RECULTIVATION AND SUSTAINABLE DEVELOPMENT OF COAL MINING IN KOLUBARA BASIN

by

Ivica M. RISTOVIĆ [a*], ***Milan P. STOJAKOVIĆ*** [b], **and** ***Milivoj I. VULIĆ*** [c]

[a] Faculty of Mining and Geology, University of Belgrade, Belgrade, Serbia
[b] ES RB Kolubara, Public Enterprise Electric Power Industry of Serbia, Lazarevac, Serbia
[c] Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia

Original scientific paper
UDC: 662.64:504.7
DOI: 10.2298/TSCI091123002R

Coal plays a fundamental role in global development, but the coal mining industry exerts impact on the environment, society, and economy. Kolubara Coal Company produces about 30 million tonnes of coal, and digs about 70 million m^3 of overburden per year. The main result of surface coal is certainly taking agricultural land, so that surface mines, which affect large areas in Kolubara, about 100 hectars a year, causing a number of problems related to the recultivation of degraded area after coal extraction.

The lignite extraction through the method of opencast mining in Kolubara is about 60 years old. The previous exploitation usage is characterised by the fact that the disposal of overburden is made non-selectively, whereas the top soil layer is not being preserved. The recultivation is carried out in parallel with overburden excavation. It is necessary to preserve the fertile soil layer through selective excavation in order to bring the soil back to its previous purpose – agricultural production.

The objective of this paper is mainly to point out the need for the further expansion of the utilisation of fossil fuels, which in turn reduces the emission of CO_2, and thus reduces or prevents global climate changes on Earth. In addition to that, bringing back deteriorated terrains to their previous purpose – agricultural production, or the afforestation – contributes to the maintenance of ecological balance in nature, which then makes coal mining sustainable.

Key words: *mining, recultivation, sustainable development, economic development, environment, social responsibility*

Introduction

A widely accepted definition of sustainable development is development that meets the needs of the present generation without undermining the capacity to meet future generations' needs. Sustainable development is a synthesis of three fields of our activity: economic development, environment protection, and social responsibility.

The open-pit mining of lignite is distinctive through the fact that it requires large terrain surfaces. Lignite is a type of coal which is relatively poor in quality and therefore mostly

* Corresponding author; e-mail: ivica@rgf.bg.ac.rs

used for the production of electrical energy in thermal power plants. In order to make this process cost-efficient, it is necessary to achieve a high coal production rate. On the other hand, a high production of electricity and thereby of coal is subject to the energy demands of modern society.

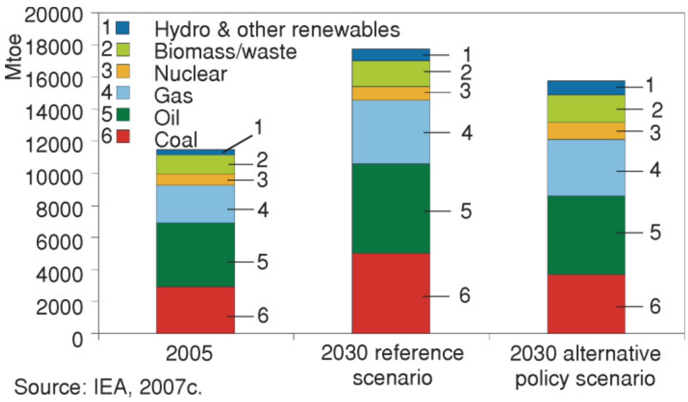

Figure 1. Energy demand changes according to two scenarios for 2030 (color image see on our web site)

According to the IEA World Energy Outlook 2007 (WEO 2007) reference scenario, "global primary energy demand is projected to increase by 55.1% between 2005 and 2030, to a total of 17.721 million tones of oil equivalent (Mtoe)". Figure 1 represents energy demand changes according to two scenarios for 2030. All of the energy growth forecasts have major CO_2 emission consequences. The WEO 2007 reference scenario sees CO_2 emissions increase from 26.6 gigatonnes CO_2 ($GtCO_2$) in 2005 to 34.1 $GtCO_2$ in 2015 and 41.9 $GtCO_2$ in 2030. In the WEO 2007 alternative policy scenario, emissions rise to 31.9 $GtCO_2$ in 2015 and 33.9 $GtCO_2$ in 2030. In the IEO 2007 forecast, CO_2 emissions in the reference case increase from 26.9 $GtCO_2$ in 2004 to 33.9 $GtCO_2$ in 2015 and 42.9 $GtCO_2$ in 2030 [1].

Table 1. Quantity of air polluters (CO_2, SO_2, and NO_x) emitted into the atmosphere in Serbia

CO_2 [kT per year]	SO_2 [kT per year]	NO_x [kT per year]
33501	449.33	59.03

According the research in Serbia at the national level, the quantity of air polluters (CO_2, SO_2, and NO_x) emitted into the atmosphere in Serbia is presented in tab. 1 [2].

For a country (either developed or developing) to understand the role of energy use at the national level, it is necessary to understand the relationship of energy use to economic activity and social well-being, and the relationship between energy and GDP indicates the economic development of a country. Industrial production in modern societies is kept in pace by socio-economic growth [3].

Depending on energy resources available, any country may choose the method of its utilisation. The Republic of Serbia has several coal basins, with three of them being dominant: the Kosovo, Kolubara, and Kostolac coal basins. According the Strategy of Development of Energy System in the Republic Serbia up to 2015, and according the literature, the greatest geological energy resource in Serbia is coal (about 80%), particularly low rank lignite (about 65%) [4]. Lignite is the largest natural energy source in Serbia. The share of coal is about 88% in total, and possible energy production using the remaining reserves available (small rivers, small coal mines, and oil shale), can be about 10% most [5, 6].

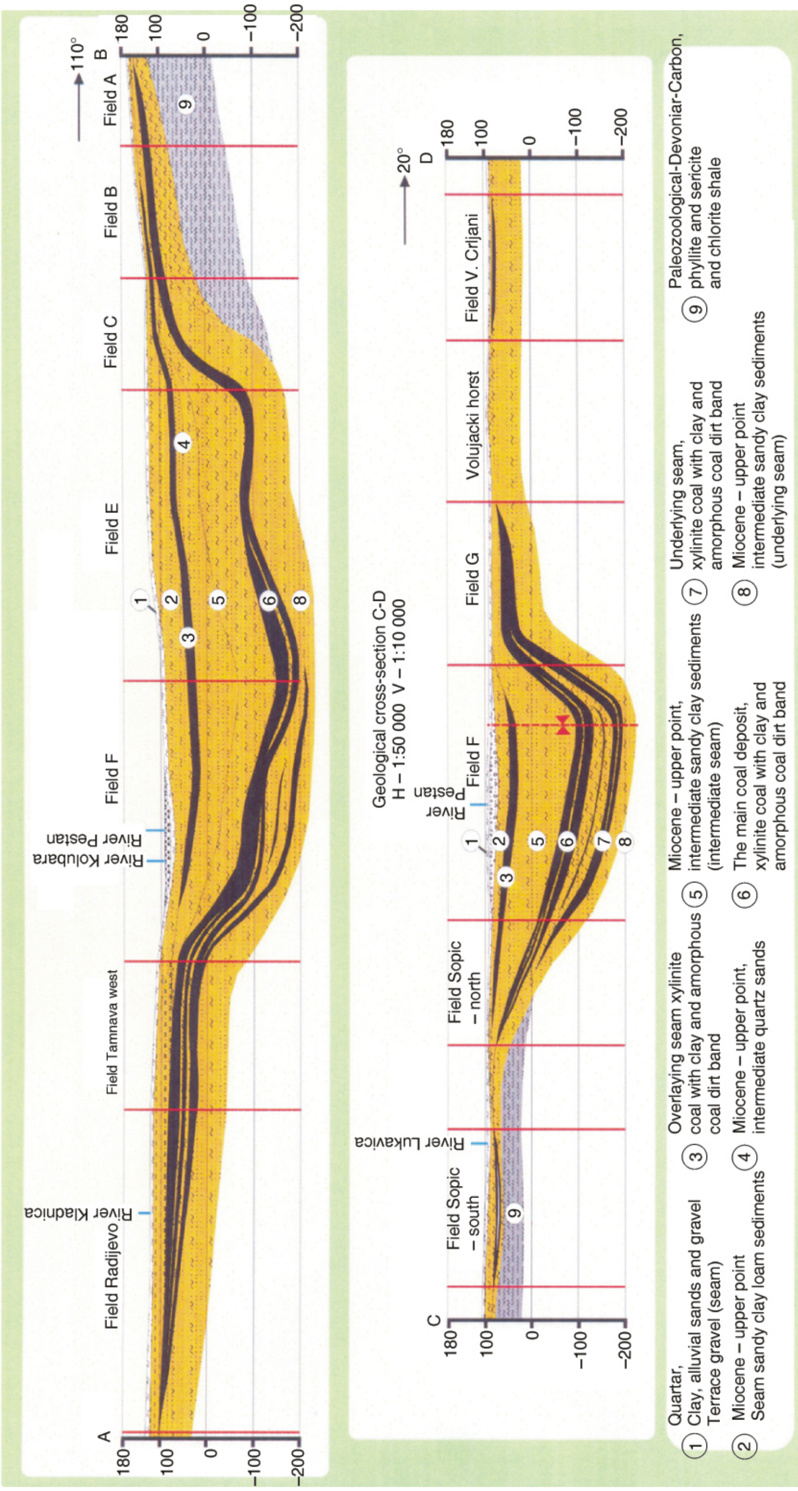

Figure 2. Typical geological profiles throughout the Kolubara coal basin (Source Kolubara coal basin)

Material and methods

Method of lignite extraction

The coal from Kolubara basin is lignite of relatively low quality, *i. e.* of low carbonisation degree, and therefore it is largely used for combustion in thermal power plants and for the generation of electricity. The Kolubara coal was formed some 10 million years ago in shallow waters of the Panonian sea. The coal was formed in the time when the climate in this area was a warm, subtropical one. Figure 2 shows typical geological profiles of the Kolubara coal basin.

The lignite extraction through the method of open-cast mining in Kolubara is about 60 years old. It is a period when there were major changes in operating conditions. The equipment, laws, regulations, even the approach to open-pit mining has changed in compliance with international trends. The Kolubara coal basin is situated 50 km in the south-east of Belgrade, and occupies a territory of approximately 600 km^2. The coal production is being carried out in four open-pits: fields C and D, Tamnava eastern field and Tamnava western field [7]. Figure 3 shows the mining fields of Kolubara coal basin.

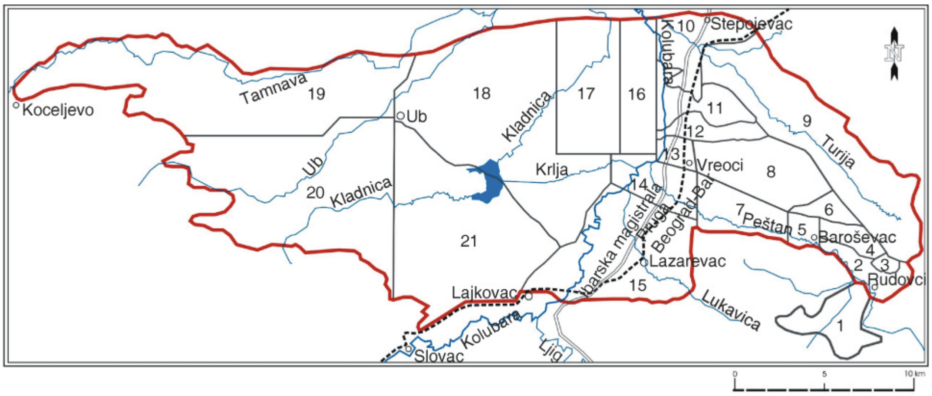

Figure 3. Kolubara basin divided into mining fields
1 – field Kruševica, 2 – field Rudovci, 3 – field A, 4 – field B, 5 – field C, 6 – field Baroševac, 7 – field E, 8 – field D, 9 – field Turija, 10 – field Stepojevac, 11 – field Veliki Crljeni, 12 – field Volujak-Vreoci, 13 – field G, 14 – field F, 15 – Šopić-Lazarevac, 16 – field Tamnava-east, 17 – field Tamnava-west, 18 – field Radljevo, 19 field – Trlić, 20 – field Zvizdar, 21 – field Ruklade

Table 2. Coal and overburden production in Kolubara in 2008

Open pit	Realised overburden production [m^3]	Realised coal production [t]
Field B	2,981,897	1,091,320
Field D	39,590,875	14,069,026
Tamnava – eastern field	7,998,299	5,016,965
Veliki Crljeni	1,923,670	–
Tamnava – western field	24,672,871	10,361,665
Total	77,167,612	30,538,976

An average annual production amounts to approximately 30 million tonnes of coal and about 70 million m^3 of overburden. Table 2 shows the coal and overburden production in Kolubara in 2008. The coal and overburden are mainly excavated by bucket wheel excavators and transported by conveyor belts.

Figure 4 shows overburden and coal benches in the open-pit mine Kolubara.

Figure 4. Overburden and coal benches in the open-pit mine Kolubara

The process of coal excavation consists of several cycles: the cycle of excavation, disposal, and recultivation. The mining works begin after the expropriation. First, the preparation of the terrain envisaged for mining is conducted. The preparation of the terrain necessitates the demolition of constructions, felling of trees, relocation of watercourses, roads, *etc*. Then the overburden is excavated, transported and dumped using the mining machinery. Today, bucket wheel excavators, conveyor belts and stackers are mainly used. When the coal seam appears, such a seam is excavated and transported to the crushing plant.

Based on the process of coal excavation, explained up to this point, and its relation to the recultivation, there are few important characteristics that stand out:

– notwithstanding the occupancy of large areas and the change in the purpose of the land, large parts are still brought back to the previous state; it virtually means that they are temporarily occupied by mining activities, in a period of some ten years, and that they can be reused as before following this period,
– a part of the area occupied by the exploitation cannot be brought back to the state prior to the beginning of the exploitation,
– area occupied by the external dump, although it is generally (as a rule) higher than the terrain before mining activities, is still brought back to the state so that it can be reused, and
– at the end of mining activities, the mine becomes the owner of large areas of agricultural land and forests; according to the law, the owner of an agricultural land and forest is obliged to work the soil and control forest husbandry.

Figure 5 represents the paths of landscape development following a disturbance [8].

In practice, there is a number of ways to resolve this issue. There are many possibilities for, and many examples of an efficient utilisation reclaimed areas of lignite mines in the world [9-13].

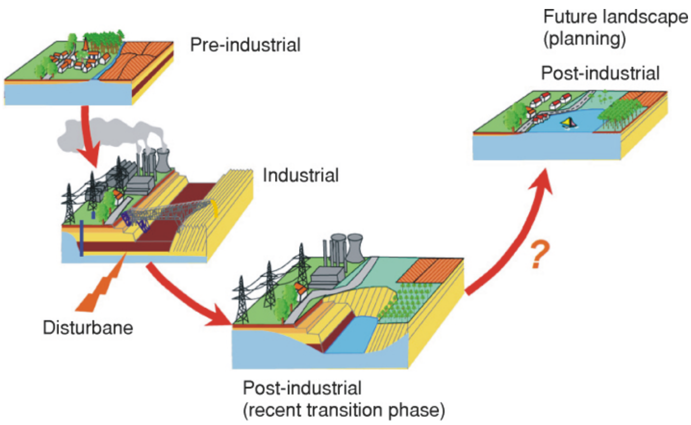

Figure 5. Landscape development following a disturbance (Source Huttl, R. F.)

Method of recultivation of Kolubara open pit mine

Recultivation is a process whereby a part of a dump is brought back to the state of land similar to the one before the excavation. In this way, the negative impact of the excavation of overburden and coal is lessened. The recultivation process is a legal obligation, which is to be implemented according to a recultivation project. The recultivation project is a mandatory, integral part of a mining project. There is a need for a national system of quality control inspection for land recultivation and reclamation sites, and provision for training in the special problems of managing reclaimed lands [14]. It consists of two parts: technical recultivation and biological recultivation and reclamation.

Technical recultivation is a procedure of levelling and preparation of a dump area for the biological recultivation. The dump, especially its vertical part, is highly rough and it is necessary to put it into such a state which enables biological recultivation. Criteria for the creation of a dump are that it is stable, technically, and economically justified, and that it is not ideally flat. Before the biological recultivation begins, the quality of land is to be investigated, in two directions. Primarily, it has to be determined whether the soil contains an inadmissible concentration of harmful, toxic matters such as heavy metals. Then the soil quality is determined, in terms of the contents of humus matters, minerals, and acidity, in order to define corrective measures. If the soil contains heavy metals, their concentration and mobility have to be identified. Then we should determine if and which type of agricultural products may be cultivated, or the type of forestation that would be needed [15].

All these factors, area topography and its quality define the recultivation type. Flat parts are used for the agricultural reclamation and production, while rough parts and slopes are afforested [16]. In addition to the dump area, there is also a depression that remains after mining activities, which is naturally being filled with water. It results from the fact that the excavated coal is carried away and only the overburden is brought back to the working cavity, so there is a deficit of material. As a result of the processes of mining and recultivation, *i. e*. the land and watercourse restructuring, we obtain three units. The first unit is an external dump, which is restored by agricultural species at its flat parts of slopes while the rough parts are reclaimed by for-

Table 3. Overview of the existing condition of soil in reclaimed areas

Field	Expropriated area [ha]	Dump [ha]		Reclaimed [ha]			
		Internal	External	Forests	Agricultural land	Orchards	Seed-plots
Field D	2.754	1.231	723	509	235	16	12
Field B	885	–	–	301	6	–	–
Tamnava-eastern field	2.219	825	378	60	23	–	4
Tamnava-western field	618	192	–	–	–	–	–
Total	6.476	2.248	1.101	870	264	16	16

est seedlings. The second and largest part is the area of an internal dump, which is also reclaimed, depending on the type of the terrain and the composition of the soil. The third part is a lake, or a number of them, that could be also arranged to serve as tourist facilities, which is a common practice in some countries, or for other purposes [17, 18].

The recultivation is carried out in parallel with overburden excavation. Today we have about 1100 ha of reclaimed land in Kolubara, about 870 ha of forest seedlings, generally situated in rough parts of a dump and about 260 ha of agricultural land. Table 3 shows the overview of the existing condition of the soil in reclaimed areas.

As we can see from given information, open-pit lignite extraction in Kolubara coal basin has minimised by approximately 6500 ha, the cultivable and arable land and wood area. In order to reduce negative environmental effects, it is necessary to recultivate, reclaim, and afforest or convert into cultivable agricultural land all of the 6500 ha, which are in the structure of the expropriated land in the Kolubara coal basin. Figure 6 shows reclaimed soil turned into an arable agricultural land and fig. 7 shows the afforested reclaimed soil in the open-pit mine Kolubara.

Figure 6. Reclaimed arable soil

Figure 7. Afforested reclaimed soil

Due to the coal extraction and ground dumping, a large number of lakes have been formed, by intersecting certain watercourses of rivers, and streams which even now fill the latter with water, and by accumulating water in certain depressions and mining shifts which were formed in ground dumps. During summertime, the accumulated water may be very successfully used for the irrigation of the crops that will be grown on the reclaimed surfaces. The seventeen

Figure 8. Reclaimed depression of the pit

Figure 9. Lake during the reclamation

lakes could be used, as well as for the irrigation, for fish and spawn breeding. Figure 8 shows one of the reclaimed depressions in the open-pit mine Kolubara and fig. 9 shows a lake in the process of reclamation.

Chemical analysis

Maximum allowable concentrations of hazardous and harmful substances in soil differ from country to country. Table 4 shows maximum allowable concentrations (MAC) of trace elements in agricultural soils, proposed or given in directives in various countries and in different years [19].

Table 4. Maximum allowable concentrations of trace elements in agricultural soils proposed or given in the directives in various countries, and different years [19]

Chemical element	Poland (1993)	UK (1987)	Germany (1992)	Euro comm. (1986)	USA (1993)
Cadmium (Cd)	1-3	3-15	1.5	1-3	20
Lead (Pb)	70-150	500-2000	100	50-300	150
Mercury (Hg)	5	–	1	1-1.5	8
Arsenic (As)	30	10	–	–	–
Chromium (Cr)	50-80	–	100	50-150	1500
Nickel (Ni)	30-75	20	50	30-75	210
Fluorine (F)	–	–	–	–	–
Copper (Cu)	30-70	50	60	50-140	750
Zinc (Zn)	100-300	130	200	150-300	1400
Boron (B)	–	–	–	–	–

In Serbia, maximum allowable quantities of hazardous and harmful substances in soil and water for irrigation and the methods for their examination (Official Gazette of the Republic of Serbia No. 23/94), which may damage or modify the production capacity (fertility) of an agricultural land and the quality of water for irrigation, are envisaged in the rules on maximum allowable concentrations of hazardous and harmful substances. Hazardous substances, in terms of the rules, are: cadmium, lead, mercury, arsenic, chromium, nickel, and fluor; while harmful substances are: copper, zinc, and boron. Table 5 shows maximum allowable concentrations of hazardous and harmful substances as prescribed in the Republic of Serbia [20].

In order to perceive the environmental aspect of the current state and further preservation of the soil in the area of the open-cast mine Kolubara, which is mainly agricultural, analyses of the overall contents of heavy metals in the soil have been made, in the mine itself and in its vicinity, which is the area of future mining operations. The collected data serves to formulate and further enforce certain regulatory and institutional procedures which contribute to the soil keeping its economical and social potential after the reclamation. Table 6 shows the analyses of the overall content of heavy metals.

Table 5. Maximum allowable concentrations of hazardous and harmful substances prescribed by the rules in the Republic of Serbia

Chemical element	Maximum level in soil [mg per kg soil]	Maximum level in water [mg per liter of water]
Cadmium (Cd)	3	0.01
Lead (Pb)	100	0.1
Mercury (Hg)	2	0.001
Arsenic (As)	25	0.05
Chromium (Cr)	100	0.5
Nickel (Ni)	50	0.1
Fluorine (F)	300	1.5
Copper (Cu)	100	0.1
Zinc (Zn)	300	1.0
Boron (B)	50	1.0

Table 6. Overall content of heavy metals in the soil.

Depth [cm]	Fe [%]	Mn [mgkg^{-1}]	Cu [mgkg^{-1}]	Zn [mgkg^{-1}]	Co [mgkg^{-1}]	Ni [mgkg^{-1}]	Cr [mgkg^{-1}]	Pb [mgkg^{-1}]	Cd [mgkg^{-1}]
Sample 1									
0-30	4.59	714	34.40	54.71	17.24	173.83	85.80	26.09	–
30-60	5.45	718	33.30	58.69	18.31	192.29	97.44	30.60	–
60-90	4.50	660	34.50	62.42	20.30	204.82	109.17	34.14	–
Sample 2									
0-30	4.46	650	29.55	50.02	17.29	159.44	83.32	30.60	–
30-60	4.34	661	27.00	46.60	17.03	155.03	89.43	27.89	–
Sample 3									
0-30	4.38	695	33.40	56.00	18.26	170.10	92.00	33.66	–
30-60	4.25	668	26.15	48.88	17.75	130.51	79.28	28.66	–
Sample 4									
0-30	3.70	658	29.10	50.73	17.32	161.12	88.54	24.82	–
30-60	4.17	689	29.90	53.07	18.72	169.15	95.99	28.70	–
Sample 5									
0-30	3.72	543	24.70	37.41	17.06	231.23	123.31	21.06	–
30-60	4.90	548	24.40	37.21	17.32	235.39	108.67	18.41	–

The analysis of the overall content of heavy metals indicates an increased content of some heavy metals (mainly nickel and chromium, shading values), of which the presence relates to the origin of these alluvial lands. Such analysis is the analysis of potential pollution agents, because their accumulation in herbal products may cause the removal of these products from the further utilisation. As such large concentrations of heavy metals appear mostly in deep seams, in the process of soil reclamation, the possible soil pollution caused by these metals has to be considered, as well as measures which could reduce their accessibility to the flora [21].

Social aspects of mining extraction and recultivation

Sustainable development is a synthesis of three fields of our activities: economic development, environmental protection, and social responsibility. The social responsibility of the company is defined as a balance of working and personal life of the employees, equal opportunities, diversity at the workplace (ethnical minorities, handicapped and older people), ensuring of retraining of the dismissed employees, *etc*. The European Commission defines corporate social responsibility (CSR) as a conception under which the company integrates the social and environmental points of view into its business and into communication with the interested parties [22].

In addition to the afore-mentioned, typical changes, and the condition of the environment, it would also be interesting to discuss the flow of other resources, *i. e.* of social changes accompanying the exploitation. At the beginning of its operation, a mine has a whole deposit (coal) and mining machinery available to it. There is not enough skilled staff, considering that the population in the vicinity is agricultural, and there is no developed industry supporting said mining activities.

During mining operations, excavations lead to the decrease in coal reserves and to the increase in the number of skilled workers. The occupied area, and therefore the reclaimed area, are enlarged. It leads to the increase in the number of inhabitants in the vicinity, due to the increase in monetary flow and the demand for experts. The starting point is typically the acceptance of sustainable developmental principles at board-room level as corporate goals, and then informing the workforce, investors, and others of that commitment. Relevant employees need to be engaged as a first step in the practical application of sustainable development principles, followed by the gradual extension of training in sustainable methods of working to the workforce as a whole [23]. Mining companies were among the first to introduce the practice, now common, of building and maintaining schools, clinics, and sports facilities for their employees. It is not uncommon for them to be made available to other people living in the vicinity of the company location [24, 25].

At the end of the coal exploitation, there is no coal; however, there are large agricultural and forest areas. Both the structure and the number of inhabitants are suitable for industry, not agriculture or forestry. There are also machines with repair shops and plants, which formerly served as a support to the coal production. However, they cannot be used for land farming; the same is the case with the existing population structure. Big social problems then arise. A whole functional environment which has been developing for many years is no longer functional because mineral resources are not renewable, but rather limited by time and space.

The whole environment turns into an environment with new characteristics and non-functional social content. At that, it has to comply with the sustainable development. The solution for this problem may go into two directions. One being that during the enlargement of agricultural and forest areas after the recultivation process, it is necessary to adapt the companies which had been specialised for the production of mining equipment and to turn them into profitable ones. In addition to that, factories and repair shops, unless market oriented, should be turned into rentable factories of related products.

Results and discussion

All of the issues in connection to the relationship between an open-pit mine and the environment are defined by relations arising from the soil pollution. The technological process of lignite exploitation causes, to a certain extent, the change, *i. e.* deterioration, of the original morphological and pedological structure of the terrain and soil, and the release of harmful substances – mineral dust into the air, in a certain concentration. The main impact is related to the deterioration of the upper seam structure during mining operations. The above negative impact may occur as a result of the excavation of the upper seam and its inadequate disposal, and of mixing the upper seam with the lower one, as well as other barren materials. The impact of lignite exploitation also represents a potential contamination of the upper seam due to the precipitation of dust from the air. In addition to the afore-mentioned impacts, it is necessary to emphasise the disappearance of the arable upper seam as a result of the building-up in infrastructure facilities (roads, railroad tracks, water-ways, industrial areas, *etc.*) and of the change in the purpose of the soil in the vicinity of the mine.

In any case, open-cast coal mining leads to the disturbance of geological layers where different sedimentary products are being mixed, which means that a completely new, anthropogenic land, *i. e.* substratum, is created, without any resemblance to the original land, which is now called a deposol. The previous exploitation usage is characterised by the fact that the disposal of overburden is made non-selectively, whereas the top soil layer is not being preserved, which can later cause a number of complex problems in making the overburden suitable for herbal production, and in bringing the land back to its previous state.

Visual pollution as a criterion of the relationship between a mine and its environment implies that the characteristics of the landscapes' appearance are a qualitative factor which occurs as an element of degradation of the existing and established relations. In order to switch from a descriptive impact assessment in this domain to quantitative methods, which include a complex valorisation of the area, it is necessary to perform a series of specific analytical procedures during which high-technology graphic and visual pieces of information are needed. The impact of open-cast lignite exploitation on modifications of landscape characteristics, in terms of morphological modifications of the terrain, indicates the creation of large-scale depressions and the formation of outside overburden dumps. Due to the excavation process, depressions are created in the working cavities, and this causes changes and deterioration of the morphological and aesthetic characteristics of the existing natural landscape [26]. Considering that the character and the scope of mining works are such that the previous morphological appearance of the degraded areas cannot be restored, the obligation of a company is to adapt, in the best possible way, through the technological exploitation process, *i. e.* overburden disposal activities and technical reclamation, the working cavity to the existing natural environment, in terms of functionality and aesthetics.

Generally speaking, within the recultivation of deteriorated surfaces, it is necessary to apply [27]:

- technical measures – which contribute to the improvement of resistant and deformable characteristics of the dump and directly influence the enhancement of the erosion stability of slopes,
- biotechnical measures – which, along with the technical measures, contribute to faster achieving and maintaining the dump stability, and
- biological measures – which imply the implementation of agricultural and forest improvements that contribute to the stability and maintenance of reclaimed areas, but they are much more significant from the aspect of area revitalisation and establishing natural biocenoses.

Notwithstanding all the restructuring cases, a number of people will be superfluous. They will then be re-educated or they will leave, which is certainly a problem accompanying the mining industry. Favourable circumstances in the whole process of turning an agricultural terrain into an industrial one, which is reclaimed at a later stage, is the fact that this process is very slow and that good planning may adequately rearrange it. Depending on the size of the deposit, the process of turning an agricultural, forest, or urban environment into an industrial (mining) one, and then, by the recultivation process, back again into the agricultural or forest one, may be of different durations, but such processes often last for many decades. The unfavourable characteristic of this transformation process is that, due to its long duration, there is a high probability of the emergence of economic and social crises and negative flows.

Conclusions

"Coal is a crucial and enduring element in a modern, balanced energy portfolio, providing a bridge to the future as an important low cost and secure energy solution to sustainability challenges " [28]. The coal extraction in Kolubara coal basin may last for about 50 years, which is the corresponding amount of coal reserves. Namely, we shall spend the coal 10.000 times faster than it took it to be formed. It is certainly a great disturbance of the natural cycle of oxygen and CO_2 circulation. Sustainable development requires the maintenance, rational use, and enhancement of natural resources, as well as a balanced consideration of ecology, economy, and social justice [29].

There are plenty of arguments to prevent further expansion of the utilisation of fossil fuels and therefore coal [30]. This is one reason, among others, why it is necessary to perform the recultivation of a dump even though it has a relatively low, although favourable, impact on the environment. As we are talking about fertile alluvial lands, it is necessary to preserve the fertile soil layer through selective excavation in order to bring the soil back to its previous purpose – agricultural production. The forestation of soil and terrains deteriorated by open-cast lignite mining prevents further deterioration processes, contributes to the maintenance of the ecological balance in nature, and enhances the absorption of CO_2 from the air and the content of the oxygen therein.

Notwithstanding the fact that nature has efficient mechanisms for balancing and equilibrating the gas concentration in the air, it also has limited capacities in this process. We gave ourselves the right to use the coal, as it is suitable for us. Because of this, we have a great responsibility to do that in the best possible way, bearing in mind future generations, by utilising coal reserves in compliance with the principles of the sustainable development referring to the utilisation of non-renewable energy resources and by reclaiming deteriorated surfaces resulting from the process of coal extraction, and all that in the function of sustainable development, mining exploitation, and utilisation of energy from nature.

References

[1] ***, Coal Industry Advisory Board, Clean Coal Technologies, Accelerating Commercial and Policy Drivers for Deployment, OECD/IEA, 2008

[2] Stefanović, G., Trajanović, M., Duić, N., Ferk, M., Pollution Data Tracking in the Western Balkan Countries: A State-of-the-Art Review, *Thermal Science, 12* (2008), 4, pp. 105-112

[3] Dincer, I., Energy and GDP Analysis of OECD Countries, *Energy Conversion and Management, 38* (1997), 7, pp. 685-696

[4] Strategy of Development of Energy System in the Republic Serbia up to 2015 (in Serbian), Published by Ministry of Mining and Energy, Belgrade, 2005, *Serbian Official Gazette*, No. 44, 2005, Belgrade

[5] Oka, S., Sedmak, A., Djurović-Petrović, M., Energy Efficiency in Serbia – Research and Development Activity, *Thermal Science, 10* (2006), 2, pp. 5-32

[6] Oka, S., Sedmak, A., Djurović-Petrović, M., Energy Efficiency in Serbia National Energy Efficiency Program – Strategy and Priorities for the Future, *Thermal Science, 10* (2006), 4, pp. 7-16

[7] Ristović, I., Curent Situation and Development of Energy Mining in Serbia, 2nd International Symposium Energy Mining 08, Modern Tendencies in the Development of Energy Mining (Ed. I. Ristović), Tara, Serbia, 2008, pp. 1-10

[8] Huttl, R. F., Ecology Development of Post-Mining Landscapes in the Lusatian Lignite Mine District, International Conference Sustainable Post-Industrial Land Management, Kraków, Poland, 2004, http://www.minpan.krakow./pl/pbs/spilm/prez/Huettl.pdf

[9] Handley, J. F., *et al*., Land Restoration Using an Ecologically Informed and Participative Approach, Land Reclamation: Acheving Sustainable Benefits, Balkema, 1998, pp. 171-185

[10] Huttl, R. F ., Ecology of Post-Mining Landscapes in the Lusatian Lignite Mine District, Germany, Land Restoration Using an Ecologically Informed and Participative Approach, Land Reclamation: Acheving Sustainable Benefits, Balkema, 1998, pp. 187-192

[11] Strzyszcz, Z., Recultivation and Landscaping in Areas after Brown-Coal Mining in the Middle-East European Countries, *Water, air and Soil Pollution, 91* (1996), 1-2, pp. 145-157

[12] Haigh, M., The Aims of Land Reclamation, Reclaimed Land: Erosion Control, Soils and Ecology (Ed. M. Haigh), Land Reconstruction and Management, Vol. 1, A. A.Balkema, The Netherlands, 2000, pp. 1-20

[13] Ibarra, J. M. N., Heras, M. M., Opencast Mining Reclamation, Forest Restoration in Landscapes, Springer-Verlag, New York, USA, 2005, pp. 370-376

[14] Haigh, M. J., Degradation of Reclaimed Lands Previously Disturbed by Coal Mining in Wales: Causes and Remedies, *Land Degradation & Development, 3* (2006), 3, pp. 169-180

[15] Broll, G., *et al*., Rekultivierung in Bergbaufolgelandschaften: Bodenorganismen, bodenökologische Prozesse und Standortentwicklung, Rekultivierung in Bergbaufolgelandschaften, 2000, Springer-Verlag, pp. 1-306

[16] Huttl, R., Minesite Recultivation, Springer-Verlag, New York, USA, 2002, pp. 1-172

[17] Hage, K., Recultivation in the Lusatian Mining Region – Targets and Prospects, *Water, Air & Soil Pollution, 91* (1996), 1-2, pp. 43-57

[18] Kuntze, H., Soil Reclamation, Improvement, Recultivation and Conservation in Germany, *Zeitschrift für Pflanzenerährung und Bodenkunde*, VCH, Weinheim, *149* (1986), 4, pp. 500-512

[19] Kabata-Pendias, A., Trace Elements in Soils and Plants, 3rd ed., CRC Press, Boca Raton, Fla., USA, 2001

[20] Ristovic, I., Jovanovic-Ilic, B., Mining and Hazardous Waste in the View of Regulations in Serbia and Legal Acts of Environmental Protection World Agencies (in Serbian), 15th International Symposium Ecological Truth, Soko Banja, Serbia, 2007, pp. 514-519

[21] ***, University of Belgrade, Faculty of Agronomy, Zero Analysis of Agrochemical Characteristics of Open Pit Mine Kolubara (in Serbian), Belgrade, 2008, pp. 1-20

[22] Kalabis, J., Brokeš, J., Vacková, L., Sustainable Development in Management of a Construction Company, International Workshop Economic and Social Aspects of Sustainable Development, Brno, Czech Republic, 2005, pp. 2-11

[23] ***, University of Belgrade, Faculty of Mining and Geology, Analysis of the Impact of Surface Mine Tamnava East Field on the Environment (in Serbian), Belgrade, 2004, pp. 1-110
[24] ***, HPC Harress Pickel Consult AG, LDK Consultants SA, EAR, Assessing the Environmental Impact the Mine Expansion Tamnava West Field (in Serbian), 2002, pp. 1-150
[25] Ristović, I., Soil Protection Against the Influence of Mining Activities, *Proceedings*, 1st International Conference Environment Protection in Industrial Areas (in Serbian), Kosovska Mitrovica, Serbia, 2007, pp. 131-138
[26] ***, Coal Industry Advisory Board, International Energy Agency, Case Studies in Sustainable Development in the Coal Industry, Case Studies: People, IEA Publications, Paris, 2006
[27] ***, The Aluminium Industry's Sustainable Development Report, International Aluminium Institute, London, Associations and Int. Org/UNEP Report dated 20.11.01 CPC and EE&LCI/LCA, London, 2001
[28] Singh, G., Environmental Issues with Best Management Practice of Coal Mining in India, Responsible Mining – a Multi-Stakeholder Perspective, TERI, New Delhi, 2006, pp. 189-198
[29] Wellmer, F. W., Becker-Platen, J. D., Sustainable Development and the Exploitation of Mineral and Energy Resources: a Review, *International Journal of Earth Sciences, 91* (2002), 5, pp. 723-745
[30] Suwala, W., Modelling Adaptation of the Coal Industry to Sustainability Conditions, *Energy, 33* (2008), 7, pp. 1015-1026

Paper submitted: November 23, 2009
Paper revised: February 10, 2010
Paper accepted: February 13, 2010