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RESILIENCE OF THE GLOBAL COAL SECTOR UNDER EXOGENOUS ECONOMIC SHOCKS

This paper presents the research and quantitation estimation of influence exerted by different factors on consumption of primary energy sources. The authors propose a functional dependence between the factors of economy, demography and resources, which describes consumption of primary energy sources in the developed and developing countries. The base research method is the Logarithmic Mean Divisia Index (LMDI). As distinct from the other indices, LMDI is free from the problem of indecomposable remainder and is applicable to multi-factor models. Using this methodical approach, the authors show that the major energy source having the highest influence on energy consumption is coal in the developed countries and alternative (non-fossil) energy sources in the developing countries. The researchers draw the inference on instability of the coal sector in the period of 1995–2020 and define some ways to stabilizing the situation both in the industry and in the coal mining regions.

***Keywords:** Energy transition, coal sector, stress resilience, LMDI method, patent analytics*
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Introduction

So far civilization developed conjointly with an unswerving and extensive growth of production of energy resources, and conventional hydrocarbons (coal, oil and natural gas) provided more than 80% of global energy consumption. The current depletion of the conventional energy resources, reduction in the energy consumption, drop and volatility of the demand and price of the conventional energy sources, accelerated energy transition accompanied by an increase in renewable energy sources, as well as the global economic uncertainty as a result of the Covid-19 pandemic and a new geopolitical situation makes the energy resources-producing industry particularly vulnerable and enforces novel, intense, adaptive and flexible development model.

Although the world's second largest energy source, coal experiences reducing consumption since 2004 in view of transition to eco-friendly economy and to reduction in greenhouse gas emissions. In 2020 the world coal consumption decreased by 7%. The policy of responsible investment (ESG) makes business to reject investment in coal mining and preparation projects. Russia is faced with these problems too. In the last 15 years, the Russian coal industry demonstrates extreme volatility and has an uncertain future. Aside from the pressure of altered geotechnical conditions in production of energy resources, the industry loses its competitive ability because of the Paris Agreement, decarbonization and boom in energy transition [1–5]. In view of the global trends, the Russian coal industry is dramatically vulnerable, while the 2022 foreign policy crisis and sanctions make the growth prospects yet more vague.

There are two potential scenarios of advancement in the coal industry on a global and national scale. The first scenario is reduction in coal production, rejection of coal-fired generation and setting of high cross-border taxes for coal use in production. The second scenario is competitive recovery of the industry thanks to intense development and stress resilience. The coal industry is still a backbone in the Russian economy, and closure of coal mines will bring inevitable social, environmental and economic tensions both in the whole country and in individual coal-mining regions [6, 7]. Preservation of competitive ability of the industry, based on intense development and stress resilience is a critical strategic challenge [8, 9]. Accordingly, the stress resilience analysis of the industry is an urgent theoretical task.

This paper offers an estimate of impact of different factors on the consumption of fossil and renewable energy sources in the mature economies and less developed countries. This approach allows revealing specifics of the coal industry development in different countries at different times, including exogenous shocks.

Methods and data

There exist many methods to evaluate the influence exerted by some factor on the dynamics of an aggregative index: the factor decomposition analyses. The main methods are the Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA) [10].

In this study, we have chosen the Logarithmic Mean Divisia Index (LMDI) as the most widely used index as it is free from the problem of indecomposable remainder and is applicable to both two-factor and multi-factor models as against the Laspeyres index, Paasche index and Fisher index.

LMDI represents a weighted sum of logarithmic growth rates, with weights being components in the total cost in the form of a linear integral. Regarding advantages over other approaches, this method, solely, offers a symmetrical and additive index of relative change, which allows eliminating a remainder and greatly simplifies application. There are additive and multiplicative LMDI for the analysis of absolute and relative changes, respectively. The scope of this study encompasses absolute changes [11].

The index decomposition analysis was put forward in the second half of the 1970s to assess influence of industry transformation on energy consumption. Later on, being more convenient as against structural decomposition, it was addressed in policy making in other areas of economy [12]. To date the index decomposition analysis finds application in five major spheres:

1) Energy demand and supply;
2) Emission of power industry-related gases;
3) Material flows and dematerialization;
4) National monitoring of energy efficiency trends;
5) International comparative research.

The algorithm constructed for using the specified method includes:

1. Identification of influences on energy consumption dynamics.

Based on the review of the related topic research [13–17], the authors distinguish 4 mainframe factors which influence the change in energy consumption (**Table 1**).

2. Data capture.

The data required for the analysis are collected from the website of the World Bank and British Petroleum over the period of 1990–2020 for two groups of countries: members of the Organization for Economic Co-Operation and Development OECD (37 countries) and nonmembers of OECD (41 countries) (**Table 2**).

Factors:

1) Population;

Table 1. Factors that influence energy consumption

Factor	Formula
Energy/output ratio	E_j/GDP_j
GDP per capita	GDP_j/P_j
Population	P_j
Ratio of certain kind of energy in total consumption	E_{ij}/E_j

Source: compiled by the authors

Tables 2. Countries grouped in conformity with economic development

Developed countries	Developing countries
Australia, Austria, Belgium, Canada, Chile, the Check Republic, Columbia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States	Algeria, Argentina, Azerbaijan, Bangladesh, Belarus, Brazil, Bulgaria, China, Croatia, Cyprus, Ecuador, Egypt, Hong Kong, India, Indonesia, Iran, Iraq, Kazakhstan, Kuwait, Macedonia, Malaysia, Morocco, Oman, Pakistan, Peru, Philippines, Qatar, Romania, Russia, Saudi Arabia, Singapore, Sri-Lanka, South Africa, Thailand, Trinidad and Tobago, Turkmenistan, Ukraine, United Arab Emirates, Uzbekistan, Venezuela, and Vietnam

Source: compiled by the authors

2) Energy consumption in exajoules;
3) PPP-based GDP at 2017 values;
4) Oil consumption;
5) Gas consumption;
6) Coal consumption;
7) Consumption of nonconventional (non-fossil) energy sources
3. LMDI-based modeling of energy consumption.

The formula to assess influences of the above-listed factors on energy consumption in a country is given by:

$$E_j = \sum_i \frac{E_{ij}}{E_j} \cdot \frac{E_j}{GPD_j} \cdot \frac{GDP_j}{P_j} \cdot P_j = SE_j \cdot EI_j \cdot ES_j \cdot P_j, \qquad (1)$$

where E_j is the energy consumption in a j-th country; E_{ij} is the consumption of an i-th energy source in the j-th country; GDP_j is GDP of the j-th country; P_j is the population of the j-th country; $SE_j = E_{ij}/E_j$ is the ratio of the i-th source energy consumption in the total energy consumption in the j-th country; $E_{Ij} = E_j/GDP_j$ is the energy/output ratio in the j-th country; $ES_j = GDP_j/P_j$ is the specific GDP in the j-th country.

4. Estimation of influence of factors on energy consumption.

The influence of factors is calculated for each of the test 78 developed and developing countries in the test period of time (1990–2020).

Decomposition of energy consumption using the proposed model determines contribution of all selected factors: $\Delta E_i(SE_i)$—effect of change in the energy source ratio, $\Delta E_i(E_{Ii})$—effect of change in the energy/output ratio, $\Delta E_i(ES_i)$—effect of change in the economic structure and $\Delta E_i(P)$—effect of change in the population:

$$\Delta E_j = E_j^t - E_j^{t-1} = \Delta E_j(SE_j) + \Delta E_j(EI_j) + \Delta E_j(ES_j) + \Delta E_j(P_j). \qquad (2)$$

The authors obtained the wanted estimate using LMDI in terms of the influence of an i-th source energy ratio in the total consumption the other factors being unchanged:

$$\Delta E_i(SE_i) = \frac{E_i^t - E_i^{t-1}}{\ln(E_i^t) - \ln(E_i^{t-1})} \cdot \ln \frac{SE_i^t}{SE_i^{t-1}}, \qquad (3)$$

$$\Delta E_i(EI_i) = \frac{E_i^t - E_i^{t-1}}{\ln(E_i^t) - \ln(E_i^{t-1})} \cdot \ln \frac{EI_i^t}{EI_i^{t-1}}, \qquad (4)$$

$$\Delta E_i(ES_i) = \frac{E_i^t - E_i^{t-1}}{\ln(E_i^t) - \ln(E_i^{t-1})} \cdot \ln \frac{ES_i^t}{ES_i^{t-1}}, \qquad (5)$$

$$\Delta E_i(P_i) = \frac{E_i^t - E_i^{t-1}}{\ln(E_i^t) - \ln(E_i^{t-1})} \cdot \ln \frac{P_i^t}{P_i^{t-1}}. \qquad (6)$$

5. Interpretation of results.

At the final stage, contribution of each factor in the energy consumption dynamics within the specified time period is determined separately for the developed and developing countries.

Results and discussion

Influence of structural transformation in fuel and energy sector on energy consumption

The change in the energy ratio of each specific source in the test time period had influenced the dynamics of energy consumption both in the developed and developing countries (**Table 3**). Each energy source has higher influence in a certain time, i.e., the energy consumption structure is fluid.

Although each source of energy has larger or smaller contribution to the dynamics of energy consumption, some trends are all the same traceable. First, the trend in coal and oil consumption in the developed countries is exclusively negative. These countries endeavor to reduce the use of fossil energy resources. In the meantime, gas as the eco-friendliest source of energy has a positive influence on the energy consumption dynamics as the countries actively advance the gas industry.

After 2005 the developed countries pursue the so-called energy transition: only eco-friendly energy sources, such as natural gas and alternative sources of energy, have positive influence on energy consumption, while the change in the use of oil and coal causes opposite dynamics in energy consumption (**Fig. 1**).

Energy transition in the developing countries becomes observable only after 2015 (**Fig. 2**): gas and alternative energy sources have positive effect on change in energy consumption, while oil and gas affect it adversely.

Table 3. Influence of change in energy source ratio on total energy consumption

Group	Energy source	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020
Developed countries	Oil	–0.38	–1.79	–0.53	–7.60	–0.56	–5.00
	Coal	–5.40	–0.64	0.03	–1.30	–5.02	–10.81
	Gas	3.48	2.52	1.04	5.59	3.50	8.40
	Alternative sources	2.30	–0.09	–0.54	3.30	2.08	7.38
Developing countries	Oil	–1.20	1.03	–6.40	–1.87	1.06	–6.25
	Coal	1.30	–2.45	10.59	2.62	–3.49	–4.58
	Gas	–1.65	0.93	–2.97	–1.67	–1.08	1.90
	Alternative sources	1.55	0.49	–1.14	0.93	3.52	8.94
Source: compiled by the authors using LMDI model							

In the last test period, from 2016 to 2020, the major influence on energy consumption in the developed countries belongs to coal. In the last 5 years (from 2016 to 2020), coal consumption dropped by 31% (**Fig. 3**). The principal reduction took place in Spain (87.3%), Portugal (82.3%) and in the United Kingdom (80%).

In the developing countries, alternative energy sources dominate. From 2016 to 2020, consumption of the alternative energy sources increased by 40%, mainly owing to China which was an absolute leader in the alternative energy consumption (22.78 EJ).

Dominant factors of influence on change in energy consumption in developed and developing countries.

The quantitative estimation of influence exerted by different factors on energy consumption dynamics both in the developed and developing countries is given in **Table 4**. The dominant factors of influence on change in the energy consumption is the energy/output ratio and the economic activity [18]. The former factor has the highest weight in the energy consumption in the countries-members of OECD (four out of six test time periods), and the latter factor is the most influential in the countries-nonmembers of OECD (five out of size test time periods) [18–19].

The overall effect of change in the energy consumption structure on its dynamic is zero in each time period in both groups of the selected countries. The reason is that the model uses not the absolute value but percentage of each energy source in the total consumption. Therefore, we can estimate contribution of each source rather than the fact of change in the structure of the energy consumption in whole.

The last factor—the population of a country—has a beneficial effect on the energy consumption dynamics both in the developed and developing countries over the whole test period of time. This factor had the highest weight between 1991 and 1995 in the developing countries. Later on, the influence of this factor dropped.

Factor of increasing energy density of energy sources in use.

One of the governing factors in the global power engineering advancement is the persistent increase in the energy density (calorific equivalents) of the energy sources in use. For instance, 1 kg of hydrogen produces 7 times more energy than coal combustion. The authors of the research [20] forecast that the average calorific equivalent of the application energy sources will double in 2025–2030 as compared with the present-day value. Moreover, the calorific equivalent will triple by 2055–2060 as against the expectations of 2025–2030, and can grow 100 times as against the current level by the end of the 21st century. Accordingly, the coal mining industry should pursue introduction of advanced technologies at all stages of the production process, starting from coal extraction and finishing with marketing of coal products. Appropriate targets in this respect result from the patent analytics (patent landscapes) which contributes to shaping technological priorities for the coal mining regions, with regard to allied technologies and products, including coal industry, metallurgy, machine building, power engineering, chemical industry, manufacture of medical goods, etc. [21]. The promising technologies of coal seam methane drainage, including in-situ gas drainage, as well as ecologically clean coal production are described in industrial patents of the Japanese (RU 2433163), Russian (RU 2345116, RU 2339672, RU 2285715) and Chinese researchers (RU 2434931, CN114032126,CN113980708). Furthermore, the Russian (RU 2646607, RU 2694033) and Japanese (JP2022020046, JP2022001644) specialists tackle promising ways of hydrogen production.

On the basis of expert judgment, the authors have arrived at a conclusion that the main obstacles on the way of technological innovations are the coal industry additivity and the prevailing profit-oriented value chains [22–25]. On this evidence, the most promising approach to enhancing resilience of the coal industry is to use the technologies capable to improve production flexibility and interoperability to create a framework

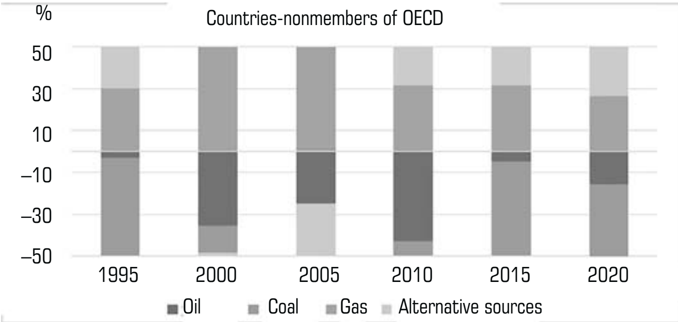

Fig. 1. Influence of different sources of energy on energy consumption dynamics in developed countries

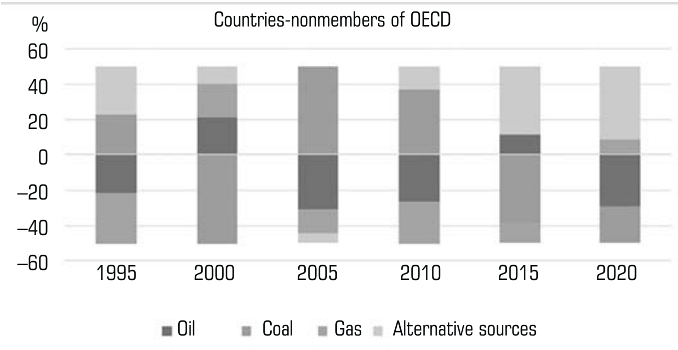

Fig. 2. Influence of different sources of energy on energy consumption dynamics in developing countries

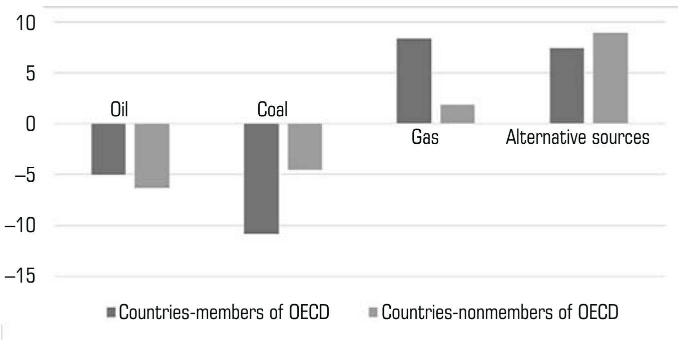

Fig. 3. Effect of different energy sources on total energy consumption in 2016–2020

Table 4. Estimates of influence on energy consumption dynamics

Time period	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020
Countries-members of OECD						
dE	15.37	17.68	8.06	–4.15	–3.94	–13.14
dE(SE)	0.01	0.00	0.00	0.00	0.00	–0.03
dE(EI)	–9.36	–25.40	–18.32	–18.01	–26.67	–21.84
dE(ES)	15.79	34.87	17.80	5.27	15.56	2.47
dE(P)	8.94	8.20	8.58	8.59	7.17	6.27
Countries-nonmembers of OECD						
dE	4.68	12.41	51.29	51.19	41.51	23.93
dE(SE)	0.00	0.00	0.07	0.00	0.01	0.02
dE(EI)	–9.28	–16.15	1.59	–18.86	–24.62	–24.22
dE(ES)	3.57	18.89	39.67	57.99	51.77	34.45
dE(P)	10.39	9.66	9.96	12.06	14.3	

for including coal mining companies in modular value chains and in relational value chains based on the lean manufacturing networks.

Conclusions

Finally, we have found that the main energy source to exert the highest effect on the energy consumption is coal in the developed countries and the alternative (non-fossil) energy sources in the developing countries. Over the whole test period, the key part in the global energy consumption change belongs to the energy/output ratio and specific GDP. The former factor is dominant in the developed countries, while the latter factor prevails in the developing countries.

The implemented research has revealed the specifics of the coal industry development in different countries in different periods of time, including exogenous shocks. It is concluded on instability of the global coal sector in 1995–2020 and the situation worsens under conditions of energy transition, economic sanctions and the Global Climate Agenda of the Paris Agreement. The most influential countries are going to transit to more efficient utilization of coal and alternative energy sources in power production.

However, despite the currently shaping paradigm of zero carbon power generation, rejection of coal-fired generation and risk of drop in demand for Russian coal on the international market, the coal sector in Russia and in the other countries can be preserved based on the differentiated approach to business support and by formation of high tech economy sectors in the coal mining regions backed up by the promising eco-friendly innovative technologies in the form of new added-value chains.

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