

Editorial

# Coal Mining Sustainable Development: Economics and Technological Outlook

Sergey Zhironkin <sup>1,2,3,\*</sup>  and Michal Cehlár <sup>4</sup> 

<sup>1</sup> Institute of Trade and Economy, Siberian Federal University, 79 Svobodny av., 660041 Krasnoyarsk, Russia

<sup>2</sup> Mezhdurechensk Branch, T.F. Gorbachev Kuzbass State Technical University, 36 Stroiteley St., 652881 Mezhdurechensk, Kemerovo Region-Kuzbass, Russia

<sup>3</sup> School of Core Engineering Education, National Research Tomsk Polytechnic University, 30 Lenina st., 634050 Tomsk, Russia

<sup>4</sup> Institute of Earth Sources, Faculty of Mining, Ecology, Process Technologies and Geotechnology, Technical University of Košice, Letná 9, 040 01 Košice, Slovakia; michal.cehlar@tuke.sk

\* Correspondence: szhironkin@sfu-kras.ru; Tel.: +7-3842-39-63-68

## 1. Introduction

The modern paradigm of sustainable development is based on concepts and theories in which the needs of individuals and society, the limits of economic growth and the balance of industrial and natural systems are close to consistency. The need for sustainable development has become a dominant feature of both academic and public thinking, bringing to the fore the issues of the impact of industrial civilization on Earth's climate and surface, lithosphere, water and air. At the same time, modern science faces the challenge of providing the required resources and, above all, energy, for the emerging post-industrial society, in which a high quality of life is taken for granted, and the solution to environmental problems is an important imperative of the state. Therefore, the methodological issue of sustainable development (balance or dichotomy) can be solved in the system of scientific support of innovations in energy production, distribution and consumption. To a large extent, this applies to traditional sources of energy—the coal, oil and gas.

The coal industry is the oldest method of obtaining energy resources for industrial and domestic needs, which gave rise to the first industrial revolution, urbanization and economic growth at the end of the 18th century. At the same time, along with the main role in changing the structure of the economy and society, since the 19th century the development of coal mining has identified the problems of industrial negative impact on the environment, such as air pollution by coal combustion products and dust, anthropogenic changes in the landscape, pollution of water basins in coal mining clusters. These sectoral-scaled problems are now being summed up in the planetary problems of climate change; the reduction in agricultural land and water resources. At the same time, for centuries, coal mining has posed a serious threat to the health and life of the population.

The mining and use of coal has occupied a fairly stable place in the global energy balance for a long time, having recovered from the recession of the 1960s–1970s, caused by the growth of oil production and the decline in mining in countries that were historically known as the largest suppliers of coal to the world market. Since the beginning of the 20th century, the new industrialization of Southeast Asian countries and the growing demand for energy supply to the digital economy led to an increase in coal production by more than one and a half times in 2001–2010 [1]. That made people consider the types of coal that were not previously used as a fuel (for example, brown coal, lignite).

To date, the prospects for sustainable development of coal mining in the world are influenced by two opposite trends. On the one hand, the world population's need for cheap electricity is growing, increased by the growth in the production of electric vehicles, the use of Big Data computing power, and mobile communication technologies. This raises the issue of low-cost energy production in increasing volumes. Thanks to this, coal continues



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to play a major role in the world economy, occupying 29% of the consumption of fuel and energy resources (for comparison, the share of oil is 33%), and the current volume of coal production is about six billion tons [2]. At the same time, coal serves as a driver of energy supply for up-to-date the fourth industrial revolution in the leading economies of the world (China occupies 49% of world coal consumption, India—12%, the United States—10%). Such significant volumes of coal production and consumption are the result of innovative modernization of mining enterprises around the world, the introduction of equipment with a high specific capacity, and the development of coal beneficiation technologies. In addition, the introduction of modern digital technologies in the process of mining, transportation and use of coal has significantly reduced industrial injuries and excluded the coal mining from among the most dangerous industries for humans.

On the other hand, since 2014, for the first time since the beginning of the 21st century, there has been a decline in global coal consumption; mining in the largest coal-mining countries (China, USA, Indonesia, South Africa, Germany, and Poland) is decreasing. In some years, the decline in global coal consumption is 9%, and by 2030, a turning point in the transition of electricity production from coal to natural gas may be reached [2]. The benchmark for the medium term is to reduce the share of coal in the world fuel and energy balance to 25% [2]. Without reducing energy production, many countries are cutting the consumption of fossil fuels by developing renewable energy sources. Thus, the world leaders in the use of solar and wind energy are Germany, the USA and China; in the use of the energy of sea tides, Norway; and in motor biofuels, Brazil.

Along with technological breakthroughs in the use of alternative energy sources, a significant reason for the decrease in global coal consumption is the tightening of environmental requirements for the use of energy resources, including related to the decisions of the Climate Conference in Paris, 2015. As a result, even in the main coal-consuming countries, high-cost reconstruction of coal-fired power plants, as well as the development of low-carbon technologies, are inevitable.

Therefore, the sustainable development of coal mining is closely related to three challenges:

- reducing environmental damage during the production and use of coal;
- digital modernization of the coal industry and the introduction of unmanned technologies;
- the search for a new place by the coal industry in the resource supply of energy in the context of the rapid development of renewable energy sources.

In this regard, scientific support for the sustainable development of coal mining has acquired a certain duality associated with fundamental and applied research in the field of technological modernization of coal production, along with the synchronization of this process with the development of renewable energy sources. The technological level of coal production determines the possibilities of reducing the negative anthropogenic impact on the ecosystem of the regions and industrial injuries and, at the same time, improving the quality of life of the population of coal clusters. Today, in the scientific community there is a special interest in the diversification of the industry in coal clusters and its energy supply based on the formation of an advanced technological platform of energetics.

The goal of this Special Issue is to bring together the results of cutting-edge research by leading scientists related to technological breakthroughs in coal mining, as well as the development of renewable energy production in coal clusters, which can be broadly defined as Coal Mining Sustainable Development. The latter is called upon to solve some of the most pressing problems that hinder the transition of modern industry in achieving the environmental and technological standards of the 21st century, ensuring a new quality of life for the whole mankind.

As Guest Editors of this Special Issue, we were able to ascertain that a comprehensive understanding of the problems of coal mining sustainable development was taking shape in the scientific community, and researchers are now aware that more embracing paradigm is necessary for further research in the field of the balanced development of traditional and alternative energy.

The positive reply from the research community, supported by the number and high quality of the articles submitted, confirms the prospects of understanding the coal mining sustainable development, based on the accumulated research and practical experience in the use of fossil resources, and the potential of alternative renewable energy sources. Combining the possibilities of traditional and alternative energy in ensuring the satisfaction of the growing needs of society goes beyond the strict framework of academic debates. A stable increase in the production of available energy must be accompanied by a reduction in anthropogenic impact on the environment, which is the key idea for coal mining sustainable development. This is the main message being promoted by this Special Issue.

The articles, submitted to the Special Issue, and selected to be published, address a wide range of sustainable coal mining issues, including the development of surface and underground geotechnology, geomechanics, coal beneficiation, modernization of mining machinery, coal-steam power producing, occupational safety and environmental conservation, as well as the development of alternative energy in coal clusters. It should be noted that some articles extend the frontiers of mining science and its traditional subjects, emphasizing the complex nature of the problems of coal mining sustainable development and the prospects for research on the deep diversification of coal region's economy.

In the next section, a brief review of the articles published in the *Energies* journal's Special Issue "Coal Mining Sustainable Development" will be presented reflecting above-mentioned thematic areas.

## 2. Special Issue Articles' Short Review

Articles published in *Energies* as a part of this Special Issue can be grouped according to their thematic immanence of research in the field of coal mining sustainable development (as well as for other energy resources extraction).

As far as geotechnology is concerned, two articles address innovations in the development of coal deposits by surface mining and uranium deposits by underground mining, respectively. Their provisions are connected with increasing the efficiency of mining operations and decreasing environmental damage caused by mining.

Sofranko et al. [3] propose a methodology for the selection of Uranium ore mining technologies to reduce valuable raw material losses, based on example of Kuriskova deposit (Slovak Republic). The authors substantiated the way to determine the amount of recoverable Uranium reserves. The block mining method of cut and fill, stopping with a solidifying backfill substance—which was selected in the paper, within the methodology proposed by authors—meets the requirements of environmental protection and labor safety for ore deposits development. It is important that the proposed mining method allows the highest possible extraction of reserves from the field to be achieved, without any tied reserves in protecting pillars within a mining block, because they are left only among the individual blocks. Therefore, low ore losses and contamination are arisen. The analysis and determination of the energy potential of Uranium deposit of Kuriskova, presented in the article, shows that development of the field can fully cover 40 years need of Slovak Republic nuclear power plants for the nuclear fuel with energy potential of 600 TWh.

In the article by Zhironkin et al. [4], an idea of transition from the deepening longitudinal to the lateral mining method for inclined and steep coal seams development is applied to the important case of Kuzbass coal basin (Western Siberia, Russia). Being a part of advanced surface geotechnology, the change in the mining methods is aimed at reducing the environmental damage caused to land and air resources by external dumping at coal open pits. Greeted as a promising breakthrough in the 1960s, surface mining began to be perceived as the most environmentally hazardous method of subsoils extraction. To restore social benefit of surface mining, the authors substantiated the choice of peculiar technology for a block-and-layer continuous lateral mining method, which allows filling worked-out space of a quarry with overburden using direct dumping. Therefore, the land capacity of surface mining can be radically decreased (by 6–11 times, depending on the depth of the pit), as well as the dust emissions from the dumps (by 5–9 times). Proposed technology is

designed for inclined and steep coal seams surface mining, although it was used for flat coal seams extraction before.

The role of geomechanics research in sustainable development of mining enterprises is analyzed in three articles dedicated to rock mechanics, induced seismic events in mining clusters and ground control. Prevention of landslides and collapses of rocks in the areas of underground and surface mining is especially important for the development of coal deposits, in which the host rock has relatively low strength properties.

Thus, the investigation of rock material damage characteristics under the influence of cyclic and impact load was conducted by Chen et al. [5] using provisions of energy dissipation theory. By sample of red sandstone, it was found that for jointed action of uniaxial cyclic and impact loads, when the load stress is 60–80% of the uniaxial compressive strength, existing microcracks can be still promoted and the new cracks can appear in the rock, reducing its strength. This is especially important for soil stability at coal surface mines. Accordingly, research results, for cyclic loading, the damage variable of the rock considers, on the one hand, the influence of the energy dissipation ratio of the rock under single cycle, and the circulation number on the other. Therefore, the practical damage condition of the rock can be defined more accurately. It was also found that, as the initial damage of the rock increases, the average diameter of broken rock particles also increases gradually, which should be taken into account in ground control.

Boroń et al. [6] show uniform and non-uniform kinematic excitation models adopted for assessment of mining-induced seismic events that are dangerous for large-scale structures in mining clusters. Induced earthquakes are considered in the article as long-term consequences of continuous mining, and the effect of spatial variation of ground motion is explored. Authors conclude that using a widespread response spectrum analysis may cause underestimation of the dynamic response of large-scale multiple-support structures in areas with intensive mining. The article indicates that the large-scale structure's dynamic performance depends on the frequency range specific for the particular site. Following the research presented in the article, an important conclusion was made regarding stability and seismic safety of the large-scale structures: for identical ones located in various mining regions, the dynamic performance under tremors with near maximal amplitudes may be more different, due to the frequency contents discrepancy. For this reason, to minimize a risk of unforeseeable damage of the structures located in mining activity zones, their predictive modal analysis should be conducted.

Liu et al. [7] explore the inverse problem of rock mechanics—improving the strength of the rock surrounding deep underground constructions by grouting reinforcement, which is important for labor safety and accidents prevention. The article displays the results of the series of systematic experiments aimed on discovering the tensile and shear strength properties of rock after grouting reinforcement, including studies considering the presence of gas. It was found that considering the presence of fracture gas in grouting, the maximal shear strength of grouted fractures was 8.34–29.9% less than without taking into account the fracture gas. An essential authors' conclusion for grouting engineering development is that the tensile strength of fractures in the rock is increasing with the growth of grout viscosity, but the complete tensile strength remains relatively low. When unsaturated cementation in the grouting reinforcement is used, cemented pore surface was the main reason for the decrease in cohesion and frictional angle of rock fractures. Generally, the provisions given in the article are valuable for further research on the stability of underground mine workings. The results of such a research are intended to change the attitude of specialists and the public towards underground mining as a potentially highly hazardous method of subsoils extraction.

A number of contributions are devoted to mining machinery development, including improvement of technical basis of coal beneficiation—the most advanced segment of modern geotechnology.

Li et al. [8] examine optimization and subdivision of the finite element simulation of the pantograph catenary system of electric underground mining vehicles. The authors es-

established the finite element models of the pantograph and the catenary systems, improved the motion equation of the catenary and performed a dynamic simulation experiment. To ensure sufficient power, energy charge and supply for the wire electrical actuated load, haul and dump machines, the validity of the finite element model was proven in the article. It was calculated that for the tension of contact wire of 30 KN and the wire radius of 0.00564 m, current collection parameters fully meet the requirements. It is of importance that the results of the presented research, despite the single-discipline meaning, make an industry-level contribution to coal mining sustainable development. The overall results show that trolley wire electric mining vehicles with zero emissions have excellent mobility and unlimited running distance, and thus compare favorably with traditional fuel equipment.

The issue of mining machinery energy efficiency is observed in the article of Kawalec et al. [9], in which the belt conveyor system is considered the most effective for transporting the large volumes of bulk material, especially at surface mining. Exploring the specific energy consumption of a belt conveyor system, the authors found that energy usage optimization as a key environmental issue of mining transport can be achieved by increasing conveyor capacity with simultaneous belt motion resistance. Using the example of lignite surface mines, an energy-saving and environmentally friendly solution of electric energy consumption decrease was found using multi-parameter simulations and evaluation of relationship between specific energy consumption and material flow rate for different parameters of conveyor design. Exact computations made by authors showed that the modernization of belt conveyor system at lignite surface mine as well as variation of some design parameters and the number of conveyors allow reducing the energy consumption by 27.78% and cut CO<sub>2</sub> emissions by 5097.88 tons per year.

Stańczyk [10] set forth results of research in development of coal beneficiation equipment—negative pressure pneumatic separator, used for dry separation based on the distinctions in physical properties of coal and host rock. The author presented working models of negative pressure pneumatic separator operations and validated them by calculations, which outcomes were compared with experimental results of another studies. This comparison proved that the author's models could predict the results of dry separation with high accuracy and allow optimizing the process of coal beneficiation and improving the quality of clean coal. In particular, determining the air velocity vectors means that unnecessary medium turbulence in the form of numerous local swirls in the separation device can be prevented. In addition, it was noted that the more streamlined shape of the separator could reduce power consumption of the whole installation as well as noise due to vibrations.

Reliable method of spontaneous coal combustion fighting in underground mines plays a vital role in labor safety upgrade. It can give the coal industry a chance to restore the credibility of mining as a privileged occupation.

Szurgacz et al. [11] investigate the major natural hazard for mining—endogenous fires induced by coal combustion and causing immense material losses and great threat to miners' health and life. To prevent the damages and radically decrease the risks, authors propose a new original method based on the equipment for feeding an ash and water mixture with carbon dioxide to the zones with high probability of spontaneous coal combustion. The distinctive feature of the method proposed is a preparation of the mixture on the daylight area with subsequent transporting to underground workings with a high level of the fire hazard through the pipelines. An important part of authors' idea is a monitoring of gases' chemical composition for taking timely measures on firefighting, including use of carbon dioxide as an inert substance and the water and ash mixture as a matter to stop the air inflow with oxygen to the working. Analyzed gases should include oxygen, nitrogen, carbon monoxide and dioxide, hydrogen and unsaturated hydrocarbons, the concentration of which gives a clear picture of fire risk only while being analyzed in complex, along with external factors such as changes in the barometric pressure and rock array conditions, especially the presence of cracks.

One submission to the Special Issue “Coal Mining Sustainable Development” is devoted to the progress in decision-making in reducing the harmful influence of mining on the environment.

Mbedzi et al. [12] present a new approach to stakeholders’ involvement to the regulation of mining mainly based on environmental management accounting tools (material-flow costs and life-cycle costing, mining company accountability, etc.), as well as stakeholder education and training in the field of environmental risk management, post-mining and financial modelling. In this article, the author’s idea is considered on an example of a case study of the Emalahleni mining cluster (Mpumalanga Province, South Africa). In this region, the development of coal mining for over a century led to serious environmental challenges such as underground fires that caused land sterilization, acidification of topsoil and surface collapse. All these have a negative effect on human and animal health. To move on to solving the accumulated environmental problems, the article proposes a shift in emphasis from punitive regulation to finding a balance between mining enterprises profitability and maintaining the environment. For this purpose, coal mining companies must observe a number of important legalities, the most significant of which are King IV corporate report guidelines, Global Reporting Initiative, health and carbon tax regulations.

Three special contributions to the Special Issue go beyond coal mining as an essential part of economy of some regions rich in minerals, and explore innovative technologies of using renewable energy sources. Such studies are of particular importance for the historical mining regions of Europe, where traditional coal-fired power industry gradually gives way to alternative energy producing.

Beer et al. [13] propose a new concept of an innovative manifold header for evacuated tube solar collector that can improve its functionality in uneven conditions. The design of the manifold header, proposed by the authors, is aimed at increasing the heat exchange surface. The overall result is increasing in total efficiency of solar collector system, which is proven, on the one hand, by computational fluid dynamics analysis (using Ansys Fluent software), and on the other by selection of the most suitable hardware elements incorporated into the pre-prototype final design of a manifold header, which is ready for manufacturing. During the study, five variants were sequentially considered as representing an evolution in terms of hydraulic optimization and existence of turbulent regions in fluid domain. The authors are confident of success in prototyping the manifold header suitable for experiments in real operating conditions.

Sivák et al. [14] analyze new technological and engineering capabilities of creating the energy storage based on solar energy and suitable not only for the new low-energy buildings, but also for older family houses. It is possible due to the use of header pipes as a special kind of solar absorber. In the article, a new ice storage system is proposed that combines solar absorber, heat pump and ice storage tank made of phase change material. The latter gives an opportunity not only to use solar energy, but to absorb thermal energy from the environment, which is especially important for the countries with a continental climate, with contrast seasonal weather, rain and snow. Real assembling of the ice storage system on an approximately 40-year-old family house has proved its efficiency in the conditions of the Slovak Republic. The increase in total efficiency by 46.6% with seasonal coefficient of performance of 4.4 allows the homeowners of the older houses, reducing their expenditures significantly.

Beer et al. [15] published the results of a detailed study of innovative material for energy absorbers—the metal foams and perspective for power engineering. The proposed economical and non-destructive method is based on the image capture of metal foam with the subsequent analysis of the results obtained with available widespread devices (photo technics and image analysis software), instead of expensive high-resolution X-ray microtomography. Using this method, it is possible to define the important geometrical characteristics of metal foam, such as pore and ligament diameter, which provide input to the calculation of the pressure drop of the flowing medium. The production and economic value of the author’s idea lies in the fact that for replacing the widely used non-renewable

energy sources with renewable ones, it is critically important to develop the new materials for highly efficient power plants with zero emissions.

The relevance of the three articles mentioned above for coal mining sustainable development is ensured with the formation of alternative power production in coal clusters, which can reduce the environmental burden on the regions with a simultaneous increase in their energy supply.

### 3. Conclusions

The articles presented in the Special Issue “Coal Mining Sustainable Development” reflect the range of scholarly disputes, the keynote of which is the need for the integrated development of resource support for modern power industry, represented by the extraction of minerals as a traditional segment of the economy, and by increasing energy production from renewable sources. Over the past ten years, the need for energy supply to industrial and urban areas around the world has significantly increased, which required both traditional and alternative power production to reach new levels of productivity and efficiency. At the same time, the global trend towards the greening of industry and the emergence of a “green economy” has created significant obstacles to the development of coal mining without significantly reducing environmental pollution. The issues of labor safety in the mining sector of national economy and the wellbeing of miners remain in the focus of public attention.

Articles published in the Special Issue cover a wide range of issues related to research in key areas of coal mining sustainable development: innovative development of geotechnology aimed at reducing land, water and air pollution; geomechanics research to prevent uncontrolled landscape changes and induced seismic events in areas of intensive mining; fighting endogenous fires; mining machinery development as a way to improve the efficiency of coal mining; rationalization of environment management. A special place among the articles published in the Special Issue is occupied by research in the field of improving the efficiency of the use of renewable energy resources.

We associate the future of scientific thought in the field of sustainable energy with the development of green mining and green technologies of extraction and use of coal in power engineering and chemistry. We are confident that future Special Issues of *Energies* will help consolidate and popularize the ideas of scientists and research teams in the field of sustainable development.

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