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2.7 Prognostic model of industry sustainable development (the example of coal mining)

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Total resources of coal in Ukraine are 112,3 billion tonnes, proved coal reserves – 51,9 billion tonnes, including 17,1 billion tonnes of coking coal (30,5 %) and 7,6 billion tonnes of anthracite (13,5 %). Reserves of coking coal and anthracite amount to 31,5 % and 14,3 % of total resources of coal in Ukraine. However, there is a need to develop system of rational treatment for this important mineral. Coal industry is one of the basic sectors of the national economy. It is also the key to the national energy security. Armed hostilities in the East of Ukraine which began in 2014 led to the destruction of the infrastructure, damage and destruction of coal mines, so domestic coal sector is in the clutch. Today, the coal deficit in Ukraine, offset by forced imports, is 27%. That is why there is a need to build system for

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

The model was verified on the basis of official statistics on coking coal, anthracite and other coal mining data disseminated by the State Scientific Geological Fund of Ukraine; on coke, semi-coke and anthracite production; cast iron and thermal energy production data presented by the State Statistics Service of Ukraine («Statistical Yearbook of Ukraine»)

Figures 1-3 illustrate calculations' results for the 1st model: cast iron production, coking coal mining, coke and semi-coke production.

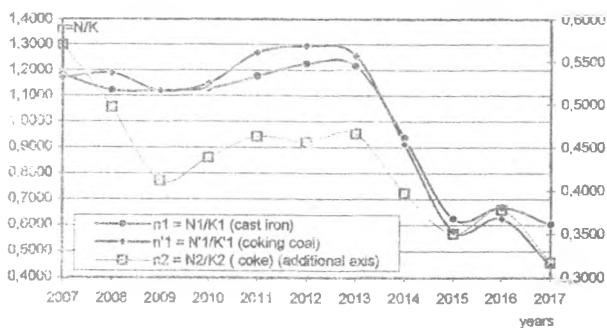


Fig. 1 Dynamics of basic cast iron production growth rates, coking coal mining, coke and semi-coke production during 2007-2017.

Fig.1 shows basic growth rates. Cast iron increment rates $\varepsilon_1(t)$, coking coal mining $\varepsilon'_1(t)$ coke and semi-coke production $\varepsilon_2(t)$. Dependencies of increment rates $\varepsilon_1(t)$, $\varepsilon'_1(t)$ i $\varepsilon_2(t)$ characterize each models' value autonomously (Fig. 2).

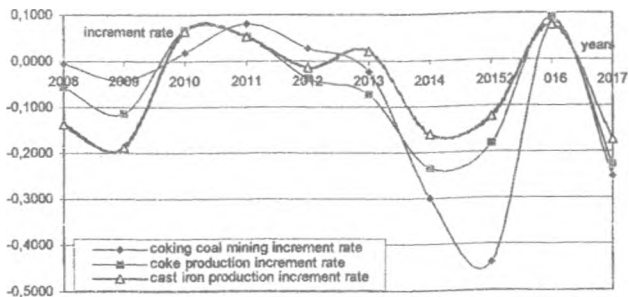


Fig. 2 Dynamics of increment rates of coking coal mining, coke and semi-coke production, cast iron production during 2007-2017 without correlation.

Solution of the system of equations (1) reveals the dependence of the increment rate of coking coal mining $\lambda_1'(t) = \varepsilon_1(t) + \gamma_1'(t) N_2(t)$, coke and semi-coke production's increment rate depending on coking coal mining $\lambda_2'(t) = \varepsilon_2(t) + \gamma_2'(t) N_1(t)$, cast iron increment rate $\lambda_1(t) = \varepsilon_1(t) + \gamma_1(t) N_2(t)$, coke and semi-coke production's increment rate depending on cast iron production $\lambda_2(t) = \varepsilon_2(t) + \gamma_2(t) N_1(t)$ if there is correlation between indices (Fig.3).

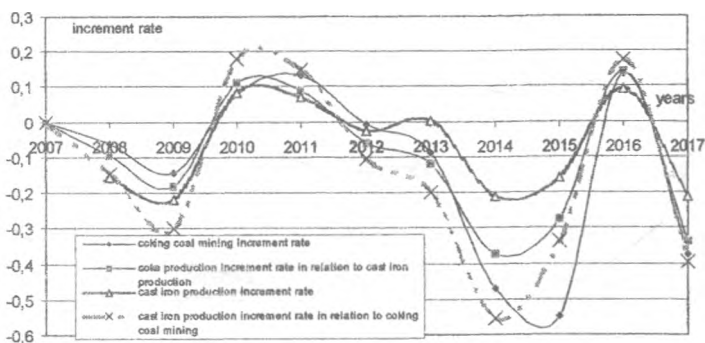


Fig. 3 Dynamics of increment rates of coking coal mining, cast iron production, coke and semi-coke production in relation to cast iron production and cast iron production in relation to coking coal mining during 2007-2017 with correlation.

Thus, the proposed model allows to forecast coking coal mining correlating to coke and semi-coke production and metallurgical industry demand (cast iron production), taking into account its cyclical development.

Figures 4-6 give information about calculations' results for the 2nd model: thermal energy production; anthracite and other coal mining, anthracite production.

Fig.4 illustrates basic growth rates. Fig.5 shows increment rates of thermal energy production $\varepsilon_1(t)$, anthracite and other coal mining $\varepsilon'_1(t)$ and anthracite production $\varepsilon_2(t)$. Dependencies of increment rates $\varepsilon_1(t)$, $\varepsilon'_1(t)$ i $\varepsilon_2(t)$ characterize each index's dynamics autonomously.

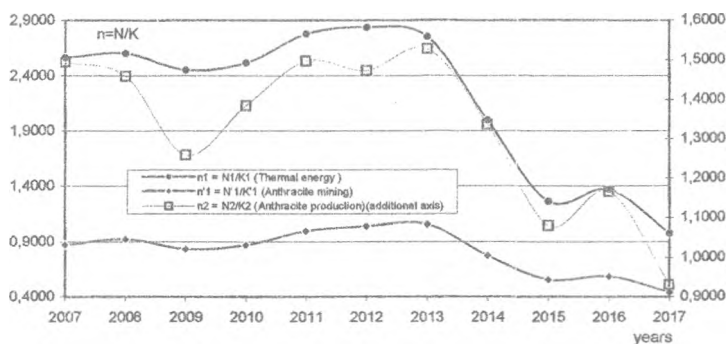


Fig. 4 Dynamics of basic thermal energy production growth rates, anthracite and other coal mining, anthracite production during 2007-2017

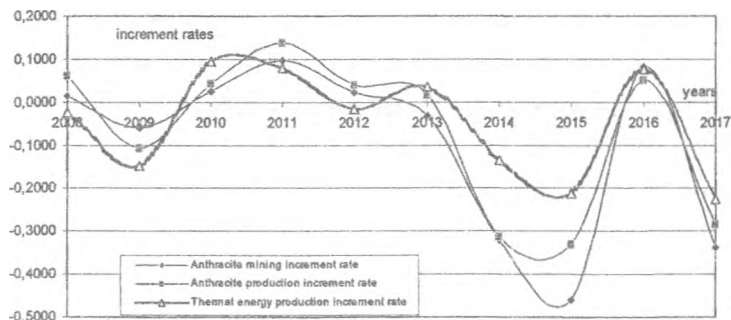


Fig. 5 Dynamics of increment rates of anthracite and other coal mining, production and thermal energy production during 2007-2017 without correlation.

Solution of the system of equations (1) makes it possible to find out correlation between anthracite and other hard coal mining's increment rate, anthracite and other hard coal production's increment rate depending on anthracite and other hard coal mining, thermal energy production's increment rate, anthracite and other hard coal production's increment rate depending on thermal energy production, if there is correlation between indices (Fig.4).

With this result, the proposed model allows to predict anthracite and other coal production, depending on their and thermal energy production, taking into account the cyclical nature of power industry development.

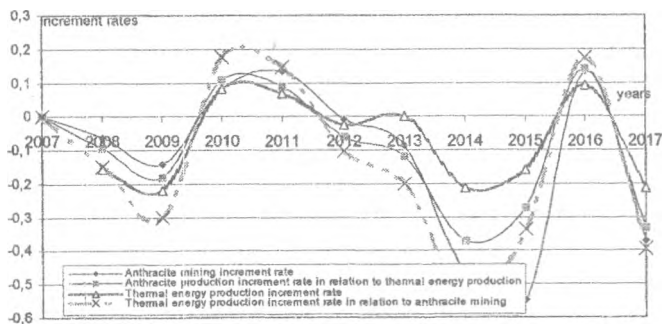


Fig. 6 Dynamics of increment rates of coal, coking coal, anthracite and other coal mining during 2007-2017 if correlated to extraction.

The study of correlation between coking coal mining and production growth rates, coke production, export and import of coke, cast iron production during 2008–2017s has been carried out. The results are presented in Fig.7.

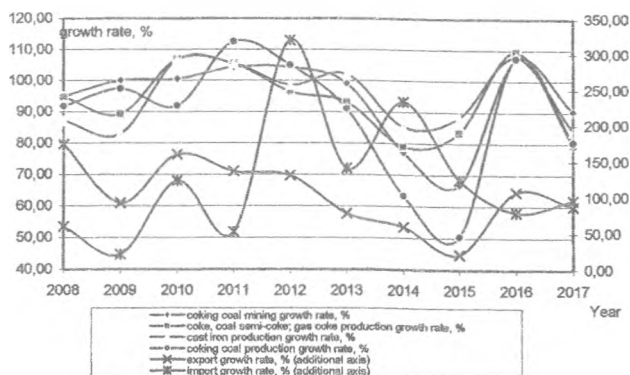


Fig. 7 Dynamics of coking coal mining and production growth rates, coke production, coke exports and imports, cast iron production during 2008 – 2017.

During 2008 – 2013s the dynamics of coking coal mining did not correspond with the relative indices of coal, coke, coal semi-coke production and metallurgy (cast iron production). The discrepancy in the dynamics of mining and production of coal can be explained by the different level of its losses in the process of mining.

Coking coal production increased by 2013, but other indices changed on a periodic basis. The significant drop in production in 2015 can be explained by the beginning of armed hostilities in Donbass, as a result part of mines came to be in temporarily uncontrolled territories. The dynamics of coke production since 2013 coincides with the dynamics of coal production. During the reviewed period, the dynamics of exports of coke were fully consistent with trends in coke production. By 2011 Ukraine imported coke during the period, when domestic coal production grew. Since 2011 the pattern has changed, import rose when production declined. Since 2013, all the named indices fit the trend – cyclical, as the small cycle period is three years.

One to one correlation coefficient was used to identify relationship between coking coal mining, coke production, its export and import. The function characterizes density of connections between each element of time series of

dependent (resultant) y_t and explanatory x_t variables' values relatively shifted to one time lag τ . One to one correlation coefficient is determined by the formula:

$$r_{\tau} = \frac{(n-\tau) \sum_{t=1}^{n-\tau} y_t x_{t-\tau} - \sum_{t=1}^{n-\tau} y_t \sum_{t=1}^{n-\tau} x_{t-\tau}}{\sqrt{[(n-\tau) \sum_{t=1}^{n-\tau} y_t^2 - (\sum_{t=1}^{n-\tau} y_t)^2][(n-\tau) \sum_{t=1}^{n-\tau} x_{t-\tau}^2 - (\sum_{t=1}^{n-\tau} x_{t-\tau})^2]}} \quad (2)$$

where y_t and x_t – elements of vector of dependent (resultant) and explanatory variables relatively shifted to one time lag τ ; n – number of quantitative r_{τ} values.

Calculations are presented graphically in Figure 8.

As we can see, the process of coke production and its export has the highest level of interconnection. Processes of coking coal production, coke production and its application in metallurgical production are characterized by almost the same interconnection level. The correlation between import of coke and its production is low, but the level has increased in recent years.

To specify export-import transactions' peculiarities we compared coke and semi-coke exports and imports growth rates; as well as of retort carbon's (code 2704 UCGEED) and corresponding price indexes. The obtained results are presented in Fig. 9.

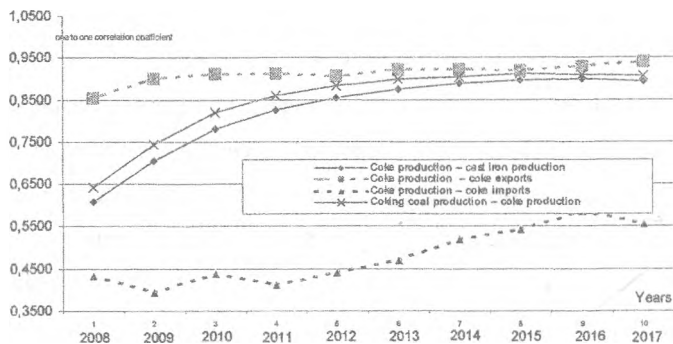


Fig. 8 One to one correlation functions for coking coal mining, coke production, exports, imports and application in metallurgy.

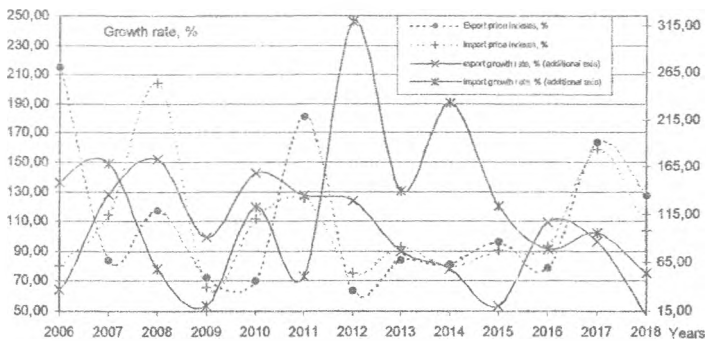


Fig. 9 Dynamics of coke and semi-coke exports and imports growth rates; retort carbon (code 2704 UCGEED) and corresponding price indexes during 2006 – 2017.

The analysis of Figure 8 shows that the frequency of export and import prices' growth rate changes coincides. Thus, we have small cycles lasting 3-4 years. Comparison of import growth rates and corresponding price growth rates proves that these indices change in counter-phase, that is, import prices increase, if imports decrease and vice versa. Interdependence between export prices and export reveals matching trends, i.e. export prices go up with export volumes, except the period of 2013 – 2015s, which is explained by the production drop as a result of armed hostilities in Donetsk and Luhansk regions.

Thus, coking coal imports are significantly dependent on price trends and are almost unrelated to the needs of Ukraine's metallurgical sector. Therefore, in our opinion, management system of the country's coking coal potential should include balanced flows of coal mining, coke and semi-coke production depending on the needs of national metallurgical sector. Taking into account cyclical nature of metallurgical sector development, coking coal mining and coke, semi-coke production have to be cyclic too. The small cycles' period is 3-4 years.

Let us make similar assessment of steam coal – anthracite. Analysis' results are shown in Fig.10. As we can see, there is correlation between anthracite mining growth rates, other coal / anthracite production, coal exports and imports, anthracite (code 2701 UCGEED) and thermal energy production during 2008–2017s.

Dependencies have periodic nature, indicating small cycles lasting 3-4 years. 2017 was the exception for exports and imports.

Figure 11 illustrates the results of correlation analysis on anthracite mining and production, exports and imports, its application in the process of thermal energy production. As we can observe, unlike the situation with coking coal, there is high level of correlation between the analyzed values regarding anthracite. Besides, since 2014, correlation between production and exports has become even more significant.

We will analyze the import growth rates and corresponding rates and prices (Fig. 12). Exports and imports growth rates are identical as the same are price indexes. The trend for imports is economically justified, as when import prices drop down, its volume goes up. Application of the same approach for exports is not economically justified, because it brings losses. The situation has changed since 2015, both export and import prices, as well as volumes began to rise. We consider, that the increase in anthracite imports is consequence of lower production caused by the armed hostilities in Donetsk and Luhansk regions, where most of the mines are concentrated. In the situation, higher exports of the deficit resource having strategic importance for the national energy security may be unjustified.

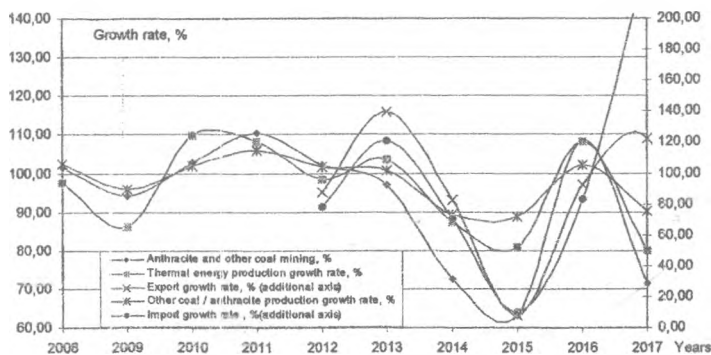


Fig. 10 Dynamics of anthracite mining, other coal / anthracite production, coal exports and imports, anthracite (code 2701 UCGEED) and thermal energy production during 2008 – 2017

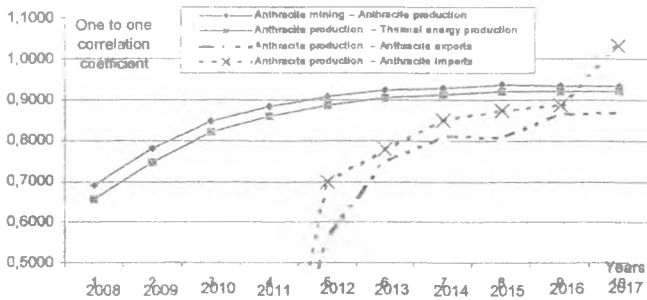


Fig. 11 Functions of one to one correlation for anthracite mining and production, exports and imports, its application for thermal energy production.

National coking coal sustainability managerial model for balancing flows of coal and semi-coal mining depending on metallurgy needs (cast iron production) has been proposed. The model of sustainable anthracite and other coal mining management for balancing coal mining and production depending on electric power energy needs (thermal energy production). The correctness and adequacy of the developed models' application is confirmed by official statistics.

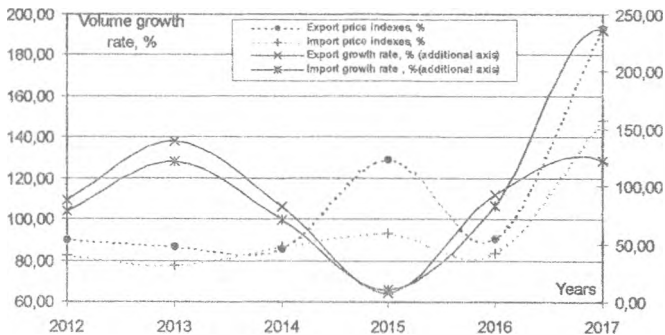


Fig. 12 Dynamics of coal exports, imports growth rates, anthracite (code 2701 UCGEED) and corresponding price indexes during 2012 – 2017

Thus, it is possible to solve the problem of systematic rational management of the country's coal resources by balancing coal mining and its consumption in

metallurgy and energy. In order to take into account cyclical nature of economic processes when planning and forecasting coal mining and production in Ukraine, it is proposed to use a multifactor economic and mathematical model for predicting the development of complex systems. The application of the proposed model will allow to form complex of managerial decisions and project proposals for ensuring mining industry's sustainable development, taking into account strict requirements for environmental safety of the entire product life cycle and territories balanced development where mineral extraction, in particular, coal mining is carried out. Current and strategic tasks of rational coal mining can be solved only by taking into account alternative resource strategies and forecasting industry's market needs for the mid- and long term.

The mechanism for Ukrainian coal mining industry's sustainable development management has been formed as a result of the study. It has been proved that balancing mining, production of coal raw materials and their subsequent use in the production processes are the ways to ensure rational use of coal resources of Ukraine. The processes for coking coal is metal production, and for anthracite - thermal energy production. Relationship between growth rates of coking coal mining and production, coke mining, exports and imports of coke and ironmaking during 2008-2017s have been studied. It has been demonstrated that imports of coking coal essentially depends on the market pricing and has little to do with the needs of the metallurgical industry of Ukraine. It has been shown that the system for rational use of coking coal's capacity in Ukraine should include balancing flows of coal mining, coke and semi-coke mining according to the needs of national metallurgical industry, taking into account cyclical nature of its development. The necessity of coordinating the volumes of anthracite extraction, production and consumption and taking into account short cycles of heat power development has been defined.

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