Mining in Poland in Light of Energy Transition: Case Study of Changes Based on the Knowledge Economy

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Abstract: Implementing climate policy goals, such as achieving climate neutrality by 2050, requires significant transformation of the mining sector—which for some countries and regions where mining is still the basis of the economy and part of the identity is very difficult and results in significant social and economic costs. Focusing on regional aspects and characteristics of the mining sector in Poland and its impact on energy security, the paper provides insight into the noticeable process of mining modernization in the globalized world economy through its transition from the industrial era to a knowledge-based economy and the impact of these changes on regional development. The described process is directly related to implementation of innovative and new technical concepts and technological solutions for the mining industry. The indicated changes imply the need to redefine operating principles and organizational models in the mining industry in order to build responsive solutions based on innovations—shaping modern (intelligent) mining of the future—while at the same time being part of the transformation of (post-)mining regions into a multi-industry region. All the described elements are proposed as supporting elements of the transformation process—to ensure full use of the technological and infrastructural potential during the energy transition process.

Keywords: energy transition; knowledge economy (knowledge-based economy); Industry 4.0; transformation of mining in Poland

1. Introduction

The ongoing changes in energy systems—resulting from, among other things, the move towards climate neutrality, especially noticeable in Europe—poses a huge challenge for the mining sector. One of the critical challenges for global mining is need for a skillful and innovative promotion of modern attitudes and persuading both decision makers and miners that innovation and the resulting changes are necessary. Additionally, most importantly, that departure from the mindset prevailing in the industrial era is purposeful and inevitable, because only turning to the future—by caring for self-development and the environment—can guarantee success [1]. The primary determinant in shaping this thesis is the paradigm shift in the development of the current model of the global economy as a result of its dynamic transition from the era of the Industrial Revolution to a knowledge-based economy, determined in its development by a new process called Revolution 4.0 [2]. From the content of the above thesis emerges the image of the future, in which humans, industry and digitization and automation processes developing with hitherto unknown dynamics will shape the surrounding reality. They can lead to the disappearance of the world dominated by the era of the Industrial Revolution and the transition to a new era shaped by technologies determined by data flow and their analysis. Given the indicated megatrends and transformation driven by the change in the meaning and role of knowledge, the term “knowledge society” emerged [3], in which creation and utilization of competitive and innovative solutions have become an essential capital. It seems that the automation process, together with the deepening phenomenon of demographic depression in the
context of increasing competitiveness of economies, which is particularly noticeable in the
depopulation of cities and regions that are post-mining or in transition, will determine
the need to permanently raise the level of education, competences and to create and
master new knowledge. Although modern institutions and their global reach provide
people with incomparably higher chances of experiencing a safe and satisfying life than
in any of the pre-modern systems, modernity has also a dark side which is the loss of the
individual between the global aspirations of modernity and the local dimension of human
existence, the breakdown of space–time relationships, the reorganization of social relations
within the network society or the constant struggle with the processes of marginalization,
differentiation and exclusion [4].

In this light, the future of mining industry is determined by a few trends, the most
important being energy transition. The article presents the current state and possibilities
of technological changes in the mining sector in Poland. In the context of trends in the
EU climate policy, the Polish energy economy, based on the generation of electricity from
solid fuels, requires a deep transformation. In order to successfully implement an energy
transition system, engineering, technological and social approaches need to be considered
simultaneously and on different levels—individuals, occupational groups, regions and
nations, as well as political, economic and energy security aspects. On the one hand,
there are the necessary changes implemented for gradual phasing out of coal mines with
the application of social safeguards, ensuring that the welfare of the individual does not
become a victim of technological development promoting alternative energy sources. At
the same time, the social contract for energy transformation must go beyond a single
interest group, encompassing not only workers of the mining sector, but also many other
stakeholders from mining and post-mining regions. On the other hand, the transition
should also take into account the opportunities to build on existing knowledge held in
enterprises and technological infrastructure for the effective change of power generation
mix [5].

The paper analyzes the history and possible future of mining sector transformation
with the view of the “Green Deal” and transformations in the energy sector. The influence
of driving forces caused by the pandemic situation are considered. The possible perspective
and chances for the mining, and particularly coal mining, sector are targeted. To the authors’
best knowledge, this is the first attempt to address this topic in the presented context.

2. Materials and Methods

In order to achieve the main goal of the article, which is to analyze the meaning of the
future of mining, the phenomenon of a knowledge-based economy and the assumptions,
theses and megatrends adopted in the introduction to the article, various research methods
were used. The indicated research methods focus on available cognitive methods, aspects
of the knowledge economy and Industry 4.0 in the context of mining corresponding to
contemporary challenges.

Critical analysis of the literature covered numerous complementary works and fo-
cused mainly on processes and megatrends crucial for energy transition determined by
the mentioned globalization, knowledge-based economy and Industry 4.0, shaping the
state and development perspectives of the mining industry. The critical analysis covered
both professional and scientific literature, including theoretical publications as well as
publications discussing research results and forecasts in numerous cognitive sections. The
conclusions and recommendations resulting from them are aimed at strengthening the
utilitarian part of the conducted analyses.

The study also used studies devoted to the development perspectives of the studied ar-
areas in the light of analyses of strategic documents regarding their future. These documents
were, in particular, the multi-annual development strategies for Europe, the country and
the voivodship, in various quality sections. In addition to formal and legal issues related
to the development perspectives of the studied areas—including, among others in appli-
cable law—the studies referred to European and national documents in which medium-
and long-term goals and tasks in the field of economic and social policies were outlined, especially in the context of ongoing and forecast mining transition processes. Scenario forecasts in the perspective of the knowledge-based economy focus on predictions of both future internal and external development conditions in order to achieve the desired target state, i.e., the justified need and vision of the mining industry responding to contemporary challenges. When presenting forecasts, it is assumed ex ante that the specificity of the area under study sets preferences outlining organizational and systemic solutions directly related to the future education, development and transition models. It is also assumed that the current state of the coronavirus epidemic in the territory of the Republic of Poland will accelerate the implementation—as an unfavorable circumstance—of numerous elements of the anticipated forecasts.

The implementation of climate policy is also a technological challenge. However, the term "technology" has a very broad meaning, so it is hardly possible to give a simple answer for technological readiness for upcoming changes. The problem arises where the used hardware machinery is concerned. Though the mining sector puts great effort into continuous exchange of its equipment and exchanging it with up to date, technically fluent solutions, the process is costly and requires both time and well-qualified staff. Despite the anticipated necessity of dramatic changes in the methods of raw material excavation and processing, one seems undebatable: the increasing role of digitalization and information science. Poland has more than satisfactory capabilities in preparing numerous, well-educated staff in areas such as IT, electronics and telecommunications. The same is true for mechanical engineering and geoscience. However, the problem which has to be solved is the relatively poor competitiveness of the Polish labor market. Many highly qualified specialists are able to find better opportunities for professional development abroad. Despite that, it should be noticed that there is a suitable and satisfactory potential both in technology and human resources already present. It is possible to lean on it for the upcoming necessary transformations. However, the implementation of such a scenario requires appropriate policy and incentives on the part of the state.

The unexpected outbreak of the pandemic dramatically affected many areas of life. It is difficult to find an area of life that would not experience perturbation related to the actions taken to reduce the health effects of the pathogen. The mining industry is no exception here. The pandemic has shifted the focus from working in plants and offices to working over telecommunications lines. The shift is not only technical. In fact, it changed the perception of work: it does not matter where and how the work is provided, what matters is the result delivered to the employer. It allowed focusing on the delivered value, limiting controlling the conditions, which is less important. There is natural way for such a movement in many occupations and services, but at a first glance it may seem impossible for mining industry to organize the work this way. Though it is still difficult to limit the necessity of personal engagement of workers in the mining activities, it can be noticed that development of remote control, remote sensing and autonomous machinery makes personal engagement in the excavation process less and less required. The use of machines allows people to be withdrawn from the most safety-critical areas of operation. It becomes possible to supervise the production first by the use of remote control and finally by the autonomous execution of work by the devices. However, this does not mean withdrawing people from the mining process completely. However, their role, scope of duties and required competences are changing. In this light, the COVID-19 pandemic appears as a factor that accelerated and catalyzed the ongoing process of digitization and the next level of production automation. Forcing the necessity to protect health and life made it possible to see the possibilities of development based on IT solutions of underground mining. The presented conditions allow one more regularity to be observed: even in the mining industry, dominated for many years by work consisting mainly in physical effort, there is a re-evaluation. In automated, computerized mining, it is not muscle strength, but knowledge and competences, that play and will play a fundamental role. However,
these processes would take place regardless of the epidemic threat, although its role in their intensification cannot be overestimated.

3. Discussion

3.1. Polish Hard Coal Mining—An Overview of State and Perspectives in Light of Energy Security Needs

The mining industry is still one of the most significant sectors in shaping the global economic situation. In countries with low and medium economic efficiency, it ensures the creation of new jobs, reduces poverty phenomena and improves the conditions for economic development [6]. Despite ongoing changes in approach and efforts to achieve climate neutrality, in Poland both hard coal and lignite are still very important parts of development, as Poland has significant coal resources that may serve as an essential stabilizer of the country’s energy security, which is of particular importance to the dependence of the Polish economy on gas imports (over 70%) and crude oil (over 95%). More precisely, in terms of hard coal mining, Poland ranks 10th in the global rankings and first in the European Union. The Polish energy mix is unique in Europe because it is heavily based on domestic solid energy resources (hard coal and lignite) [7] and, for Poland, hard coal is a guarantee of energy security, still being the primary source of energy [8]. Therefore, for many years one of primary objectives of Polish energy policy, in the field of security of fuel and energy supplies, has been rational and effective management of coal deposits located in the territory of the Republic of Poland [8].

Additionally, as noted by P. Czaja (2014), it should be remembered that mining in Poland is not only about coal. Polish mining is primarily mineral resources—almost 430 million tons of mining per nation with 38 million inhabitants is more than the European average per citizen. Most of the raw materials, without which modern technology cannot function, such as critical or rare earth elements, come from mining [9]. The global comparison of the share of hard coal and lignite in global reserves of energy resources (64%), crude oil (18%) and natural gas (18%) also shows that coal is the largest carrier of primary and electric energy [10]. According to forecasts by the International Energy Agency, the demand for electricity is still increasing, especially in Asia, and coal remains the largest source of generated electricity [11]. Not only will the demand for energy resources increase, but also—according to global forecasts—demand for other mineral resources [12]. Due to a forecasted increase in the global demand for electricity, it is necessary to develop energy production from all fossil fuels as well as renewable and atomic energy. Although the decline of coal-based energy production is an ongoing reality in Europe, it is highly probable that, globally, hard coal will remain the most critical fuel in the next few decades, mainly for the production of electricity with the simultaneous development of new combustion technologies and reducing the costs of mining and emissions to the atmosphere [10]. From the Polish government’s point of view, “the most important in this dimension is to cover the growing demand for fuels and energy in connection with the forecasted economic growth, while ensuring uninterrupted energy supplies. It is important to maintain a high index of energy independence, increase diversification of the energy mix and diversification of directions of supplies of imported fuels” [13], guaranteeing appropriate quality parameters. This is especially important in light of the paradox noticeable in the Polish domestic coal market. On the one hand, the share of coal in electricity generation in 2019 was nearly five percentage points lower than the year before. The trend of decreasing hard coal output in domestic mines, which has been visible for years, also continues—last year it decreased by 2 million tons. Other hand, the demand for steam coal remains high. A large part of it, almost 20% of On the domestic consumption, is supplemented with imported coal. Ten million tons originate from Russia, and the remaining 3 million tons come from such countries as Colombia, the USA or Kazakhstan [5].

On one hand, many experts, in their opinion about the best approach to the energy transition process and generally the best decisions for the future of Polish mining sector, agree with Lisowski (2016), who—in his thesis concerning a recovery program for Polish hard coal mining—referred to the Polish raison d’État, noting that further country develop-
ment requires a base of strategic areas of the economy and energy security of the country on its own substantial reserves of hard coal and lignite, and on the labor resources offered by society and not only on imports of oil, gas, nuclear technologies and fuels or renewable energy technologies [14]. This is particularly important given the fact that, under Polish conditions, development of gas sources means the need to increase imports. Domestic natural gas production, i.e., 143.3 PJ in both 2018 and 2019, accounts for less than 20% of the total consumption of this raw material in the economy of the country (19.8% in 2018 and 18.9% in 2019, respectively), whereas the rest needs to be imported, mainly from the east. The high import prices of this raw material limit the effectiveness of its use in the power sector, and the relatively little supplier diversification poses a threat to their reliability [7].

On the other hand, due to the changes in the global, and especially European, coal market, as well as changing conditions—including those resulting from the European Green Deal [15] and Energy Roadmap 2050 [16]—transformation of the mining sector is essential. Although, with the development of carbon capture and storage (CCS) and other emerging clean technologies, coal could continue to play an important role in a sustainable and secure supply in the future, there is a need for investments to enable technological transformation. Additionally, in light of the fact that Polish hard coal reserves suitable for economically and technically efficient production are diminishing [17] and some used technologies are outdated and impacting the environment, there is a growing need for effective and sustainable management of resources and utilization of new technologies and eco-innovations necessary to eliminate or minimize the negative effects of mining processes [12,18].

In the light of the theses outlined above, it seems that the mining industry, in line with the issue of energy security, should manage its own resources and transition to cleaner forms of energy based on reliable information on its impact on the regional socio-economic environment and on the global environment and climate. As the information is treated as the third most fundamental quantity, next to energy and matter, with a decisive impact on society, its forms of intercourse and cooperation [19] and adequately shaped system of obtaining and transmitting information between the mining enterprise and its surroundings can create a kind of mechanism of coexistence and relations between these entities. Changes in the environment have a key impact on the organization, especially because they occur quickly and are hardly predictable or even unpredictable. These include, among others:

- globalization processes and, consequently, the need for enterprises to operate on the international market;
- intensifying competition, leading to a focus on customer needs and the relationship: results—outlays;
- the disappearance of many existing markets and creation of new ones;
- the emergence of new organizational forms, being a consequence of networking, numerous mergers and alliances, which result in organizing work in the form of multi-task, interdisciplinary teams;
- the fast pace of development and implementation of new technologies and operating techniques, which result in shortening of product implementation cycles and product life cycles [19].

These changes concern all aspects of business operations, taking place in the civilization, cultural and socio-economic area, leading to a turbulent environment, which shapes the decision-making processes. Therefore, the coexistence mechanism should fit into the indicated dimensions and make the relations between the mining enterprise and the environment dependent on these dimensions.

The question that arises in this context is what information should be the key content shaping the indicated mechanism? It seems that the factors characteristic for creative thinking about the relations between the mining company and its social and economic environment, especially in terms of regional development, will be an appropriate level of information aggregation consistent with the expectations of the mining company and its
environment and ensuring, through information, growth of knowledge and the ability to respond effectively to the challenges facing the mining company and the region.

At the same time, for the smooth transition of the region, the information obtained should have a deeper meaning in the decision-making process, especially in the context of the accuracy of the phenomena and processes diagnosed. Acquired, collected, ordered and aggregated information should guarantee its practical application, allowing the identification and analysis of trends, forces, events and phenomena that may be of fundamental importance for building and functioning of the coexistence mechanism and relationships between the mining enterprise and its environment [20].

The general information-specific features and formulated theses and forecasts above—concerning the mining restructuring process—should create premises guaranteeing the desire to stimulate and maintain harmony and balance between the goals of the mining enterprise and its environment—in the social, economic, environmental and infrastructural dimension. Anticipating the broad spectrum of the impact of hard coal mining on its surroundings—taking into account the previously indicated areas: society, economy, environment and infrastructure—it seems that developing a model for gathering information on the relationship between a mining enterprise and its environment will require an alternative to the existing solutions’ interdisciplinary approach. It seems that this function can be considered as crucial and horizontal—apart from energy security—and a challenge for the future of global and Polish mining in the knowledge-based economy.

3.2. Polish Mining at the End of Industrial Revolution Era—Selected Aspects

The term “Industrial Era” is derived from the worldwide process of “Industrial Revolution”, which can be defined by its division into three periods called the First, Second and Third Industrial Revolutions. The first Industrial Revolution developed in the period from the late 18th to the second half of the 19th century. This period was characterized above all by the dynamic development of inventions, including that of a steam engine in 1769, which determined the industrialization process [21]. The beginning of the Second Industrial Revolution was the turn of the 19th and 20th century, when humankind became acquainted with further inventions (e.g., the method of oil refining, the internal combustion engine or the light bulb), which determined further development and modernization of copper and aluminum in metallurgy and the chemical industry—including crude oil processing—and limited the use of low-calorific coal in transport [22]. Two critical indicators of the Third Industrial Revolution that occurred in the last three decades of the 20th century are automation and computerization. This period was characterized by subsequent inventions leading to the high-technology industry and the production of atomic energy. In this phase of the Industrial Revolution, natural resources and their convenient location started losing importance as the key factors determining the allocation of industrial centers [23].

In Poland, the 19th and 20th centuries—that is, the Second and Third Industrial Revolution—were the period of dynamic development of the mining industry, which determined the flourishing of other industries, including railways and metallurgy [24]. The beginnings of the first mines were characterized by numerous unfavorable actions related to improper management, focused mainly on maximizing profits from production with irrational management of deposits. The technical condition of the mines in this period caused a very low level of occupational safety. This was the result of a lack of investments, which, with the vast supply of cheap labor, became unprofitable [25]. A radical change in Polish mining took place after the end of the Second World War. In the former political and economic system of the socialist state, the development of mining became even more decisive for the development of other strategic industrial areas. The discovery, investigation and documentation of hard coal deposits determined the formation of new mining areas and mines. Poland in the 1970s was in the fifth position in the world and the third in Europe in terms of hard coal mining. This is also the period in which the extraction of the raw material was maximized at the expense of work safety, even while attempts to modernize the mining industry were made. The time of change in the
political and economic system of the country, i.e., the period after 1989, brought a new paradigm for the development of Polish mining. As a result, the more than 20-year period of permanent restructuring of the Polish hard coal mining industry led to the increase in rationalization and efficiency of managing coal deposits, so that these resources would serve the next generations of Poles. Activities related to the diversification of energy sources and the search for new opportunities to obtain energy, including from hard coal, have been undertaken at the national policy level. The vision of the development of the Polish hard coal mining industry was based on the assumption that, after 2015, mining will be a competitive sector and successfully operate in the realities of the market economy, characterized by a high degree of occupational safety, modernity and innovation of the production process and low degree of negative impact on the environment [26]. Although measures to meet environmental and safety standards are becoming increasingly important for the hard coal mining sector in Poland in the context of social and economic development of the whole country [18], the government’s forecasts, assuming development rather than a decrease in output, turned out to be overly optimistic [27]. Although coal will remain the basic fuel in the power sector until 2030, it is planned to reduce its share in electricity generation to 56–60% coal. Therefore, it is necessary to ensure optimization of extraction and use of the raw material [13]. Currently (October 2020), a new plan for the mining industry is being developed, which will contain solutions acceptable to the social side and at the same time give a chance to continue extraction of coal by those mines that are profitable and necessary to provide the minimum of energy security.

At the same time, mining companies, striving to implement the policy of sustainable development—combining activities for economic success with care for the natural and social environment—more and more often exceed the minimum legal requirements, into those resulting directly from the implementation of corporate social responsibility (CSR) [28]. These, combined with the stability and flexibility of employment and work systems, can foster the scientific and technological development of mining regions, minimizing the social costs of energy transition process.

3.3. Polish Mining in the Context of Changes Resulting from Revolution 4.0 and the Knowledge-Based Economy

As has already been noted, along with the end of the Industrial Revolution, Polish hard coal mining entered the era of the knowledge-based economy in a state of profound organizational and technical changes. The described condition of the Polish mining industry is still evolving, determined by two processes—already mentioned several times—the Industrial Revolution 4.0 and a dynamically developing knowledge economy. The terms “knowledge economy” and “knowledge-based economy” (KBE) were introduced at the end of 20th century and a significant reorientation from a material-consumption economy to an economy based on information and knowledge has started [29–32]. According to the basic definition of this term, economic development is correlated with the appropriate use of knowledge [33], whereas its sub-dimensions cover aspects of economic and institutional regime, education and skills, information and communication infrastructure and the innovation system [34,35].

From this perspective, it is worth noting that the phenomena and processes related to automation cause transformations within companies and other institutions, related to areas of employment, human resource management and education [36]. As noted in numerous works [37–41], automation is a huge challenge for whole societies, because it forces changes in companies in terms of production processes, as well as operating principles, organizational models and information methods to build sensitive solutions based on innovation. This results in the need to adapt the entire labor market and education systems [36] in order to minimize the negative social impact of automation [42], improve skills [43] and professional flexibility [44] and build and support the competitiveness of emerging smart businesses of the future [45,46].

The described condition and development perspectives increasingly determine the disappearance of the impact on the development of economies of factors such as capital
and labor resources in the areas of productivity, competitiveness and efficiency in favor of the increase in impact on the abovementioned areas of knowledge in the field of technical sciences, economics, organization and management. As indicated in the literature, relations shaped in this way enable the competitiveness of economies to increase, which additionally determines the following vital factors: innovative technologies and products as well as efficient management [47,48]. In the context of the aforementioned factors—especially focusing on the future of mining in the knowledge-based economy—it is worth anticipating a dynamically progressing process of increasing significance of the phenomenon of digitalization in the economic processes, changing the way the society operates and accelerating development of the digital society [49,50]. Digital knowledge becomes the foundation of the power of the global economy and technological possibilities empower individuals and their ability to contribute to and participate in decision making processes [51].

According to the results of research on the artificial intelligence of scientists from the universities of Oxford and Yale, in 45 years machines will outperform people in all aspects of intelligence, and in 120 years all work will be automated [52]. As already mentioned, in the area of the labor market, digitization determines the disappearance and emergence of new professions. The 2016 study of the American Pew Research Center showed that 65% of Americans are convinced that in 50 years robots will do most of the work that people currently do, but at the same time 80% believe that their own profession in five decades will still exist [53]. In Poland, within the study developed by DELab University of Warsaw, 54% of the surveyed Poles acknowledged that in the future they will have to work in a few occupations in order to survive [54]. Based on the results of reports by the Organization for Economic Co-operation and Development (OECD), which analyzed 39 countries participating in the survey of adults skills (PIAAC) [55,56], it has been estimated that the average percentage of work susceptible to automation is about 48%, and 52% in Poland [57] and, importantly, even specialties which are the basis for the development of the modern business services sector may be at risk [58]. At the same time, in a PwC international analysis of the potential long-term impact of automation, the average for Poland is less than 35%, but 49% for people with a low education level [59]. In this light, it is clear that the future belongs to so-called smart enterprises (intelligent systems) whose strategic resources combine access to (and ability to use) data and information, broad knowledge and creativity [30,60]. However, enterprise intelligence is complicated to measure and even more challenging to manage [61]. One of the interrelated elements, the basis for effective knowledge management, is importing/extracting knowledge from the environment.

This condition determines the decline in the influence of such factors as capital and labor resources in the areas of productivity, competitiveness and efficiency on increasing the impact on the areas mentioned above of knowledge in the field of technical sciences, economics, organization and management. As the literature shows, relationships formed in this way enable the growth of competitiveness of economies, which is additionally determined by the following key factors: innovative technologies and products as well as efficient management. In conclusion, the dynamics of changes taking place in globalized economies are determined by the resources and accuracy of people’s knowledge, the quality of work, education and training, the ability to think quickly and innovatively and to implement new solutions in production, distribution and services [62,63]. Knowledge also becomes a critical potential assigned to a better-educated unit that serves as an animator of the development of a knowledge-based society. In parallel with the process of developing a knowledge-based economy, the paradigm shaping the organizational and technical functionality of hard coal mining follows [64]. The primary determinant of the process is the change referring to the already mentioned concept of the Fourth Industrial Revolution commonly known as Industrial Revolution 4.0 or Industry 4.0 [65,66]. Although the concept is variously defined, it can briefly be defined as an advanced stage of business development triggered by digital transformation [67], in which value chains, products, services and business models change [68,69].
The Industry 4.0 focuses on combining IT models to strengthen their impact [70]. At the same time, it aims to involve people in the work of digitally controlled machines and the universal introduction of practical wireless networks and information and communication technologies. The described process is directly related to the implementation of innovative and new technical concepts and technological solutions in industry, with simultaneous and wider than before ICT instruments, and a new concept of business management. Due to the need to redefine the production management model, the company moves away from mass production, responding to the needs of a precisely defined group of recipients for personalized production and focusing on the needs of a precisely specified customer. As a result of these activities, the enterprise diversifies production and transitions to the method of production management related to so-called agile production, i.e., permanent improvement, immediate reaction, a cyclical increase in quality, social responsibility and focusing on the needs of the recipient [71]. The indicated method of management implies many new terms in the environment relating to technical and technological solutions, such as the Industrial Internet of Things (IIoT) [72,73], incremental technologies and augmented reality and simulation and information techniques using large databases and systems for their processing, which in reality redefine the previously binding processes and concepts, shaping the directions of progress and civilization’s development based on the knowledge society. Along with these processes, the importance of cyber-physical systems, which correctly connect the computational area with physical processes, is growing dynamically. These are, in particular, forms of complex systems and models for monitoring and controlling physical processes operating in a feedback loop, where physical processes are the source of data for calculating the object control signal [74].

The processes mentioned above and trends based on them determine a new quality in the perception and understanding of the future of Polish mining. As there are four pillars in the knowledge economy: education and training, IT infrastructure, economic and institutional conditions and potential for innovation, therefore, the analysis of activities in the mining industry also took into account the above aspects. New IT solutions bring with them a whole new range of cost-saving possibilities [75]. Currently, more and more often, assumptions are being formulated that lead to plans to build smart mines in Poland, i.e., e-mines, in which system solutions connected with remote control of machines from the surface will be applied. Intelligent mines imply the possibility of effective control and monitoring of machines based on information and communication solutions. Remote and local control, aggregation, transmission, visualization, archiving and data analysis, as well as generating reports, are critical tasks in the area of application of information and communication technologies. The effect of these activities (in the e-mine) will primarily be an increase in the quantitative and qualitative safety of work. This will result from the fact that the staffing is far away from areas threatening safety and human life, in which only machines will be present. Therefore, the main goal of an intelligent mine is to optimize unit production costs through high technical and economic efficiency of technological processes, while striving to reduce the negative impact on the natural environment. The concept of an intelligent mine is dominated by the belief in the increase in human safety, resulting from the reduction in participation in the production process, which will be dominated by analytical skills. People will focus on controlling machines and monitoring them in subsequent phases. Thus, the highest priority in the e-mine vision was assigned to the knowledge and competences of future mining staff, whose work will focus mainly on remote control centers as well as underground and surface monitoring of machinery and equipment [76]. The process described above is becoming realistic in the real conditions of the organizational and technical functionality of the Polish hard coal mining industry. Strategic plans of KGHM Polska Miedź S.A. (hereinafter referred to as KGHM S.A.) foresee that new “intelligent” technologies and production management systems based on online communication between elements of the production process and advanced data analysis are the key factors determining success or failure in business [77]. The scope of tasks related to information management at KGHM includes the following issues: analysis and stan-
dardization of the needs reported by process owners, standardization of technical solutions (process sensing), optimization of resource use (hardware, programming), data quality management (verification, interference elimination) and supervision over the processes of generating and distributing information. Against this background, critical directions of activities at KGHM S.A. will be broadband data transmission in underground excavations, media monitoring power supply, ventilation, drainage, systems for locating and identifying machines and people underground, robotization of production and auxiliary processes and multi-dimensional analysis of data from production processes [78]. Therefore, the main objectives of the mine of the future’s vision are: the improvement of operational and investment efficiency, cost effectiveness and safety, whereas the overriding goal in the mine of the future remains to ensure the highest possible level of safety. The adoption of pioneering innovations, accompanied by extensive use of data analytics with the use of the latest solutions in the area of business intelligence and big data, should enable a complete redesign of the traditional mining process [79].

Similarly, Jastrzębska Spółka Węglowa S.A. (hereinafter referred to as JSW S.A.) has as its future undertaking the goal “Towards JSW 4.0”. According to the assumptions adopted by JSW Innowacje S.A., the essential tool determining the achievement of the leading business goal, which is optimization of efficiency, is the technological enhancement of the entire production process from coal to coke, including coal deposit exploration, analytics of the extraction process, online knowledge about extracted coal, optimal increase in underground work safety, inclusion of all production stages in one model subject to a continuous supply of real-time source data and the construction of analytical and data-mining models [80].

In this context, it is essential to ensure constant development of the competences and qualifications of mining sector employees by a high level and availability of continuous vocational training, also aimed at improving knowledge and skills in using the latest technologies available, in order to fully use arising opportunities [76]. One of the important elements is all kinds of cooperation between universities and research units and mining companies, to the benefit of all parties. In Poland, these are often agreements aimed at long-term cooperation in the field of education, training, joint work on innovations [81] or joint implementation of research projects. In the Silesian voivodeship these included, among others, projects implemented as part of Horizon 2020 aimed at technological development and the introduction of IT innovations (such as IlluMINEation, SIMS, RockVader) and projects implemented under the Research Fund for Coal and Steel, aimed at improving environmental results (such as MERIDA, RECOVERY, TEXMIN, STRATEGY CCUS, STAMS, MapROC), occupational safety and health using modern technologies (such as ROCD and INDIRES) and improving economic efficiency (such as INESI, COMEX, Coal2GAS).

The aforementioned approaches and solutions clearly show that, in the mining sector, globalization and the knowledge economy also caused material capital, natural resources or labor force to lose their primacy as the leading economic resources and were replaced by knowledge accumulated in person. Human capital is currently a key economic resource that is recognized as a development determinant for all other factors, most fully shaping global development [82]. Its size will determine the current and future situation of national economies and inequalities between them [83]. Therefore, the view that increasing human capital resources through a proper education system should become the imperative of modern times can be considered as fully legitimate. In this approach, education, shaping ethical values and prevailing cultural norms reduce the costs of business activity, including by minimizing wasting resources and increasing the importance of responsibility for the work performed. It implies a more dynamic and stable economic development. Secondly, well-developed social capital, social norms and trust imply more effective anticipation of human behavior and minimize the behavior of interest groups [84], limiting the unpredictability of socio-economic processes and transaction costs. It allows the society to manage the occurring phenomena more correctly and confidently, and the exchange of resources, skills and information becomes more efficient [85].
In this context—from the perspective of investing in the development of human resources—it can be said that the knowledge economy and the Industrial Revolution 4.0 are key determinants shaping the future of Polish mining, in which knowledge accumulated by humans will dominate.

3.4. Space Mining—The Way for the Future

The development of technology is constantly accompanied by an increase in the demand for mineral resources. Both the growing demand for consumer goods and the increased demand for energy put pressure on the mining industry. It is necessary to supply ever greater amounts, but also more and more diversified mineral resources. The development of mining techniques, the progressive automation and digitization of mining, continuous improvement and also the continuous increase in the requirements for staff competences, referred to in the previous paragraphs, allow for a significant increase in the efficiency of the mining process and thus meeting the growing demand. In the long run, even despite further technological development, it does not seem possible to maintain this state of affairs. Natural resources that can be obtained relatively easily are limited. The very process of obtaining them is always associated with some form of interference with the environment. Therefore, it is necessary to try to solve this problem early. It seems that the right direction of exploration is to consider the possibility of acquiring mineral resources beyond the terrestrial globe, i.e., the development of space mining [86–88]. Although the goal set in this way seems abstract and far from practical, it should be noted that for many years space has been perceived as an area of potential mining exploitation. The process to start the economically viable exploitation of celestial resources has therefore basically begun. Space mining can also be seen not only as a way to avoid the inevitably impending crisis related to the possibilities of extracting minerals on Earth, but also as a natural consequence and the culmination of the technology development and staff competences presented in the previous paragraphs. In space mining, one finds the culmination of technology developed for the needs of traditional (on Earth) forms of deposit exploitation. Here, first of all, digital technologies are directly translated. The exploitation of resources identified on both larger (the Moon, Mars) and smaller (asteroids) celestial bodies will require advanced automation of processes. In unfavorable conditions, with delays in signal transmission resulting from the fundamental laws of physics, the use of autonomous devices capable of carrying out independent work and independently solving at least typical problems that arise during it acquires special importance. This area is a special opportunity for the Polish economy. The creation of conditions and incentives conducive to the development of methods and tools of artificial intelligence seems to be one of the key actions that should be taken and, in fact, already is being taken. Although most of the research and research and development works undertaken in these areas do not refer directly to space mining, they nevertheless develop solutions that can be relatively easily adapted to this area of application.

Another aspect that will require undertaking development works is the technologies of mining the material and enriching the obtained output. These technologies must be adapted to the conditions of the exploited celestial body. It seems, however, that the presence of the atmosphere and significant gravity, as in the case of Mars, will allow the use of solutions structurally similar to those currently used on Earth. However, the challenge will be the lack of an atmosphere and the virtually no gravity found on asteroids. It seems, however, that the competences obtained during the development of devices intended for use in terrestrial conditions can be used to develop innovative solutions dedicated to space mining. It will be necessary to solve the problem of the economically efficient transport of excavated material to the vicinity of the Earth, development of a technology for enrichment of minerals in space conditions and ensuring proper service of the machinery and equipment used, so that it is possible to maintain the continuity of production.

Meeting many of the technological and organizational challenges listed here is beyond the capabilities of the vast majority of countries or enterprises. It is therefore necessary to promote far-reaching cooperation in this area. The Luxembourg Space Agency, the
European Space Agency and the National Aeronautics and Space Administration are particularly active in this field. Poland is also involved in the initiatives of these organizations, especially the LSA. Regardless, the current transition from fossil fuels creates specific conditions in countries such as Poland that can and should be used as a lever to accelerate space-oriented development. The transformation that we are already witnessing should be directed with a vision of long-term actions, and not only solving problems that arise on a regular basis. Only this approach will allow for the redirection and appropriate training of staff and the creation of the potential to gain a leadership position in the newly emerging space mining market. This is an opportunity that, in particular, Poland must not miss. Although the transformation of Polish mining towards space mining, as has already been mentioned, will not be possible without extensive international cooperation, it is worth defining the areas in which Poland can be at the forefront of countries providing key solutions for space mining. Achieving such a goal will allow the use of the wealth of experience and many years of mining tradition, on the one hand, and obtaining a stable and inalienable role of a key state in the newly emerging industry.

4. Conclusions

Based on the theses presented in the article, conducted literature research and described megatrends related to the knowledge-based economy and the Industrial Revolution 4.0, it can be assumed that traditional hard coal mining determined by industrialization will diminish. The process of digitization and automation of the mining industry is inevitable and necessary to maintain any efficiency in the mining sector. At the same time, it leads to the departure from a world based on work and traditional industry, as mentioned earlier, and to the transition to a time when work, progress and prosperity are built on the basis of innovation and technological development. The changes taking place focus on selected social and economic aspects and on enhancing of entrepreneurial skills and thus enabling mining regions to become multi-industry regions [89]. For example, in the Silesian voivodeship, the development strategy and an established list of priorities for the region’s pro-technological development shape the convergence process between technologies for the energy and mining industry with biological environmental protection technologies, nanotechnologies, production and processing of materials and information technologies as well as cognitive sciences [90]. These also should enable the full use of the diversified potential of different companies and institutions to ensure energy security of the country and the development of innovation in the mining and energy sector, in line with the knowledge economy principles. All these aspects have to be taken into consideration when preparing regional transition plans to minimize negative social and economic costs.

According to the above thesis, a considerable role should be attributed to education, not only as a tool for transferring knowledge and skills, but also a key determinant for shaping social attitudes and behavior. In this light, processes related to the knowledge-based economy, the Industrial Revolution 4.0 and the automation of the economy may determine, to an increasing extent, the unexpected and previously unknown phenomena and processes in the social, environmental and economic sphere. The vision of the future of hard coal mining fits in with the above theses. It seems that a breakthrough factor shaping the future of this industry—coherent with the knowledge-based economy and Industry 4.0 logic—is the implementation of principles of intelligent mining. As an example, the assumptions and work in progress on “e-mines” are described in this article. At the same time, intelligent mining is a broader organizational transformation, not just a “digital mine”. This process also involves incorporating new solutions into all aspects of a mining company’s operations, affecting the way decisions are made, the way employees are involved and the range of necessary skills of employees [91]. Achieving the goal of an intelligent mine can be comprehensively defined by the available model for the development of the mining offer in the direction of moving away from the traditional “miner shift” to permanent development based on the most modern and integrated solutions supporting the automation of extraction of raw material. In this process, knowledge and appropriately profiled qualified
staff must form the most valuable resource shaping the future of hard coal mining [80]. A decisive role in creating the development of intelligent mining may be played by overcoming mental barriers to the implementation of the principles of a knowledge-based economy and the Industrial Revolution 4.0. As many sources mentioned in this article prove, the pursuit of development determined by the abovementioned processes leads directly to economic growth in the dimension of companies, regions, state and local communities, favoring social inclusion and strengthening people’s sense of full life [92]. Therefore, it is worth integrating existing and innovative solutions already implemented in the mining sector to decrease its carbon emissions as part of a long-term transformation plan.

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