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Dynamic balance of natural resource use aimed at national economy`s sustainable development (the case of coal mining adaptive modelling)

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SUMMARY

It has been proposed to improve the coal mining management system in Ukraine applying a bifurcation and adaptation mechanism for the development of natural resource use in Ukraine. The economic and mathematical modelling was used to prove the necessity of taking into account small fluctuations and coking coal and anthracite export-import flows to rise the efficiency of the resource base of Ukraine exploitation. The methods of efficient consideration of the world market price`s environment as a mechanism of own resource base preservation, long-term forecasting of its development parameters and paving the way for safe development of metallurgy and energy production in Ukraine have been argued.

Introduction

Ukraine ranks 7th in the world of proven coal reserves. It has 834 years of coal left at current production level. Never the less, the National Programme for the Mineral Resources Base (MRB) Development of Ukraine by 2030, which takes into account the reproduction of mineral reserves, outlines geological research aimed at coal production growth. Meeting economy's needs for coal resources and their efficient application is one of the important factors to overcome the crisis in Ukraine's economy. That is, anthracite is the only type of energy raw materials, which reserves are potentially sufficient to ensure the country's energy security. At the same time, the metallurgy`s efficiency depends on production capacity of coking coal. The field provides up to 30% of national foreign exchange earnings. That is why there is a need to model and forecast the volume of coal production in Ukraine.

Method

In the analysis, general-scientific methods (analysis and synthesis, induction and deduction) and special methods of phenomena and processes analysis (abstraction, econometric and econometric-mathematical modelling) have been used.

Results

The development of coal mining and related sectors of the national economy can be or crisis or adaptive. Crisis processes correspond to the bifurcation mechanism of complex systems development; adaptive, on the contrary, supports high rates of economic growth. Therefore, the dynamic equilibrium of a complex system could be defined as unstable or stable equilibrium, respectively. Studying non-equilibrium states of open, dissipative, self-organized systems, for example mining industry, Stengers I., Prigogine I. and Moiseev N. concluded that each system in the process of its development could rise the resistance level to environmental impact, and pass through non-equilibrium states, i.e. bifurcation points. System behaviour and development trajectories cannot be forecasted here. One should mention that according to the law of conservation, the development trajectories retain the development trend. Besides, the system acquires more stable structure affected by self-organization processes in non-equilibrium state. The system is developing to increase its stability and accumulate efficiency. After reaching marginal stability, it gets bifurcation state, in which of all possible system states, those that meet the principle of minimum resource dissipation amid their scarcity are realized. A new system structure is formed to preserve the accumulated amount of efficiency being the basis for further development. According to the dynamical systems theory by A.M. Lyapunov and A. Poincaré, their evolution is described by a system of differential equations. This is the approach we have proposed when building economic and mathematical model to describe the cyclical nature of coal mining development, coal production and its use in metallurgy and energy production. In the economic and mathematical model it was assumed that the increment rates of electricity and cast iron production in relation to anthracite and coking coal mining, and anthracite and coke production, respectively, depend only on instantaneous value $N_{1,}$ so they were considered as functions of N_1. This allowed to use linear differential equations:

$$\begin{cases} \frac{dN_1}{dt} = N_1(\varepsilon_1 + \gamma_1 N_2), \\ \frac{dN_2}{dt} = N_2(\varepsilon_2 + \gamma_2 N_1), \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \frac{dN_i}{dt} = N_i(\varepsilon_i + \gamma_i N_{i-1}) \end{cases} \qquad (1)$$

where i – number of subsystems in complex system; N – cast iron production; coking coal mining, coke and semi-coke production (1st model); thermal energy production; anthracite and other coal mining , anthracite production (2nd model); ε – increment rate of the listed values, if there is no correlation with other amounts (coefficient of proportionality, which demonstrates the ratio of mining growth rate $\frac{dN}{dt}$ to N), γ - need increment rate. Taking into consideration that each model has three components, system (1) contains three equations. Further analysis and forecasting will apply the following indicators, namely basic growth rate (n) and mean value (K). Correlation between them is:

$$n = N/K,\ \text{К} = \varepsilon/\gamma,\ \varepsilon = \frac{\ln \frac{N}{N_0}}{t - t_0}.$$

The studied system – coal mining, will be in a steady equilibrium state, if $N_1 = К_1$, where $К_1$ is mean value for the period. The system stability is associated with its tendency towards equilibrium. The equilibrium is the state of maximum efficiency. However, on the one hand, a coal mining as a complex system cannot reach full equilibrium because there are industries, which differently process and consume its products, and have dynamic interaction with each other. On the other hand, the system efficiency is being accumulated in the process of system`s development. After reaching maximum for a certain development period (Pareto efficiency), there is redistribution to the disorganization of a new state. Efficiency or the ratio of production and consumption indicators change from maximum to minimum. The process of economic system efficiency accumulation has its own limits. It ends with a crisis. The state of dynamic equilibrium between marginal maximum and minimum values is stable. When some equilibrium is reached, the system tends to leave it. Thus, a stable system fluctuates around the equilibrium state (passes from one equilibrium to another), i.e. it is in a dynamic equilibrium, which ensures its development. In our opinion, one can describe coal mining`s state of dynamic equilibrium taking into consideration small fluctuations.

Our research has shown that there is correlation between the growth rates of anthracite mining, other coal / anthracite production, exports, imports of coal, anthracite and heat production during 2008-2017s. Correlations are cyclic, indicating the presence of small cycles lasting 3-4 years. Correlation analysis has shown a high level of relationship between anthracite mining, imports and its use in energy production. Moreover, no lags have been found out between those resource flows.

Thus, to model the parameters of the equilibrium development of coal mining in Ukraine, we studied small fluctuations in the development of anthracite mining (v_1) in relation to heat production (v) taking into account import flows (v_2). To do this, we use the system of equations (1). Small fluctuations also exist when the value of n is close to 1. Let us consider the correlation between fluctuations in anthracite mining and its import. Let $v_1 = n_1 - 1$ and $v_2 = n_2 - 1$, then neglecting the product $v_1 v_2$, we obtain the solution of system (1):

$$\begin{cases} v_1 = A\sqrt{\varepsilon_1}\cos(\sqrt{\varepsilon_1 \varepsilon_2}\ t + a) \\ v_2 = A\sqrt{\varepsilon_2}\sin(\sqrt{\varepsilon_1 \varepsilon_2}\ t + a), \end{cases} \qquad (2)$$

where A and a – constants.

Similarly, the equation describing fluctuations in heat production could be added to the system. Figure 1 shows graphical interpretation of the functions $v_1(t)$, $v_2(t)$ and $v_3(t)$ with the subsequent approximation and curves smoothing by polynomial functions.

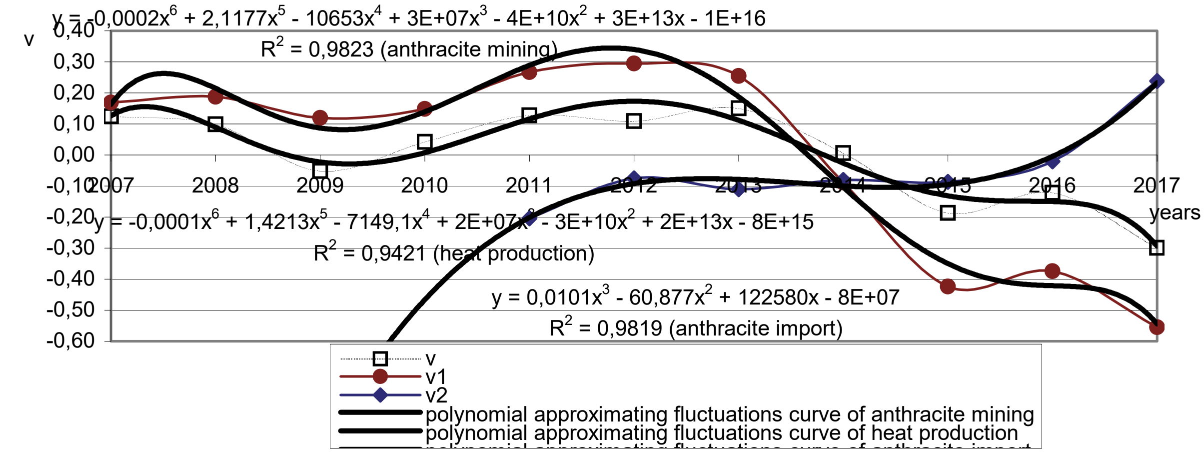

***Figure 1** Dynamics of small fluctuations of heat engineering development and thermal coal production taking into account anthracite imported flows during 2007-2017s*

Thus, the obtained results indicate fluctuations' dependence on heat engineering development, anthracite production and import during 2007 – 2014s. Due to a significant reduction (almost 27%) in domestic thermal coal production, energy sector needs have been offset by anthracite import flows since 2014. Therefore, 2014 should be considered as bifurcation point for anthracite mining in

Ukraine. In the future, aiming at shifting system to a qualitatively new state without efficiency loss, there is a need for mutual regulation of heat engineering development to meet its needs in anthracite through import flows.

We have studied the correlation between coking coal mining and production growth rates, coke production, export and import, and cast iron production during 2008-2017s. It has been found out that during 2008 – 2013s the dynamics of coking coal mining did not coincide with the corresponding indicators of coal mining, coke and semi-coke production and metallurgical industry (cast iron production). This one can explain by the extraction losses. Total coking coal production rose until 2013 and significantly dropped since 2015. The rest of indicators changed cyclically. A noticeable decline in production in 2015 one can explain by the hostilities in Donbass. As a result, some mines found themselves in an uncontrolled territory. During the study period, the dynamics of coke exports completely coincided with its production trends. As for the imports, Ukraine imported coke when its own production was growing until 2011. The trend has changed since 2012. Thus, production downturn was accompanied by higher imports. The cycle is identical to the anthracite case and lasts three years. Correlation analysis has shown a high correlation between coke mining and import, and its use in metallurgy. Besides, the lags between the resource flows have been identified.

Thus, there is a need to consider lags in small fluctuations modelling for metallurgy development (cast iron production) and coking coal mining, export and import. The model for the correlation between metallurgy and coking coal mining is described by equations (1). Considering time lags, the system of differential equations (2) must be replaced by a system of integro-differential equations (3):

$$\begin{cases} \frac{dN_1}{dt} = [\, \varepsilon_1 - \gamma_1 N_2(t) + \int_{t-T_0}^{t} F_1(t-\tau) N_2(\tau) d\tau \,]\, N_1(t) \\ \frac{dN_2}{dt} = -\, [\, \varepsilon_2 - \gamma_2 N_1(t) + \int_{t-T_0}^{t} F_2(t-\tau) N_1(\tau) d\tau \,]\, N_2(t), \end{cases} \quad (3)$$

where N_1 and N_2 – total production in metallurgy and coking coal mining, respectively, $F_1(t-\tau)$ and $F_2(t-\tau)$ – non-negative continuous functions, taking into account the lag in industries development, T_0 – lag period.

Let us study small fluctuations for the case of the distributed time lag.

Similar to the previous case without lag, let us suppose that $q_1 = n_1 - 1$ и $q_2 = n_2 - 1$, where $n_1 = \frac{N_1}{K_1}$ and $n_2 = \frac{N_2}{K_2}$; $N_1 = \frac{\varepsilon_2}{\gamma_2 - \Gamma_2}$ and $N_2 = \frac{\varepsilon_1}{\gamma_1 - \Gamma_1}$; $\Gamma_1 = \int_0^{T_0} F_1(\tau) d\tau$ and $\Gamma_2 = \int_0^{T_0} F_2(\tau) d\tau$.

Then q_1 and q_2 are defined from the system (4):

$$\begin{cases} Q_1 = \frac{dq_1}{dt} + \alpha_1 q_2 + \int_0^{T_0} F_1(\tau) q_2(t-\tau) d\tau, \\ Q_2 = \frac{dq_2}{dt} + \alpha_2 q_1 + \int_0^{T_0} F_2(\tau) q_1(t-\tau) d\tau, \end{cases} \quad (4)$$

where Q_1 and Q_2 – externalities, $Q = aq'' + bq$.

Coking coal export and import one can consider as the externalities.

Figure 2 shows graphical interpretation of functions $q(t)$ and $q_1(t)$ for cast iron production (metallurgy development) and coking coal mining, as well as for the model with the time lag.

Considering the time lag between coking coal export-import flows and cast iron production, and coking coal mining in Ukraine, the system of integro-differential equations has been applied. It has been followed by graphical interpretation of the functions $q_2(t)$ and $q_3(t)$ for coal imports and exports, respectively (Figure 3).

The obtained results reveal that fluctuations in metallurgy development and coking coal mining, and heat engineering development and anthracite mining are similar. The limits are of 40%. Fluctuations of anthracite import flows and coking coal export-import flows are much more significant. This can be explained by the world market`s price environment. Therefore, we consider it as a balanced approach, when Ukraine during 2017-2013s had reserves amid falling world prices on coking coal. It also positively effected the resource component of the coal industry, i.e. a frugal attitude to own resources.

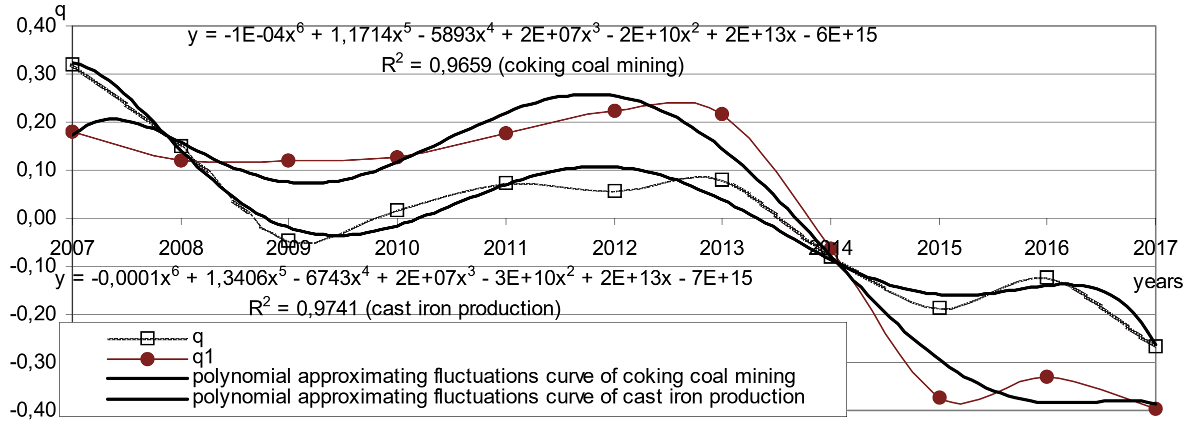

Figure 2 *Dynamics of small fluctuations in metallurgy, coking coal mining development, taking into account anthracite import flows during 2007-2017s*

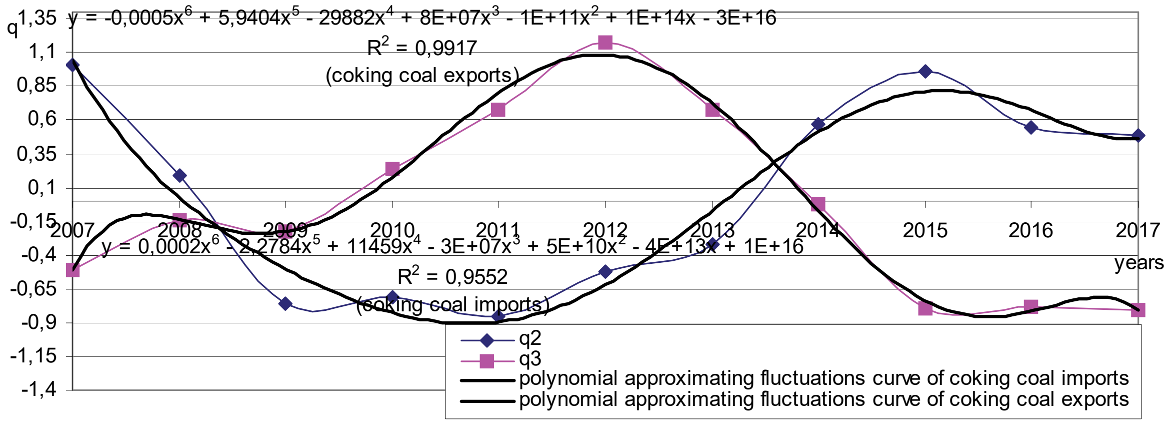

Figure 3 *Dynamics of small fluctuations of coking coal export-import flows during 2007-2017s*

The bifurcation point for coking coal mining, export and import is also considered to be in 2014. The reason is the Donbass armed conflict, which prohibited deposits development in the uncontrolled territories of Ukraine. In the context of paving the way for domestic metallurgy`s safe development, one should consider more important fluctuations (the level of 80%) of import flows in the long-term forecasting of domestic coal mining.

Research of problems of extractive branch is carried out by Kruglov, O., Menshov, O., Kuderavets, R., Chobotok, I., Kruglov, O., (Kruglov and Menshov, 2017; Menshov et al., 2014).

Conclusions. In order to determine the priorities of efficient coal industry management in Ukraine, the system parameters of the correlation between coal mining, consumption, export and import in Ukraine have been modelled in the study. It has been proved that to form a system of long-term forecasting, it is expedient to take into account small fluctuations and determine bifurcation points. These provide the framework for stable development of both mining and related industries – metallurgy and energy production. It has been found out that there are opportunities to effectively use world market`s price environment as a mechanism to preserve own resource base and pave the way for the safe development of domestic metallurgy and energy production.

Reference

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