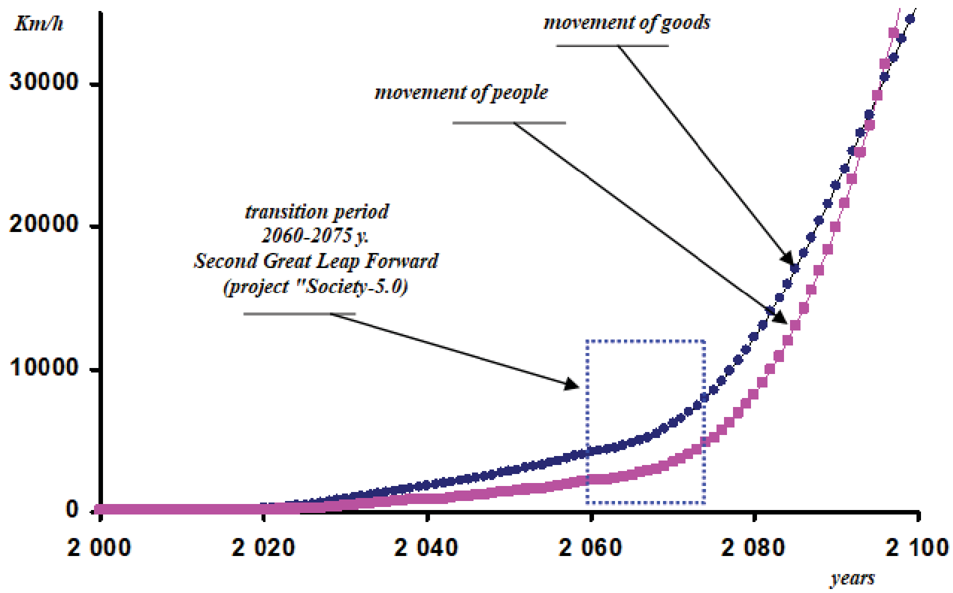
Turning to the analysis of the second period of growth in energy density (caloric equivalent) and, accordingly, an increase in the average speed of movement in the economy in the period 2055-2065, one cannot ignore the possible level of development of artificial intelligence.

This is quite obvious, since the digitalization of robotic systems, the active use of which is planned at the first technological "leap", will be improved by increasing the depth of intellectualization in all spheres of society.

Many experts believe that the existing level of artificial intelligence can be assessed as “weak”. At this level, artificial intelligence can only solve the task, but it is not able to think and make independent decisions.

According to our forecasts, by about 2040, artificial intelligence will reach a “strong” level and, like a Man, will be able not only to search for solutions, but also independently make the most optimal ones.

By 2060, artificial intelligence is likely to reach a "very strong" level, at which it will have abstract thinking, which allows completely, without human participation, to manage complex robotic systems and independently plan the production and economic activities of enterprises. Our calculations have established that it is during this period that the second significant increase in the average speed of movement of goods and people will most likely be achieved [see. 1] (Figure 6).



Source: ERI RAS

FIGURE 6. Forecast assessment of the dynamics of the average speed of movement of goods and people for the period up to 2100.

This means that the period 2055-2065 will be characterized by the second great technological "leap", which provides for an even greater growth of production labor than during the first "leap". Most likely, this great technological "leap" will be associated with the implementation of the world project "Society-5.0", which provides for the deep intellectualization of all spheres of human activity through the use of robotic systems of the 2nd and 3rd generations, independently adopting production and economic decisions, and "smart technologies" that provide self-diagnostics, self-regulation, self-organization of production systems.

Both the first and second large technological "leaps" provide a significant increase in labor productivity in the economy. The use of “smart robotic technologies” confirms the third pattern of global energy development: the growth of labor productivity in the economy is accompanied by the transition to energy sources with a higher energy density.

This means that the higher the rate of transition to more productive technologies, the higher the rate of displacement from the economic turnover of the world economy of traditional sources of energy: coal, oil, gas, which have low values of calorie equivalents.

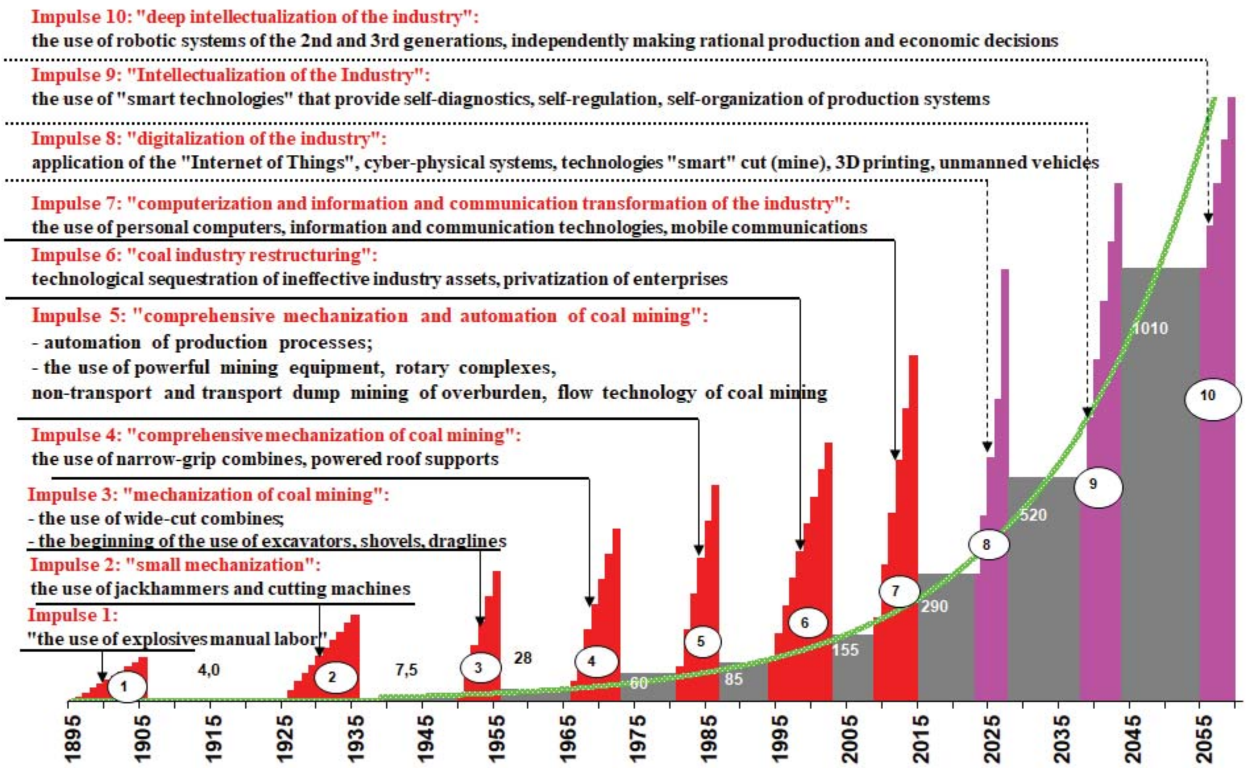
7. PREDICTIONS OF FUTURE TECHNOLOGICAL IMPULSES AND TRANSFORMATIONS

To assess further technological transformations associated with digitalization and robotization of production processes, using the example of the coal industry, an analysis of technological impulses was carried out that ensure an increase in labor productivity.

From the end of the 19th century to the beginning of the 21st century, six technological impulses occurred in the coal industry [6, 7] (Figure 7).

In accordance with the presented classification, these impulses cover the technological development of the industry, ranging from the use of manual labor to the complex mechanization and automation of coal mining, given in the period of the 70s - 80s of the twentieth century.

The restructuring of the coal industry (6th impulse), in fact, summed up the development of technologies that mechanized labor of workers, and sequestered inefficient assets, thus clearing the "space" for the development of fundamentally different technologies based not on the growth of production mechanization, but on information - communication and robotic principles.



Source: ERI RAS

FIGURE 7. Dynamics of technological impulses and labor productivity in the coal industry (2000 = 100%) after their implementation

It is characteristic that many analysts missed the initial period of development of digitalization and robotization of the coal industry. In fact, it began with the implementation of the 7th technological impulse that followed the restructuring of the coal industry. This impulse took place in 2008-2015 and was aimed at computerization and information and communication transformation of the industry. It is associated with the widespread use of personal computers, information and communication technologies, mobile communications, etc. This technological impulse, in fact, prepared the industry for the start of large-scale digitalization and robotization.

The eighth technological impulse in the coal industry, according to our calculations, will manifest itself in the period 2023-2027. This momentum is associated with the ongoing digitalization of enterprises in the industry. During this period, the use of the Internet of Things technologies will begin, the formation of robotic cyber-physical systems, which will allow at the level of individual enterprises to form production systems such as: "smart cut", "smart mine", "smart unmanned transport".

Further development of robotization will be associated with the implementation of the ninth technological impulse. According to our forecasts, it may take place in 2037-2042. This impulse will be directed to the development of intellectualization processes in the coal industry. Intellectualization of its enterprises will significantly expand the possibilities of using "smart" technologies based on the use of processes that provide self-diagnostics, self-regulation, and self-organization of production systems. This will largely lead to a reduction in production costs and to a decrease in the supply price of coal and an increase in labor productivity in the coal industry.

In fact, the eighth and ninth impulses will be associated with the implementation of the first great technological "leap" in the world economy.

8. CARBON TRAP

The tenth technological impulse to be implemented in the coal industry is associated with the depth of its intellectualization. According to our forecasts, it can be implemented in the period 2055-2065. At this time, artificial intelligence will reach a very "strong" level of development. This level of artificial intelligence will allow the coal industry to "enter" the use of robotic systems of the 2nd and 3rd generations, independently making rational production and economic decisions.

The tenth technological impulse is associated with the second great technological leap in the global economy. During the period of its implementation in the coal industry, according to our calculations, there will be another significant increase in labor productivity. On the one hand, the genesis of digitalization and robotization contributes to a significant increase in labor productivity, and on the other hand, the technological development of the world economy is associated with an increase in the energy density (caloric equivalent) of the energy sources used.

Thus, a higher rate of digitalization and robotization, characterized by a significant increase in labor productivity, is ensured by a higher level of caloric equivalent of the energy sources used. The latter leads to a decrease in the use of traditional energy resources.

With the development of robotization, fuel industries fall into a kind of carbon "trap": on the one hand, digitalization and robotization of these industries cannot be avoided, and on the other hand, this will lead to a decrease in the consumption of products produced by these industries.

The formation of a carbon "trap" is, according to our forecasts, the fourth regularity in the development of global energy. Note that, in fact, the ongoing robotization contributes to a faster abandonment of the model of export and raw material development in the economy. A decrease in the consumption of traditional energy resources is likely to lead to a systematic decrease in the average annual levels of the world oil price.

According to our calculations, by about 2040 the price of oil (average annual) may drop to less than 20-25 USD / bar.

9. CONCLUSIONS

Thus, the basic patterns of global energy development lead to the emergence of digitalization and robotization technologies in sectors of the economy, including the coal industry.

In the post-crisis period, under the influence of large technological "leaps" and impulses, further deepening and development of such technologies will take place. This process will objectively “force” the fuel industries to gradually “pull” into the so-called carbon “trap”, as a result of which traditional energy resources (coal, oil and gas) will reduce their consumption in the face of decreasing supply prices. This, in turn, will require, for example, for the coal industry:

- a significant correction of the current, very controversial "Program for the development of the coal industry for the period up to 2035" [8], aimed at achieving unreasonably high volumes of coal production and export, by developing a new Strategy for the period up to 2050, which provides for the definition of a "stress scenario" of a possible decrease in consumption volumes due to the development of digitalization and robotization in the global economy, its decarbonization by 2050 and implementation of hydrogen energy development programs by many countries of the world; special attention should be paid to assessing the export potential of the industry;
- carrying out, within the framework of the stress scenario ", an assessment of the predicted dynamics of the industry average indicators of the efficiency of the coal industry, which will make it possible to divide all enterprises of the industry into two groups:

1) the first group of enterprises capable of achieving indicators exceeding the industry average (this group of enterprises will be able to withstand the forthcoming competition in the "shrinking" foreign market, it will form the basis for the development of the coal industry, and further deep robotization should be envisaged for it);

2) the second group of enterprises, in which it is impossible to achieve the industry average indicators (this group of candidates for a possible systematic "narrowing" of production; for it, within the framework of the 2nd restructuring program of the coal industry, plans should be developed, incl. regional in terms of deep diversification of production and the organization of new jobs outside the sphere of industry competence as "points of growth of the entire economy").

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