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Technical, principle-based guidelines for designing and implementing a programme for efficient, safe and environmentally conscious mine closure in Albania and Serbia

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GENEVA, 2022

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ACKNOWLEDGEMENTS

This work was carried out by United Nations Economic Commission for Europe (UNECE) with the help of the **Central Mining Institute (GIG)** and two national consultants:

- **Mr. Genci Tomini** (Albania), and
- **Mr. Radoslav Vukas** (Serbia).

The document was developed under the supervision of **Michal Drabik**, secretary of the UNECE Group of Experts on Coal Mine Methane and Just Transition and with the support of **Oleg Dzioubinski**, Regional Adviser at the UNECE Sustainable Energy Division.

The study was reviewed and edited by **Michal Drabik** and **Raymond Pilcher**, Chair of the UNECE Group of Experts on Coal Mine Methane and Just Transition, with a contribution by **Dario Liguti**, Director of the UNECE Sustainable Energy Division.

The UNECE Group of Experts on Coal Mine Methane and Just Transition also discussed and approved the document at its 18^{th} session on 20-21 March 2023 in Geneva, Switzerland.

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Contents

Acronyms

ALL	Albanian Lek
AMM	Abandoned Mine Methane
BAT	Best Available Techniques
CCGT	Combined-Cycle Gas Turbine
CH_4	Methane
CHP	Combined Heat and Power
CMM	Coal Mine Methane
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
EP	Excavation Panel
GHG	Greenhouse Gas
GIG	the Central Mining Institute
GWP	Global Warming Potential
HTF	Heat Transfer Fluid
IT	Information Technology
kcal/kg	Kilocalories per kilogram
Km	Kilometre
km^2	Square kilometre
M	Metre
m^2	Square metre
m^3	Cubic metre
MJ/kg	Mega joules per kilogram
Mt	Million Tonnes (metric)
RFCS	The Research Fund for Coal and Steel
t	Tonnes (metric)
t/year	Tonnes (metric) per year
UNECE	United Nations Economic Commission for Europe
USD	U. S. Dollar
°C	Degrees Celsius

Executive Summary

The present study assesses the local geological and mining conditions and offers technical, principle-based guidelines for designing and implementing a programme for efficient, safe and environmentally conscious mine closure in Albania and Serbia; it provides information concerning possible hazards related to the closure of underground coal mines and addresses environmental aspects of a post-mining stage of a coal mine life cycle.

The assessment was conducted based on a literature review, information obtained during a fact-finding visit to Albania and Serbia, and the input provided by the local consultants from those countries.

The document identifies the problems related to mine closure in Albania and Serbia and evaluates their scale. It also analyses the potential for repurposing mined lands in the targeted States, emphasizing exploring opportunities for using them for green energy generation. In that context, the premises of alternative scenarios developed under two Research Fund for Coal and Steel's (RFCS) projects, namely POTENTIALS and GreenJOBS, are applied and serve as a basis for evaluation.

Underground coal mining in Albania stopped almost wholly (except for two private mines with a very insignificant output) more than 15 years ago. Since then, mining sites have changed ownership, making supervising them difficult. The most vulnerable spots are near Tirana, Albania's capital, where new settlements are being built in post-mining areas close to the city. Therefore, establishing a monitoring program for subsidence, groundwater, gas, and fire hazards is essential. In terms of repurposing, it would be possible, for example, to create water reservoirs (e.g. for agriculture or industry uses) at those locations. However, additional chemical analyses of the water would be needed, as would the development of rules for its continuous monitoring and treatment. Given the problematic environmental, geological and mining conditions and modest, low-quality coal reserves, reopening underground coal mines in Albania, which the Government has contemplated, should not be considered.

In Serbia, underground coal mining is carried out by the state-owned company that owns eight underground coal mines in southern and central Serbia with annual outputs of, respectively, 300,000 and 400,000 tons. The analysis presented in the study suggests that operations should be limited to only 2-3 active mines, which would however necessitate reorganisation and additional investments. On top of the currently active coal mines in Serbia, there is a large number of mines of various sizes that were operated in the past. Obtaining precise and trustworthy data on most closed mines is difficult for historical reasons.

As some Serbian mines are gassy and still active, serious consideration should be given to the recovery and economical use of coal mine methane (CMM), as opposed to venting it into the atmosphere. In the short term, a greater focus on methane leaks in the workings would improve the safety of underground operations. It could constitute a basis for a new business case after the mine closure. From a longer perspective, the mine closure plans and procedures should take into consideration the abandoned mine methane (AMM) potential, whichn would require a sufficient basis for long-term investments at those sites.

Recommendations on addressing the identified problems in each of the beneficiary States are given concerning the following thematic areas:

- Management and remediation of groundwater and surface water drainage systems, as the occurrence of water hazard in underground coal mines is possible at every stage of the mining cycle;

- prevention of air pollution from fugitive gases, such as methane and carbon dioxide, as these can rise to the surface after the mine is abandoned (mainly by former works that link the mine with the surface, through the covering rock layer if there is sufficient permeability, as well as with water release), and thus lead to accidents such as explosions, asphyxia, or intoxications;
- extinguishing and preventing fires in waste dumps, as spontaneous ignition is a significant and complex threat, the occurrence of which depends on many factors, such as the number of combustible substances, access to oxygen, and the potential for heat accumulation in the dump; moreover, atmospheric conditions, such as wind's speed and direction, insolation, pressure changes, and precipitation strongly influence oxygen access and heat accumulation, and thus also the possibility for spontaneous ignition;
- mined land subsidence that generates damages to buildings and civil structures overlying the mine's footprint, being an inevitable consequence of underground coal mining in mining basins; and
- waste stocks related problems, as mining waste heaps exposed to the weather can be a potential source of chlorides, sulphates and metals released into the environment in acidic surface waters.

The document also analyses the potential for repurposing mined land for future use in each beneficiary State. It describes the applicable mine closure procedures in Albania and Serbia, gives a short overview of the current state of green energy in these countries, and indicates an existing possibility of implementing there the actions identified under two European-financed projects, namely POTENTIALS and GreenJOBS.

The document concludes that the mining sites in Albania and Serbia could be used as a basis for different economic activities that may create green and quality jobs. At the same time, it refers to the experience of other countries, which shows that the effects of coal mining may appear many years after the cessation of mining operations and therefore recommends that both countries strengthen applicable regulations and create programmes for continuous monitoring of their local post-mining areas.

Annex A provides a detailed overview of coal mining in Albania and Serbia.

Annex B contains information on the geologic and mining conditions of the coal basins, and characteristics of coal seams in the targeted States, assesses their coal reserves, and describes their respective mining conditions.

Introduction

This report identifies possible hazards related to the closure of underground coal mines and the environmental challenges that need to be addressed during the mine closure process and afterwards (i.e., post-mining). It was prepared based on a thorough literature review, information obtained during a fact-finding mission (visit) in Albania and Serbia held in December 2022, and the input provided by the local consultants from the targeted countries.

The document provides a theoretical background for actions allowing to mitigate hazards and reclaim the mined land so that it becomes suitable for repurposing and sustainable development. It is designed to improve both beneficiary countries' national capacities to close coal mines and ensure the post-mining sites are safe for the environment and the population. At the end of the process, the reclaimed grounds are ready for further use unrelated to coal mining.

Virtually every action of the mine closure process is associated with a risk, and some of the related hazards can occur even many years after the closure. Hence, the proper closure and dismantling of underground infrastructure should be done to ensure the required safety level over the long term.

This study analyses the below-listed problems related to mine closure. It identifies specific actions allowing to address them in the particular circumstances governing on the ground in the two beneficiary states:

- Management and remediation of groundwater and surface water drainage systems;
- Prevention of air pollution from fugitive gases such as methane, carbon dioxide, and others;
- Extinguishing and preventing underground coal fires or those that occur in waste dumps;
- Monitoring of subsidence of mined lands and prevention of other ground surface movement; and
- Monitoring and remediation of chemical pollutants that may leach from mine waste dumps.

The above actions are critical prerequisites to the sustainable redevelopment of mined lands. Successful results depend upon identifying risks and must be followed by the appropriate corrective actions to reclaim and remediate. Completion of the post-mining reclamation and remediation processes are, in turn, critical preconditions for repurposing mined land for future use.

1. Identification of problems related to mine closure and their scale in the beneficiary States

1.1. Brief description of the current situation of coal mining in Albania

There are currently no active state-owned underground coal mines in Albania. **Table 1.1** below provides information about the date on which coal exploitation started, the dates and government orders for closing coal mines, the volume of production during operation, and the remaining geological reserves. At the same time, two small private active mines continue operations, with a combined output of approximately 265,000 short tons in 2021.

Table 1.1 - **Primary information about coal basins in Albania where coal exploitation has taken place**

No	Name of Deposit Start	Start of exploitation	Government Order for closing coal mines	No. of closure project	Production, t	Geological reserves remained, t
1	Valias	1978	139 dt.20.03.1995	2978 / 2001	3,515,178	49,186,000
2	Mëzez	1968	824 dt.04.12.1996	2978 / 2001	1,435,320	1,426,000
3	Mushqeta	1968	550 dt.26.08.1996	2978 / 2001	2,300,000	5,365,000
4	Kërrabë	1938	101 dt.02.03.2001	2748 / 2000	1,658,270	8,100,000
5	Priska 2	1980	550 dt.26.08.1996	2978 / 2001	374,057	2,682,000
6	Priskë	1980	101 dt.02.03.2001	2978 / 2001	no data	2,460,000
7	Gërdec	1978	550 dt.26.08.1996	2978 / 2001	293,200	297,000
8	Manëz	1967	232 dt.15.05.1995	2978 / 2001	1,317,00	1,281,000
9	Mborje-Drenovë	1930	349 dt.07.07.2000	2978 / 2001	1,100,000	3,698,000
10	Selcë	1984	233 dt.15.05.1995	2978 / 2001	253,563	125,000
11	Babjen	1984	233 dt.15.05.1995	2871 / 2003	75,236	478,562
12	Krosnisht	1978	500 dt.13.08.1998	2682 / 1999	1,342,174	496,000
13	Qenckë	1978	349 dt.07.07.2000	2682 / 1999	23,000	69,750
14	Bezhan	1972	233 dt.15.05.1995	2978 / 2001	1,068,519	7,714,000
15	Alarup	1959	500 dt.13.08.1998	2978 / 2001	no data	1,600,000
16	Pretushë	1968	233 dt.15.05.1995	2809 / 2002	909,300	2,885,500
17	Dardhas	1972	349 dt.07.07.2000	2978 / 2001	1,076,100	6,087,000
18	Vërdovë	1978	349 dt.07.07.2000	2978 / 2001	900,000	2,300,000
19	Potgozhan	1985	233 dt.15.05.1995	2978 / 2001	105,000	10,869,700
20	Homezh	1986	233 dt.15.05.1995	2978 / 2001	1,377,951	8,174,500
21	Memaliaj 1 & 2	1916	268 dt.08.06.1999	2978 / 2001	10,126,170	8,200,000
22	Memaliaj 3	1980	29 dt.15.01.1996	2978 / 2001	no data	6,500,000
Total					**29,250,038**	**129,995,012**

Source: www.akbn.gov.al

Please see Annexe A for a more detailed overview of Albanian coal mining.

1.2. Brief description of the current situation of coal mines in Serbia

In Serbia, underground coal mining is carried out by the state-owned company, the Resavica Public Company for Underground Coal Mining (hereafter JP PEU Resavica). The JP PEU Resavica was established in 1992, with its head office in Resavica. The enterprise includes the following eight underground coal mines situated in southern and central Serbia (Nikolic et al. 2016):

- **RA "Vrška Čuka"** (anthracite),
- **RKU "Ibarski rudnici"** (hard coal),
- **RMU "Rembas"** (brown coal),
- **RMU "Bogovina"** (brown coal),
- **RMU "Soko"** (brown coal),
- **RMU "Jasenovac"** (brown coal),
- **RMU "Štavalj"** (lignite), and
- **RL "Lubnica"** (lignite).

The chamber carries out the coal exploitation–pillar method using blasting-drilling works, with column and chamber–column excavation methods applied in all mines. Mine rooms and coal mining extraction are constructed by drilling and mining operations with manual loading of demined material. Coal is removed from the mine by combining conveyor belts and wagons. Coal seams being excavated have thicknesses ranging: from 1.5 to over 10 m.

Please see Annexe A for a more detailed overview of Serbian coal mining.

1.3. Groundwater and surface water

Evaluation of water hazards in underground coal mines (in active mines, closed mines, and mines undergoing the process of closure) is a continuous process which has to adapt to the ever-changing conditions of the mining industry. For forecasting water hazards, it is essential to analyse particular conditions of each and any occurrence of such hazard in terms of its sources and conditions which enable it (Bukowski, 2015).

The closure of the last few mines is synonymous with the final closure of the coalfield. This is usually accompanied by the termination of decades (or even centuries) of regional-scale dewatering. The consequences of a cessation of large-scale dewatering have been catalogued on several occasions and are now known to include the following (Younger, Banwart, and Hedin, 2002):

- Relief from some negative side-effects of dewatering (drawdowns in surrounding aquifers, contamination of surface waters by dewatering effluents).
- Loss of some former benefits of dewatering (dewatering effluents have frequently played valuable roles in sustaining flows in surface watercourses and diluting other, more noxious pollutants associated with sewage effluents, etc. A cessation of dewatering usually results in the abrupt loss of these benefits).
- Geotechnical problems related to land subsidence and mine gas hazards (the reactivation of void collapse and seismicity, sometimes leading to land subsidence, have been causally linked to flooding of mine voids; in addition, the process of flooding

can also temporarily accelerate mine gas emissions as gases are pushed ahead of the rising water-table).

- Discharge of water from flooded workings to the adjoining surface and subsurface water bodies (overall, discharge of mine water to other bodies of water is the most common, most sustained, and most environmentally and economically damaging consequence of the cessation of coalfield dewatering - surface flooding from abandoned mines can result in the loss of valuable agricultural land and cause damage to the residential and business premises; water pollution by abandoned mine discharges is one of the most widely documented forms of aquatic pollution).

1.3.1. Groundwater and surface water in Albania

Albania is rich in water resources. Rivers in the northern and southern parts of the country contain, however, high levels of manganese due to the mineral content in the geological areas that lay around them, thus creating a risk from residues for the fish growing in these rivers (Selami et al., 2011).

Albania is next to the subduction boundary between the African and Euro-Asiatic plates. This setting makes the presence of geothermal resources possible. Surface manifestations of geothermal resources are found throughout the country. In the north, water temperature is about 43 °C and inflow above 14 l/s; in the central part, temperatures are around 66 °C. The thermal waters in Albania are currently used only for balneology (Kodhelaj, 2011).

Valias coal mine, located in the Tirana plain, is about 15 km northwest of Tirana City. The coal layers belong to Upper Miocene deposits filling the Tirana syncline. As described by Pano and Zoto 1985, the lithology section is constituted mainly of clay (44%) and siltstones (42%), with some presence of sandstones (7%) and coal layers and coal slates/seams (7%). The maximal thickness of coal seams is about 1.50 m. The differently intercalated rock layers are deep to the west by angles 10-12° and to the northwest by angles 3-4°. A thick Quaternary gravel layer covered by silt and clay lay above Upper Miocene deposits (Eftimi and Amataj 2003).

The Upper Miocene deposits are characterized as poor aquifers. The permeability coefficient of sandstone layers ranges from 0.04 to 0.08 m/day, and the transmissivity of rocks averages about 2 to 3.5 m^2/day. At the same time, the overlying gravel layer is an abundant aquifer, with the permeability coefficient usually varying from 10 to 80 m/day and the transmissivity ranging from 350 to 3000 m^2/day (Tafilaj, 1968).

The coal-bearing sequence in the Valias coal mine consists of some Miocene formations with minimal water content and low permeability. They fall in the east-west and southeast-northwest directions at 10-12° and 3-4°, respectively. Above them are Quaternary gravels of 30-35 m in thickness, which have permeability ranging from 10 to 70 m/d and a specific flow rate of up to 20 $l \times s^{-1} \times m^{-1}$, followed by clayey loams of 10-15 m in thickness (Ahmataj, Eftimiu, and Thereska, 1991).

1.3.2. Groundwater and surface water in Serbia

Hydrogeological research indicates a generally poor water conductivity of the sequences of black lignite and hard coal deposits in Serbia. However, in places where they are lithologically built up of igneous and sedimentary formations and tectonically broken up, the fractured aquifers within them are the primary driver of water flows in the rock mass. (Miladinović, 2015).

Hydro-chemical analyses of mine waters reveal two types of water in terms of their chemical composition:

- mine water with total dissolved solids (TDS) of less than 1000 mg/l, which occur in coal seam roofs and floors, and
- mine water with a TDS of more than 1000 mg/l occurs within the coal seams.

Within coal seams, the chemical composition of groundwater changes as a function of depth, forming the HCO_3-Na, SO_4-HCO_3-Na, SO_4-Na or Cl-Na type of groundwater.

In addition, the coal deposits at RMU “Rembas” (Strmosten mine and Jelovac mine) and RMU “Soko” feature hydro-chemical zoning of groundwater in the limestone paleo relief, along with the contact with the coal sequence.

Concerning micro-components, hydro-chemical testing reveals low concentrations of heavy metals in mine water. This is attributable to the low solubility of their hydroxides and the instability of the hydro-carbonates that hydrolyse them. The limited mobility of microelements results from the absorption of clay material, which removes them from water solutions with the aid of microorganisms. As a result, the mine water has elevated concentrations of several chemical compounds, including metals (Miladinović, 2015).

Hydrogeological research reveals that coal extraction and processing in Serbia result in effluent emissions that exceed emission limit values (ELVs) at mine water discharge outlets to recipients, mine and tailings dumps, and wastewater and sludge outlets at flotation plants and mine facilities.

According to the parameters that determine the ecological and chemical status of surface water bodies and the chemical and quantitative status of groundwater bodies, the mining operations at RL “Lubnica”, RA "Vrška Čuka", RMU “Štavalj”, RMU “Bogovina”, RMU “Soko”, RMU “Rembas” (Senjski rudnik mine), and RKU “Ibarski rudnici” (Jarando mining area) discharge mine water that contains pollutants above 2nd class ELVs (or those that determine good ecological status of surface water bodies). At the same time, the available data shows that soil in the vicinity of the RKU “Ibarski rudnici” mines flotation plant at Baljevac is contaminated with arsenic (As = 88.1 mg/kg) and nickel (Ni = 260.4 mg/kg) (Miladinović, 2015), there are no data on the genesis of the occurrence of these compounds. At the same time, the sludge from the RMU “Bogovina” flotation plant is classified as non-hazardous and non-inert waste.

Table 1.2 shows basic information about water hazards in the Serbian underground coal mines. The table presents the volumes of natural inflow to mines and the methods of dewatering the latter.

Table 1.2 - **Water hazards in coal mines in Serbia**

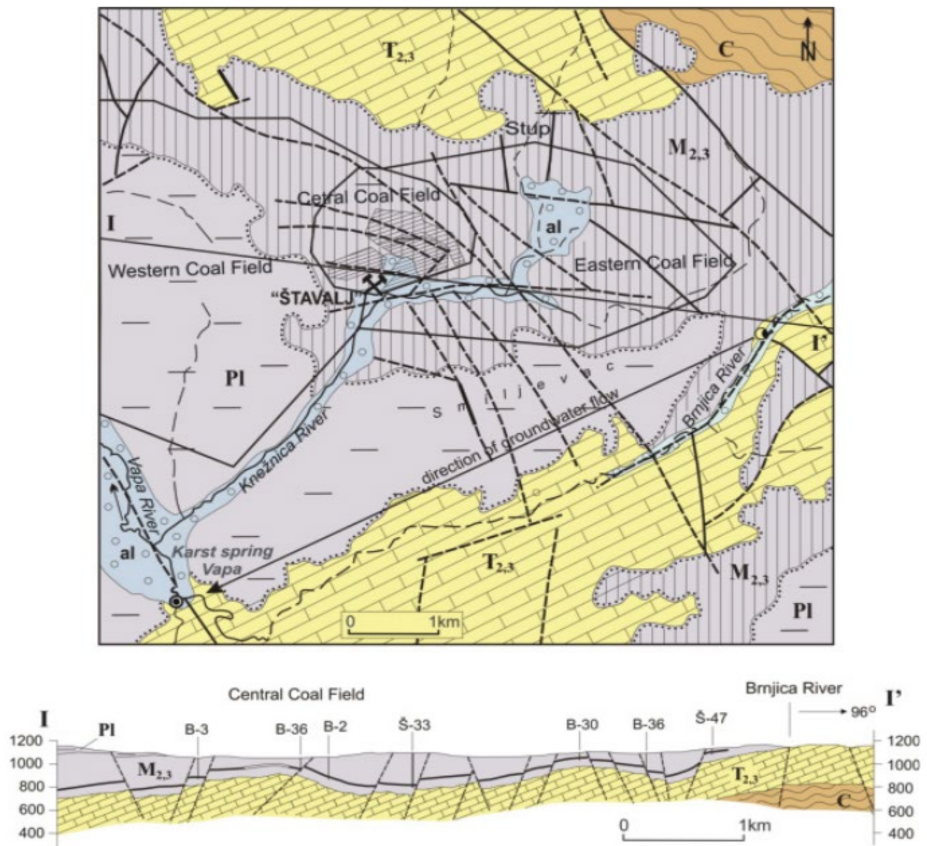
Mine	Water inflow, m^3/min	Dewatering/mineralization
RMU "Bogovina"	**0.04**	Mine has two pumping stations, while other pumps, mobile and of smaller capacity, are pumping water into the main reservoir. Mine water's arsenic (As) content is 0.247 mg/l, and the aluminium (Al) content is 4.45 mg/l.
RA "Vrška Čuka"	**0.09**	Dewatering of the mine is by gravity through channels in Avramica drift (and roadways H1, H3 and U4). Small and mobile pumps pump water into this channel according to water influx in different locations of mine, which is generally low (1 to 2 l/s). Therefore, there is no pumping station at the mine.
RKU "Ibarski rudnici"	**1 (Jarando)** **0.5 (Tadenje)**	The main dewatering of both mining areas is gravitational by channels at horizontal drifts (Baljevac drift at Jarando mining area and Tadenje drift at Tadenje mining area). Any water inflow at workings is pumped with submersible pumps to small collectors (two at the Jarando mining area) and then pumped to the level of the drifts mentioned above. The highest sulphate content (SO_4) in mine waters was determined in the Jarando mining area at 654.5 mg/l. The content of manganese (Mn) in mine water is 0.28 mg/l.
RMU "Jasenovac"	**3**	Dewatering of the mine is gravitational via a waterway (channel) at the GIP roadway, to which water is pumped from the locations of influx.
RMU "Rembas" - Senjski rudnik	**3**	The main water collector at Senjski rudnik pumps the water to the level of South drift, which is then taken to the surface (Resavica) by channels. Also, there are collectors at both shafts from which water is pumped directly to the surface.
RMU "Rembas" - Strmosten	**2.5**	At the Strmosten mine, water collects at the bottom of the blind shaft, from which it is pumped to the level of haulage drift and then, by gravity, taken out. There are also two smaller pumping stations in the GN-1 roadway, which directly pump the water into the channel in haulage drift.
RMU "Rembas" - Jelovac	**0.6-1.0**	Water is pumped to the level of Jelovac drift which streams to the surface in the direction of Vodna. The content of lead (Pb) in mine water is 0.024 mg/l.

Mine	Water inflow, m³/min	Dewatering/mineralization
RMU "Soko"	**3.67**	The mines' dewatering is done by a central water sump near the bottom of the hoisting shaft, from where it is pumped to the surface. Water is pumped into this collector from auxiliary collectors around the mine. A pumping station also exists at the bottom of the ventilation shaft. The RMU "Soko" deposit has the highest content of sodium (Na) (828.07 mg/l) in mine water in Serbia. The content of iron (Fe) in mine water is 17.1 mg/l.
RL "Lubnica"	**0.5**	Both Stara jama and Osojno-South have water collectors from which water is pumped to the surface. Mineralization of mine waters is the highest in underground coal mines in Serbia. It ranges up to 2560 mg/l and belongs to the sodium chloride type (Cl=664.8 mg/l, Na=682.0 mg/l, SO_4=244.5 mg/l, Sr=5.01 mg/l, and Li=0.762 mg/l).
RMU "Štavalj"	**6.0-8.0**	The mine has eight water sumps to combat the water inflow, some of which have several pumps. The gravity of the dewatering issue at RMU "Štavalj" mine is best described by the total installed power of the pumps, which exceeds 1.3 MW.

Source: Miladinović et al., 2015; information and data from national consultants

In RMU "Štavalj" and RMU "Soko" mines, water hazards occur. At the latter, they have begun to cause problems for mining operations.

Figure 1.1 - **Hydrogeological map of the extended area of the RMU "Štavalj"**



Source: Miladinović et al., 2015

Figure 1.1 shows the hydrogeological map of the extended area of the RMU "Štavalj", including characteristic section I-I' (al – alluvium, intergranular aquifer; Pl – Pliocene gravel, sand and clay, hydrogeological complex; M2,3 – Miocene marl, marly limestone, clay and coal, hydrogeological complex; T2,3 – Middle and Upper Triassic limestones, karst aquifer; C – Carboniferous schists, non-hydrated rocks) (Miladinović et al., 2015).

Opening the mine and the initial stages of mining at the Štavalj caused intensive groundwater drainage from a fractured aquifer formed in Miocene sediments overlying the coal seam (**Figure 1.1**). Mine water inflow to the mining operations came mainly from the faults intersected by mining (Marković, Pavlović, and Stanić, 1996). Large surfaces excavated over time and caving of the coal seam roof enhanced surface water infiltration and enabled hydraulic linking of groundwater from various faults (Zeremski, Luković, and Milentijević, 1975). Under present mining conditions, where mining operations have reached a depth of 260 m from the ground surface, the inflow interferes with coal extraction. Consequently, considerable expenditures for ongoing drainage system maintenance are necessary (Miladinović et al., 2015). To combat the water inflow, the mine has eight water sumps where water collects, some of which have several pumps. The gravity of the dewatering issue at RMU "Štavalj" is best described by the total installed power of the pumps, which exceeds 1.3 MW.

As indicated by the work of Atanacković et al. (2013), the dominant role in the formation of the chemical composition of the mine waters from metal and coal-closed mines is played by the oxidation of pyrite (FeS_2) and other sulphides, resulting in the release of hydrogen ions that lower the pH level and increase the concentrations of sulphates, metals (Fe, Cu, Pb, Zn, Cd, Co, Cr, Ni, Hg), metalloids containing supplementary material (As, Sb), and other elements (Al, Mn, Si, B, Li) in the mine water. pH values in mine water in closed coal mines average around 7, while electrical conductivity (EC) values range from 900 to 2000 µS/cm. Analysis of the relationship between mmol/L HCO_3 (bicarbonate) and mmol/L SiO_2 (silicon dioxide) has shown that mine waters from closed coal mines are carbonate dominated (HCO_3 to SiO_2 ratio of 10 to 1 or greater). The quality of the surface water samples collected upstream from the abandoned mining sites was good concerning most parameters, apart from sulphate and iron concentrations that were mildly elevated in R2U due to naturally occurring sulphide oxidation.

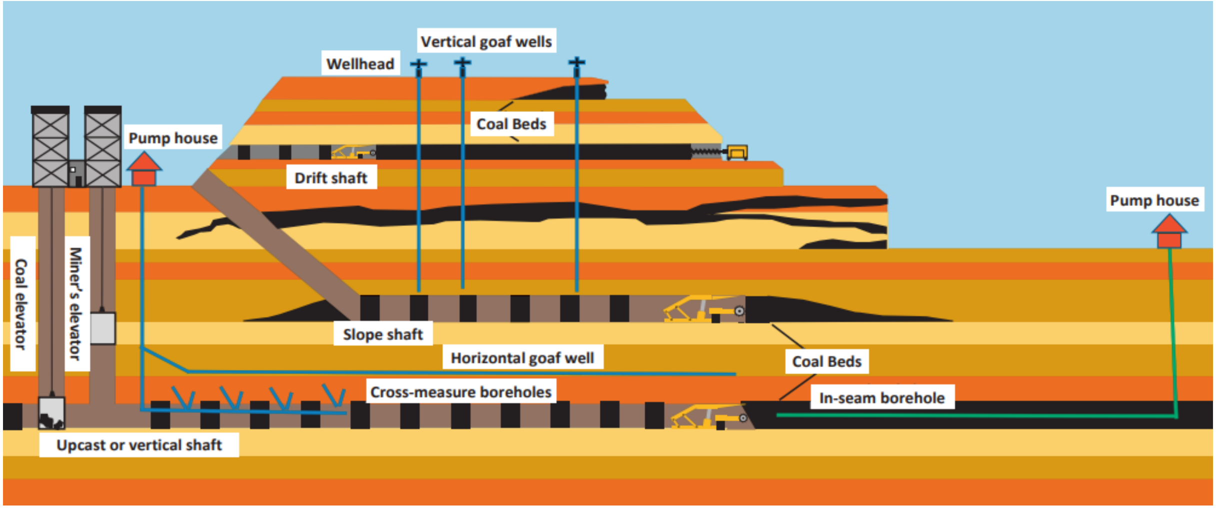
1.4. Fugitive gases (e.g. methane, carbon dioxide)

1.4.1 Overview

Methane (CH_4) is the second most prevalent anthropogenic greenhouse gas (GHG) after carbon dioxide (CO_2), with a Global Warming Potential (GWP) 28-34 times more potent than CO_2 over a 100-year timeframe. Coal mining accounts for about 12% of global anthropogenic CH_4 emissions. Most emissions come from underground coal mines, predominantly active ones, but emissions from abandoned mines are increasing (Best Practice Guidance, 2021).

Figure 1.2 shows point sources of CH_4 emission in an underground coal mine.

Figure 1.2 - **Point sources of CH_4 emission in an underground coal mine**



Source: Best Practice, 2021

The gas hazard is one of the most severe risks in mining. As the depth of mining increases, so does the gas hazard (Eugeniusz Krause, 2005; Eugeniusz Krause and Smoliński, 2013). Due to a lack of reliable data, estimating the gas hazard in closed underground coal mines in Albania is difficult. In Serbia, where several mines remain active, methane poses a significant danger (**Table 1.3** below). Furthermore, any increase in coal production at the prospective mines in Serbia (especially RMU "Soko") will be associated with deeper mining and thus present even more significant gas hazards.

1.4.2 Gas hazards in Albania

There is little information on gas hazards in underground coal mines in Albania, as they are all already closed and not subject to proper monitoring. However, the following historical methane explosions in the country have been documented (Belba et al., 1997):

- Korce mine (April 1975) – underground fire due to methane gas explosion.
- Valias mine (January 1983) – underground fire due to a methane explosion.
- Memaliaj mine (November 1990) – underground fire caused by a methane explosion.

Therefore, it can be assumed that if the considered resumption of underground coal mining in Albania ever took place, the coal mine would be exposed to methane hazards.

1.4.3 Gas hazards in Serbia

In underground coal mining in Serbia, methane hazards exist in mines: RA "Vrška Čuka", RKU "Ibarski rudnici" - Jarando, and in RMU "Soko". At RMU "Bogovina", RMU "Rembas", and RL "Lubnica", methane-bearing capacity is indicated as 'registered appearance'. No methane appearance has been found in RMU "Štavalj" and RMU "Jasenovac." (**Table 1.3**)

Table 1.3 - **Gas hazard in underground coal mines in Serbia**

Mine		Relative methane emissions m^3/tonnes of coal mined	Absolute emissions of methane in m^3/minute
RMU "Bogovina"		registered appearance	registered appearance
RA "Vrška Čuka"		8.93	0.147
RKU "Ibarski rudnici"	Jarando	0.025-0.245	0.008-0.079
	Tadenje	non-methane	non-methane
RMU "Jasenovac"		non-methane	non-methane
RMU "Rembas"	Strmosten	registered appearance	registered appearance
	Jelovac	registered appearance	registered appearance
	Senjski rudnik	registered appearance	registered appearance
RMU "Soko"		11.74	2.71
RL "Lubnica"		registered appearance	registered appearance
RMU "Štavalj"		non-methane	non-methane

Source: Ivkovic et al, 2012

In RMU "Rembas", RMU "Soko", and RKU "Ibarski rudnici" - Jarando mining area, appropriate control devices for measurement of fugitive gases were selected and installed. The principal method for deployment of control devices (CD) in the mine is presented below in the example of Senjski rudnik, one of the RMU "Rembas" mining areas".

The methane concentration in the working areas within room-and-pillar excavation is not controlled via a remote control system. Due to the lack of space and the constant danger of breakage, there are no optimal locations for measurement devices, so remote control would not be reliable. Therefore, the methane concentration in the excavation working areas is measured with portable measurement BM-3 devices. In RMU "Rembas" – Senjski rudnik, the project envisaged the installation of 11 BM-3 devices to control the following (Marjanovic, Grozdanovic, and Janackovic, 2015):

- Aggregate output airflow of a longwall excavation area and a room-and-pillar excavation area;
- The primary output airflow, just below the ventilation hole;
- Standard output airflow from a longwall excavation area and separate ventilation of preparation site for ventilation and transport corridors;
- Separate ventilation of the preparation area (worksite) for the creation of the wide transport corridor (TH-6);
- Separate ventilation of the preparation area for the creation of the wide ventilation corridors (VH-6);
- Inlet airflow from longwall excavation area;
- Output air stream directly from a longwall excavation area;
- Output airflow from the room-and-pillar excavation area;
- Separate ventilation of the preparation site;
- Output airflow from the preparation area for room-and-pillar excavation; and
- Common output airflow from the preparation area for room-and-pillar excavation.

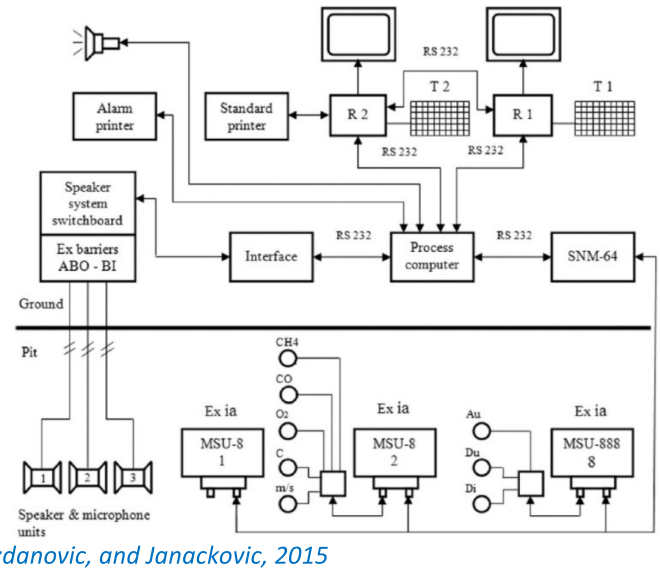
The methane concentration in working areas for room-and-pillar excavation is measured with portable measurement devices and not via a remote control system. Due to lack of space, difficulty finding the optimal location for measurement devices, and the constant danger of breakage, the remote control would not be reliable.

The BCO-1R device measures the concentration of carbon monoxide (CO). The project envisaged measuring the concentration of CO in six places to control the following (Marjanovic, Grozdanovic, and Janackovic, 2015):

- Inlet airflow of both areas (an area with longwall excavation and a room with room-and-pillar excavation). This control is necessary because of the long conveyor belts in areas N-1 and N-4 and the eventual approach of carbon monoxide in the air at the surface;
- The primary output airflow from mines;
- Inlet airflow of the longwall excavation area, which also controls relatively long transport line N-7;
- Output airflow from the longwall excavation area (based on the difference in the concentration of carbon monoxide at the entrance and exit, endogenous fires in the longwall excavation area are detected);
- Entry airflow for areas with room-and-pillar excavation, which enables control of all transport routes to the entrance of the mining area;
- Output airflow for areas with room-and-pillar excavation (based on the difference in the concentration of carbon monoxide at the entrance and exit, endogenous fires in the area are detected).

In the RMU "Rembas", RMU "Soko", and RKU "Ibarski rudnici" – Jarando mining area, a control information system (CIS) was built. The structure of CIS Ei SM-64 in RMU "Soko" is shown in **Figure 1.3**.

Figure 1.3 - **The structure of the Ei SM-64 system in RMU "Soko"**



Source: Marjanovic, Grozdanovic, and Janackovic, 2015

The equipment in CIS is designed to provide a clear and distinct permanent display of current values of ventilation, gas and fire alarm parameters and the state of the alarm-speaking sub-system, as well as to display the condition of all parameters and elements right before the alarm and during the emergency.

Table 1.4. shows the layout of the characteristic of installed fans for the main ventilation in the mines of JP PEU Resavica.

Table 1.4 - **The layout of the characteristic of installed fans for the main ventilation in the mines of JP PEU Resavica**

Mine	Ventilation	Type/manufacturer of the main fan	Type/manufacturer of the auxiliary fan
RMU "Bogovina"	Fans are located on the surface, within the ventilation station on the ventilation shaft.	N-AVV-D-125, capacity 23 m^3/min, depress. 800 Pa	N-AVV-D-125, capacity 23 m^3/min, depress. 800 Pa
RA "Vrška Čuka"	Fans are located on the surface, within the ventilation station on the ventilation shaft VO2. The ventilation station is equipped with a diesel-powered generator in case of electric power failure.	Ventilator-Zagreb, capacity 12 m^3/min, depressurization 488 Pa	Ventilator-Zagreb, capacity 12 m^3/min, depressurization 488 Pa
RKU "Ibarski rudnici"	Fresh air is taken into the **Jarando** mining area through the GIN roadway and directed toward production and working areas. In contrast, the used air is taken to the surface via Baljevac drift, which houses the ventilation station (main and spare fans, diesel power generator, sound dampening utilities, etc).	AV-1000, capacity 20 m^3/min, depressurization 1200 Pa (Jarando)	AV-1000, capacity 20 m^3/min, depressurization 1200 Pa (Jarando)
	At **Tadenje**, fresh air is taken into the mine via GIN and GTH-1 roadways and through Tadenje drift, which also houses a ventilation station.		
RMU "Jasenovac"	Fans are on the surface, within the main ventilation drift (GVN) station.	N-AVV-D-125, capacity 23 m^3/min, depressurization 800 Pa	N-AVV-D-125, capacity 23 m^3/min, depressurization 800 Pa
RMU "Rembas"	Fresh air is led into the **Senjski rudnik** mining area via a hoisting shaft and through long-term roadways directed to the production area, from where it is taken out via the ventilation shaft where the fans are installed.	AVV-D-125-2, capacity 23 m^3/min, depressurization 1030 Pa	AVV-D-125-4, capacity 28 m^3/min, depressurization 500 Pa
RMU "Rembas"	At the **Strmosten** mining area, fresh air routes are GN-1 and GTU-1, from which it is distributed to development and production areas. Used air is taken out via drift +45, blind shaft and ventilation drift, which is the location of the ventilation station.	AVV-D-125-4, capacity 40 m^3/min, depressurization 2700 Pa	

Mine	Ventilation	Type/manufacturer of the main fan	Type/manufacturer of the auxiliary fan
RMU "Rembas"	Fresh air is led into **Jelovac** mining area via Jelovac drift and distributed to development faces. Used air is taken out via Jelovac drift beyond the pit and Bučar drift connection to the surface where the fans are installed.	N-HVV-D-125, capacity 40 m^3/min, depress. 1000 Pa	
RMU "Soko"	Fresh air is brought into the RMU "Soko" through the hoisting shaft and directed toward production and working areas, while the used air is taken to the surface via the ventilation shaft. The ventilation station is at the entrance of the ventilation shaft.	AVJ-1500(45), capacity 10-40 m^3/min, depressurization 2800 Pa	CN-125, capacity 38 m^3/min, depressurization 1460 Pa
RL "Lubnica"	Intake of fresh air at Lubnica mine is through main haulage drift GTN (Osojno), and at the connection with N-3 roadway intake is split – toward Stara jama (via N-3) and toward workings on developing of Osojno-South, from where it is taken out through main ventilation drift (GVN). From the N-3 roadway, fresh air is directed toward production areas of the Stara jama and return air is taken out via ventilation roadways.	AC-160, capacity 15 m^3/min, depressurization 500 Pa	GVh-15-1605, capacity 83 m^3/min, depressurization 2800 Pa
RMU "Štavalj"	Fresh air intake at Štavalj mine is through main haulage drift GIN-1 and other long-term roadways (GIN-4 and TN-2) directed toward production. Exhaust air is taken to the surface through main ventilation drift (GVN-2). The ventilation station is located at the entrance of the GVN-2 (equipped with fans, a diesel-powered generator, etc.).	NAVV-D-140/6, capacity 40 m^3/min, depressurization 880 Pa	AVJ-1500-6-75, capacity 10-40 m^3/min, depressurization 2800 Pa

Source: Todorović et al., 2020

1.5 Underground coal fires and fires in waste dumps

1.5.1 Overview

Fire hazard is one of the dominant hazards in the Polish mining industry, and therefore the Polish experience in that field may help analyse this type of hazard in mines in Albania and Serbia (Trenczek, 2003; Tutak and Brodny, 2017). In Poland, the determination of indices of spontaneous combustion in hard coals (Sz^a and $Sz^{a'}$) and activation energy of oxidation (A) is carried out by the GIG method included in the standard PN-93/G-04558 (Słowik, 2008), which is in force since 01.01.1994. The spontaneous combustion indices (Sz^a and $Sz^{a'}$) and the activation energy (A) correspond to the propensity of hard coal to spontaneous combustion at the place where the sample was taken from the exploited seam. On the base of the spontaneous combustion index Sz^a and activation energy of oxidation A, the hard coals are classified into five groups of spontaneous combustion according to the standard PN-93/G-04558 (**Table 1.5**).

Table 1.5 - **Division of hard coals into the spontaneous combustion groups according to the propensity to spontaneous combustion**

Index of spontaneous combustion Sz^a °C/min	The activation energy of hard coal oxidation A kJ/mol	Group of spontaneous combustion	Assessment of hard coal propensity to spontaneous combustion
up to 80	over 67	I	hard coal with a very low propensity to spontaneous combustion
	46 do 67	II	hard coal with a low propensity to spontaneous combustion
	below 46	III	hard coal with an average propensity to spontaneous combustion
over 80 up to 100	over 42		
	below 42 or equal	IV	hard coal with a high propensity to spontaneous combustion
over 100 up to 120	over 34		
	below 34 or equal	V	hard coal with a very high propensity to spontaneous combustion

Source: Słowik, 2008

1.5.2 Coal fires and fires in waste dumps hazard in Albania and Serbia

There is a lack of literature and data on either fire or dust hazards in closed underground coal mines in Albania.

In Serbia, the risk of endogenous fire in most underground coal mines (except RA "Vrška Čuka" and RKU "Ibarski rudnici") is high (**Table 1.6**).

Table 1.6 - **Fire hazard in Serbian underground coal mines**

Mine		Index of spontaneous combustion Sz^a, °C/min	Group of spontaneous combustion
RMU "Bogovina"		80-120	III, IV, V
RA "Vrška Čuka"		not self-ignition	no tendency
RKU "Ibarski rudnici"	Jarando	69-98	I, II, III, IV
	Tadenje	no tendency	no tendency
RMU "Jasenovac"		80-100	III, IV
RMU "Rembas"	Strmosten	110-120	IV, V
	Jelovac	70-110	I, II, III, IV, V
	Senjski rudnik	118-140	IV, V
RMU "Soko"		115-188	IV, V
RL "Lubnica"		80	I, II, III
RMU "Štavalj"		103-111	IV, V

Source: Ivkovic et al, 2012

This hazard is mainly due to: the high propensity of coal to spontaneous combustion, the subsurface exploitation system, stresses in the rock mass associated with their cracks and discontinuous deformations of the rock mass, occurrence of numerous tectonic faults with large discharges, and past exploitation effects, allowing migration of gases between the mine excavations and surface.

As for coal dust, in certain conditions, it shows explosive and flammable characteristics in all Serbian mines except RA "Vrška Čuka" (**Table 1.7**).

Table 1.7 - **Dust hazard in Serbian underground coal mines**

Mine		**Dust explosives, g/m^3**	**Dust self-ignition, °C**
RMU "Bogovina"		225	250
RA "Vrška Čuka"		non-explosive	not self-ignition
RKU "Ibarski rudnici"	Jarando	70-100	630-700
	Tadenje	270	no data
RMU "Jasenovac"		225	260
RMU "Rembas"	Strmosten	180	280-290
	Jelovac	230	300
	Senjski rudnik	200	260-290
RMU "Soko"		230	250-350
RL "Lubnica"		100	215-235
RMU "Štavalj"		no data	220-280

Source: Ivkovic et al, 2012

1.6. Monitoring of subsidence of mined lands and prevention of other ground surface movement

1.6.1 Overview

In most cases, underground coal mining is accompanied by ground subsidence which presents a pressing issue that needs immediate attention and action to prevent harmful effects on the surface and subsurface structures. As a result, accurate prediction of subsidence using reliable methods is of great importance.

Surface subsidence and its destructive effects on overlying structures resulting from underground mining operations can cause problems even many years after mine closure. Surface slope changes, differential vertical displacements, and horizontal strains can provoke damage due to surface subsidence. Based on their respective values, the vulnerability level for individual objects on the terrain surface can be estimated. Structural damages to facilities depend on the construction method and the materials used. The mining method used at the coal mine also significantly influences the severity of subsidence (A. Malinowska and Hejmanowski, 2010).

1.6.2 Subsidence of mined lands hazard in Albania

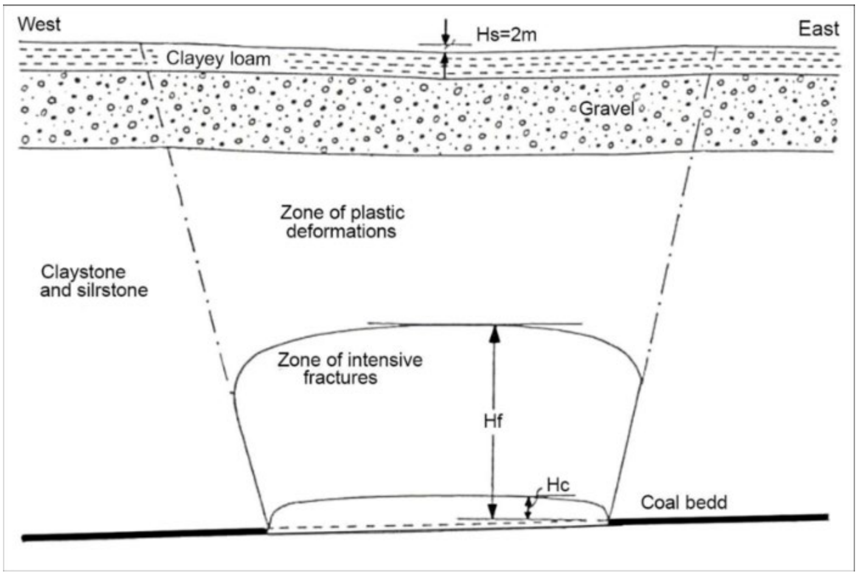
In Albanian coal mines, ensuring the stability of underground workings was challenging due to the complex geological and mining conditions, which can often lead to the immediate collapse of the surrounding rocks (Halili and Muka 2016). In the early 1990s, due to the political changes in Albania, many mines were closed due to their lack of profitability. The first mines closed were the coal mines, followed by most iron-nickel mines. The common characteristic of that closure process was mine abandonment with no proper plans for the actual closure. (Halili and Muka, 2016).

Based on the information provided by Halili and Muka (2016), it is possible to conclude that:

- The specificities of environmental issues related to abandoned mines in Albania are the location of closed mines in urbanized areas, the mining method, and the country's low level of economic development.
- The impact of underground mining often results in funnels, sinkholes, and landslides, which constitute the primary effects. Their occurrence creates the conditions and needs for assessing the susceptibility, vulnerability and geo-risk mapping of the abandoned mining exploitations.
- The location of the waste piles at every mine site has contributed to their disproportionate spreading, covering quite a large area of land and harming the natural flora and fauna. Their disposition in a few concentrated dumps constitutes an essential obligation in alleviating such an environmental problem.
- The hazardous waste piles contaminate vast territories, posing a life-threatening danger to humans, other creatures, and the landscape (area size in Serbia shown in **Table 2.2** in section *2.5.2 Waste stocks in Serbia*).
- The lack of projects for rehabilitating the abandoned mine sites increases the severity of their harmful effects, not only on the current situation but also in a longer-term perspective.

For example, the longwall mining in the Valias coal mine causes the total roof to fall behind the supports. The goafs created by the coal exploitation were held with metallic props. After removing the latter, the roof started to bend, and later the roof rocks began to fail. Three rock massive movement zones are distinguished inside the deformation funnel; caved zone (thickness H_c), zone of intensive fractures (thickness H_f), and zone of plastic deformations, as shown in **Figure 1.4**. The rock deformations are transmitted up to the ground surface where the maximal subsidence H_s, in the centre of the deformation funnel, is about 2 m.

Figure 1.4 - **Schematic view of rock deformations zones in Valias coal mine**



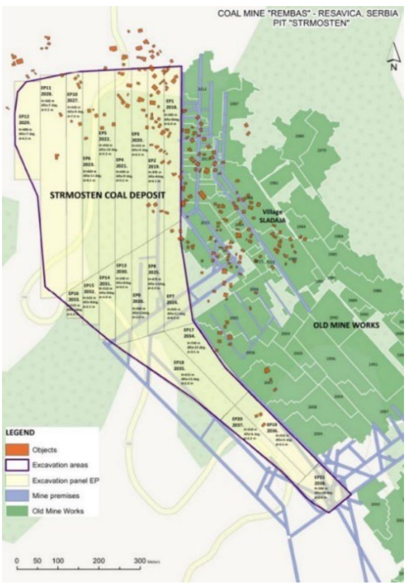
Source: Halili and Muka 2016

1.6.3 Subsidence of mined lands hazard in Serbia

The subsidence problem and the resulting need to protect objects above the mining works have been in the RMU "Rembas" - Resavica for decades. They have been linked with an underground exploitation mining area of the "Strmosten".

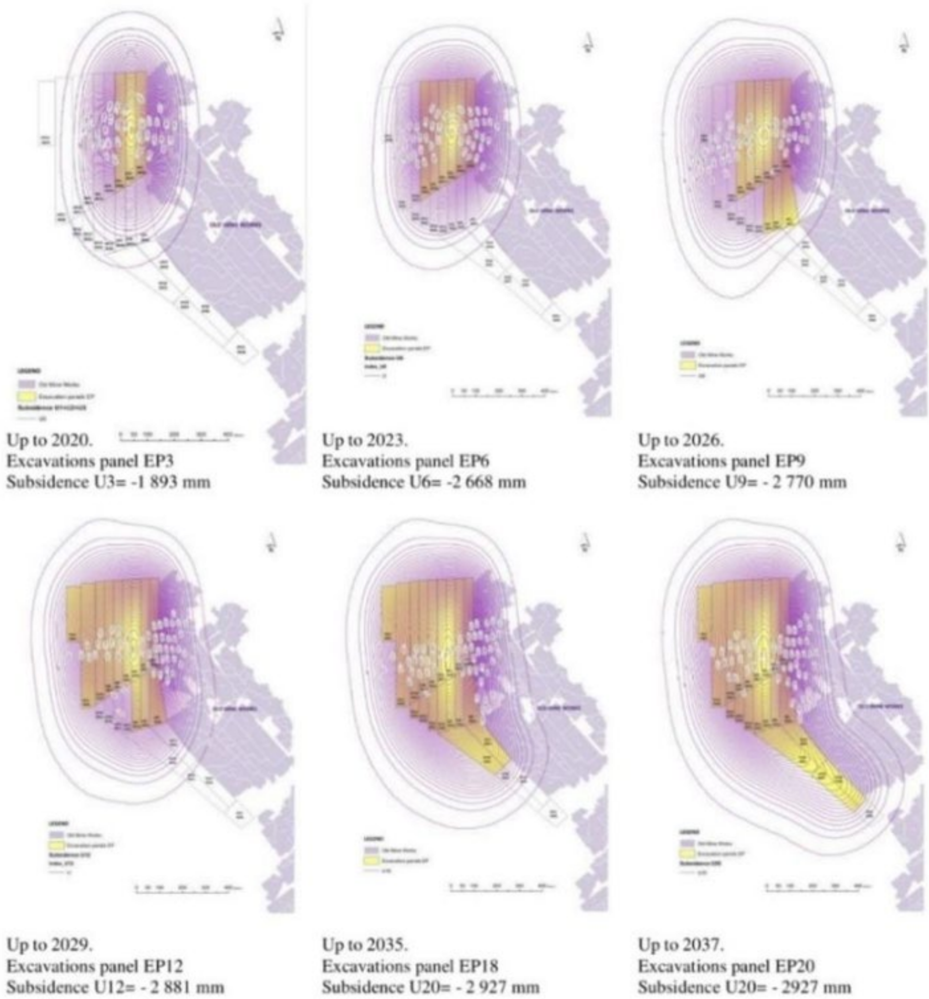
A case study in Sladaja village impacted by the underground exploitation of the coal mine "Rembas" - Resavica mine, one of the most significant Serbian coal mines, has been shown in **Figures 1.5** and **1.6**.

Figure 1.5 - **Excavation panels (EP) mined successively in the excavation field of the RMU "Rembas" - Strmosten mine**



Source: Vušović, Vlahović, and Kržanović, 2021

Figure 1.6 - **Simulation of the mine subsidence process in the RMU "Rembas" - Strmosten mine**



Source: Vušović, Vlahović, and Kržanović, 2021

The maximum relative subsidence was determined as the highest subsidence value (- 2927 mm) after the exploitation of the excavation panels EP1-EP18 (**Figure 1.6**).

1.7 Monitoring and remediation of chemical pollutants that may leach from mine waste dumps

1.7.1 Air pollution hazards in Albania

Air pollution in Albania originates mainly from industry and, to a lesser extent, from the transportation sector and urban waste incineration. Key local emitters are the iron-chromium metallurgy and the cement industry, oil refineries, the mining industry, and the transportation sector.

Arsenic (As) can be used as a primary marker of anthropogenic pollution caused by coal mining activities (Dimovska et al., 2014). The highest arsenic content is found in southern Albania, where there was no evidence of industrial emissions. Arsenic is a naturally distributed element, but its presence can also be associated with the anthropogenic consequences of coal mining, such as waste piles and coal-enriched dust. That is the case of the region hosting the Memaliaj mine, which ceased all mining activities in 1991 (Allajbeu et al., 2017).

1.7.2 Air pollution hazards in Serbia

In Serbia, the RA "Vrška Čuka" mine is particularly problematic in terms of air pollution because it mines anthracite, which is very easily crushed to the size of dust particles, and therefore, when transported by belt conveyors (whether from the mine to the separation plant or from the tailings pit where it is partly found with the tailings), it is easily blown by the wind to the surrounding areas. A similar situation occurs at the RKU "Ibarski rudnici" (Jarando mining area), where the coal is transported from the mine to the coal separation plant in Piskanja by cable car (Miladinović, 2015).

Another type of air pollution is the occasional spontaneous combustion of coal in waste piles due to oxidation. Air currents carry away the resulting carbon dioxide and carbon monoxide gases, so the characteristic smell is often felt in the surrounding areas (**Figure 1.7**). Spontaneous combustion of coal is the most common in the west waste piles of the RMU "Soko" and RMU "Štavalj" (Miladinović, 2015)

Figure 1.7 - **The appearance of spontaneous combustion of coal in RMU "Soko" waste piles (left-hand side photo) and RMU "Štavalj" waste piles (right-hand side photo)**

Source: Miladinović, 2015

2. Recommendations on addressing the identified problems in each of the beneficiary States

2.1. Management and remediation of groundwater and surface water drainage systems

Water hazards in underground coal mines are possible at every stage of the mining cycle: construction, the operation related to extraction of coal deposits and necessary dewatering of underground reservoirs, boreholes and fault zones. Water hazard in the underground part of the mine is decreasing during the mine closure process, directly related to the cessation of pumping and partial flooding.

Evaluating water balance on the surface in mine areas with subsidence is also an essential element of hazard assessment. Recognition of possible interconnections between mines, with outcrops and the surface, is vital to predicting and preventing future water-related threats during the mine closure process.

Assessing and collecting relevant data and analysis is necessary to prepare a proper mine closure plan considering water-related surface and underground excavation risks. A detailed mine closure plan should be implemented accordingly to legal regulations, environmental protection standards, and public safety issues.

A final mine closure programme should include several sustainable and safe abandonment issues. First, concerning water-related issues, it should justify the proposed cessation of pumping, an evaluation of mine water level rebound, and a prediction of mine water quantity and quality as well as of possible flooding of subsidence on the surface. Such a plan should consider the mining areas' specific conditions.

A mine closure plan should also include a water conditions monitoring plan, following which water level in the mine and mine inflows should be periodically measured. It should also provide for the collection and careful assessment of information on the current and future status of ecological, mining, and general safety on the surface, starting as early as the stage of planning and forecasting mine closure.

Due to the complexity of the issues related to mine closure and their interdisciplinary character, the closure of mines should not be done hurriedly but following the schedule of administrative decisions and the developed technical timetable. It is also necessary to analyse the methane-bearing capacity of the remaining coal seams and the content and composition of mine gases in empty spaces in the rock mass and gobs. Monitoring groundwater and surface water drainage systems should be conducted mainly in hydrogeological windows (unconfined aquifers on the surface), places threatened by discontinuous deformations, outcrops of seams and faults, and near mine excavations, shafts, and boreholes on the surface.

A mine closure programme should be done with attention to the defined water hazards and risks, and it should encompass the following:

- Assessment of the hydrographic, geological engineering and hydrogeological conditions (including water supply areas and areas with groundwater that has a higher susceptibility to contamination) and preparation of relevant documentation appraising mineral resources, particularly mine hydrogeological documentation determining the hydrogeological conditions, as well as environmental and hydrogeological monitoring conditions during and after mine flooding,
- Planning for water protection against contamination, identifying necessary actions for the treatment of water discharged to surface waters,
- Performing hydro-technical and mining work (construction of monitoring wells or boreholes),
- Establishing a monitoring network of water levels in the excavations (shafts and drifts) and on the surface,
- Identifying prospective discharges of mine water to the surface after flooding the mine (with particular attention to outcrops) as well as developing a system of mine gas capture and utilisation on the surface (if necessary),
- Monitoring in the post-closure period, as well as periodic assessments of the general hazard and the susceptibility of groundwater to contamination, and

Apart from the above, a closure programme should also Implement a legal and administrative system enabling the control of the management of post-mining terrains, as well as surface and ground-waters located within the zone of influence of the mine closure and flooding processes.

2.1.1 Remediation of groundwater in Albania

Underground coal mining in Albania ceased more than 15 years ago. Since then, mining sites have changed ownership. As a result, they no longer belong to experienced mining companies, making proper surveillance and monitoring difficult. As Tirana, Albania's capital, is expanding, new settlements are also being built in the post-mining areas close to the city. It would be, therefore, very much advisable to put the post-mining areas under surveillance and continuously monitor them regarding water hazards.

2.1.2 Remediation of groundwater in Serbia

In general, the groundwater level is not a factor that needs to be considered during the closure of the coal mines in Serbia, as all the mines in the country, except for the RMU 'Štavalj', can be regarded as “dry”. However, recent water hazard problems also appeared in the RMU "Soko".

In most cases, underground coal mining in Serbia occurs in the basins of smaller surface watercourses. Because they were formed in hilly and rugged terrain, their flow is boisterous, mainly in the spring. Erosion dams were built on smaller streams to soften flooding activity waves and partially stop the entrained material. Such dams exist in the bed of the Jarandol stream in Baljevac (RKU "Ibarski rudnici"), in the RMU "Rembas" (Senjski rudnik mine), in the bed of the Ravanica river, in the Vodnički stream in Vodna (RMU "Rembas"), as well as in the bed of the Avramički stream in RA "Vrška Čuka" (Miladinović, 2015).

2.2. Prevention of air pollution from fugitive gases (e.g. methane, carbon dioxide)

2.2.1 Overview

The process of closure of a gassy mine, which is associated with stopping the main mine ventilation, creates good conditions for gas to accumulate in underground mine workings and the surrounding rock mass and can be released as a result of different occurrences (Krause and Pokryszka, 2013) such as water level rising, barometric pressure variations, and natural draft.

According to the U.S. Environmental Protection Agency (2008), several factors influence abandoned mine emissions. Those are time since abandonment, gas content, coal adsorption characteristics, methane flow capacity, mine flooding, vent holes, and mine seals.

Methane and carbon dioxide (Sechman et al., 2013) can rise to the surface mainly through former works that link the mine with the surface, through the covering ground when there is enough permeability, and through water release. It can lead to accidents such as explosions, asphyxia, or intoxication (Besnard and Pokryszka, 2005).

Within coal seams saturated with methane, the gas is present in two forms (Kowalski, 2000; Krause and Dziurzyński, 2015):

- Sorbed gas, consisting of gas condensed on carbon receptor sites in the coal matrix pores and micropores; and
- Free gas is contained in pores and fractures in the coal and the gobs.

As an effect of the desorption phenomenon, methane released from overlying and underlying seams impacted by mining operations fills cavities in adjacent mine workings and gobs. When the closed mines are flooded, the water table rises, and gases are forced towards the surface (the piston effect). During the closure process, hydrogeological and gas phenomena in mining areas of gassy coal mines may affect the safety of works in adjacent coal mines and at the surface of mining areas (Krause, 2008).

Research-based on the results of ventilation and methane tests conducted in GIG's experimental mine *Barbara*, showed that mine workings adjacent to gobs in gassy mines led to methane emission into gobs for up to 15 years after cessation of mining operations (E. Krause and Dziurzyński, 2015). The duration and scope of emissions vary according to the range of induced mining stress relief. Mine gas can migrate to the surface, causing significant risks of explosion, suffocation, or poisoning and exerting a double environmental impact: it participates in the ozone layer depletion process and substantially contributes to the greenhouse effect.

A high methane content risks underground workers and general safety when the gas migrates through faults to the surface. At the same time, methane has a potential for economic use, so the efforts should not be focused only on its removal but should lead to its effective utilization or at least destruction. Therefore, while addressing methane-related problems, the following matters should be borne in mind:

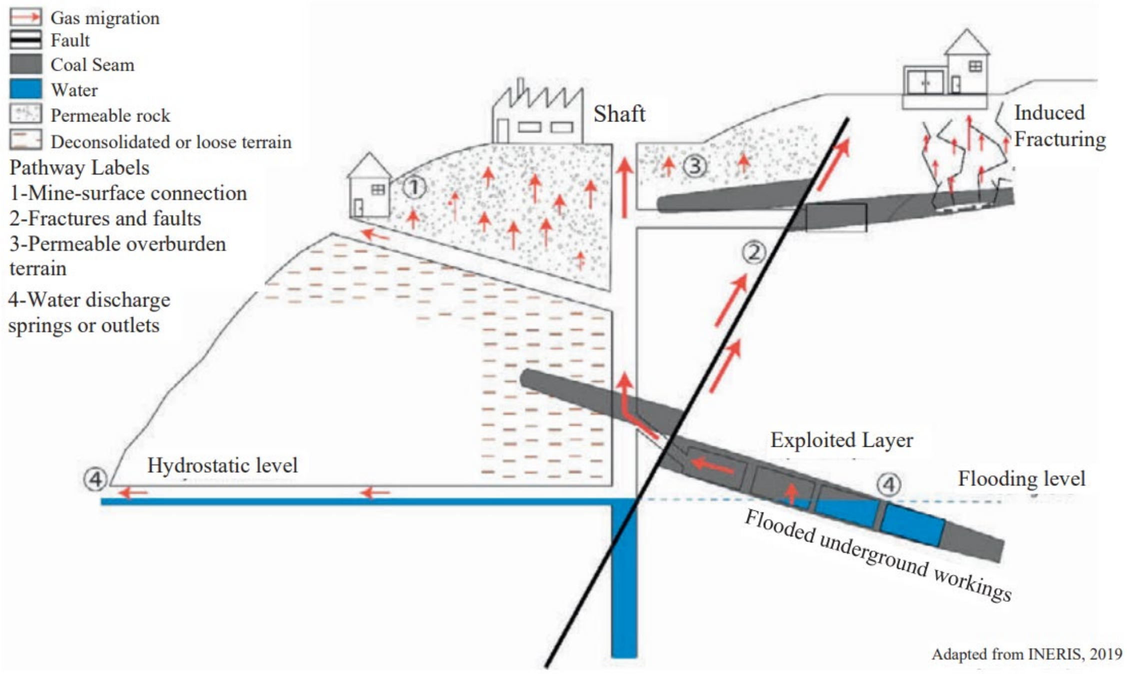
- Coal mine methane (CMM) drainage from new mining fields (before the extraction process) is technically feasible, but no attempts have been made to use modern technology and drilling procedures;
- CMM drainage in the course of extraction has a high potential for application that will improve safety with positive economic profitability;
- CMM drainage efficiency will be better when longwall or short-wall systems are used;
- AMM resources have a high potential for development in former mining areas, providing an opportunity for new economic activity in post-mining regions;
- Proper mine closure planning may increase the future AMM drainage efficiency by properly abandoning mined-out areas by providing access to the contained gas that will flow from the remaining coal and by controlled mine flooding.
- CMM and eventually AMM drainage plans, including the assessment of the gas content and methane flow capacity and other parameters, should be developed early in the mine planning process;
- Drilling test boreholes to measure methane outflow helps to assess the AMM production potential;
- Mine closure plans should consider the methane drainage potential from inception.

2.2.2 Prevention of air pollution from fugitive gases in Albania

When a mine is abandoned, as with all underground coal mines in Albania, all services are severed, including ventilation. Gas that was formerly segregated between the methane drainage systems and the ventilation is combined, and its initial emissions can be high. However, they will decline gradually over time as the sources decay. Groundwater will, in many instances, progressively flood the mine and curtail abandoned mine methane (AMM) emissions. Mines can take a few years to decades to completely flood, depending on the hydrogeology of the area and the local mining conditions. Although abandoned mines are often sealed, gas may still escape into the atmosphere. In optimal conditions, these emissions can be controlled through pressure-relief vents. However, in many instances, they are uncontrolled as leaks in shaft and drift seals, outcrops, the fractured ground above shallow workings, or underground connections with other abandoned mines' old workings.

Uncontrolled emissions from abandoned mines can sometimes arise at the surface, creating a severe public hazard necessitating remedial measures. The source of such emissions can be challenging to locate and, in some cases, can affect extensive areas (Best Practice Guidance, 2021). It is also related to mine flooding (**Figure 2.1**).

Figure 2.1 - **Emission sources and impact of flooding at abandoned mines**



Source: Best Practice Guidance, 2021

2.2.3 Prevention of air pollution from fugitive gases in Serbia

Underground coal exploitation in Serbia is linked to gas hazard disasters. One of the first recorded accidents in Serbian coal mines is the 1958 Podvis mine accident, in which 60 miners lost their lives. Apart from the number of casualties, there are no written records on the cause of that tragedy (Hirschberg, Spiekerman, and Dones, 1998). Several other tragic accidents in Serbian underground coal mining occurred (Ivaz et al., 2020):

- Aleksinački Rudnik: in 1978 (methane explosion, 14 deaths), 1984 (methane explosion and mine fire, 36 deaths), and 1989 (mine fire, 90 deaths; that accident resulted in the closure of the mine);
- RMU “Soko”: in 1974 (methane explosion, 14 deaths), 1975 (methane explosion, five deaths), 1998 (methane explosion, 29 deaths), and 2022 (methane explosion, eight deaths), and
- RMU "Rembas" – Stromsten mine, in 1984 (methane explosion, 34 deaths).

The analysis of incidence rates in Serbia showed that the country’s small underground coal mines operating under the control of the state need significant improvement in the discussed field. That is particularly apparent if fatality incidence rates are measured proportionately to production. Extremely high FI_{RW} (Fatality incidence rate according to the number of workers) indicates that the technology used in the Serbian underground coal mines is not adequate and that it is necessary to introduce new mining methods with a higher level of mechanization and automation and with significantly higher productivity (Ivaz et al., 2020). Therefore, it can be concluded that improving safety in Serbian mines must involve new investments in machinery/technology, which will require additional financial outlays.

2.3. Extinguishing and preventing fires in waste dumps

Spontaneous combustion is a significant threat in coal waste dumps, also called spoil tips or heaps. The ignition process is complex and depends on many factors, such as the amount of combustible substances, access to oxygen, and the potential for heat accumulation in the dump. Atmospheric conditions, such as wind speed and direction, insolation, pressure changes, and precipitation, strongly influence oxygen access and heat accumulation, and thus also the possibility for spontaneous ignition (Różański et al., 2022).

There are two major extractive waste types: mining waste and coal processing waste. Waste generated during the extraction and processing of coal called extractive or mining waste, is a mixture of rocks co-occurring with bituminous coal (claystones, mudstones, sandstones, shales and the like), which was not recovered during the processing and enrichment of the extracted raw material. While waste is generated during all stages of the mine development and extraction activities, starting with shaft sinking, through opening out of the seams, and finishing with all technological operations linked with the enriching and purification processes (Gogola et al., 2020), most of the mining waste is produced during the exploitation.

The factors that contribute to the occurrence and propagation of endogenous fires in extractive waste piles are (Gogola et al., 2020):

- Factors connected with the properties of the waste (the rank of coal, the content of macerals, the percentage content of coal in the waste, the mineral content, and the moisture content); and
- Factors connected with the place and the method of depositing the waste (the shape and height of the extractive waste dumping facility; the volume, the surface area, and the location of the waste as related to the surrounding land; and the technology of forming the embankment, as well as the method of waste neutralization).

The literature review demonstrates that two basic approaches exist to assess the propensity of extractive waste to the self-ignition process. The first relies on the so-called “expert methods of assessing the fire hazard” based on several site-specific criteria and the character of the deposited waste. The second approach relies on experimental methods through which the propensity of the waste to self-ignition is assessed using tests or observations of extractive waste in installations or research stands under laboratory conditions (Gogola et al., 2020).

Methods for monitoring the spontaneous combustion of coal waste piles are commonly known and used in mining worldwide. For example, there is an integrated methodology based on surface temperature detection (Hu and Xia, 2017) or vegetation as an indicator of a smouldering underground fire in coal waste dumps (Abramowicz et al., 2021).

Water erosion (associated with increased rainfall) is an essential factor that increases fire danger at mine waste dumps. A properly designed and operated drainage system is necessary to avoid slope erosion, preserve the surface layer's condition, and prevent water erosion. Another essential element that may limit the erosion of slope material is vegetation cover, the primary function of which is to disperse and reduce the speed of rainwater run-off. The best practice is to secure the dump as its subsequent levels are developed systematically; such a process gives the best protection when green cover is made immediately after the sealing layer has been laid. Plant root systems strengthen the surface layer of soil on both the plateau and slopes of the dump (Różański, 2022).

2.4. Mined lands subsidence

2.4.1 Overview

The problem of subsidence and damage to buildings overlying the mine's footprint is an inevitable consequence of underground coal mining in large mining basins. There has been a long history of recording the behaviour and damage to various facilities in different mining conditions. Many empirical observations of certain deformation types have been obtained, and statistical data on that matter has been collected. As a result, it is possible to distinguish the limits between different intensities of damage and to define the protection criteria. The observations have been performed in many countries with developed mining industries, varying in terms of the size of the population, mining conditions, as well as facilities construction methods and characteristics, thus allowing to establish protection criteria applicable to the wide range of particular circumstances. The main difference between them is the degree of detail, which depends on the scope and level of each study (Guzy and Malinowska, 2020; Hejmanowski et al., 2016).

While assessing the dangerous impact of mining on buildings at the planned mining sites, the primary criteria for the protection of objects are the allowed values of slope (N), the radius of terrain curvature (R), and horizontal deformations - dilatations (D). To determine the degree of the dangerous impact of continuous deformations on the existing and planned facilities in the analysed area, the mining terrain is divided into categories (Vušović and Vlahović, 2020; Malinowska, Hejmanowski, and Dai, 2020), the limits of which are determined based on the maximum acceptable values of deformations. Then the area of a given category is determined by selecting the maximum ranges resulting from the least favourable distributions of specific deformation indices. Accordingly, the facilities are divided into four protection categories (I-IV). The values of deformations allowed for each of them are presented in **Table 2.1**.

Table 2.1 - **Criteria for classification of the surface movements and deformations**

Terrain category	Magnitude of expected deformations			Possible degree of damage: types of surface structures	Usability for spatial development
	N_{max}, mm/m	R_{min}, km	D_{max}, mm/m		
0	N < 0.5	R ≥ 40	D ≤ 0.3		
I	0.5 < N ≤ 2.5	40 > R ≥ 20	0.3 < D ≤ 1.5	Small, easily fixable damage may occur. Monumental objects, industrial systems, essential for the safety of life reasons, or regarded as especially important, e.g., gas pipelines, the damaging of which may cause gas outbursts; water reservoirs.	In safe areas, no protection of objects is needed.
II	2.5 < N ≤ 5.0	20 > R ≥ 12	1.5 < D ≤ 3.0	Small damage to objects may occur; relatively easy to remove. The most important objects, industrial objects, large furnaces, coke furnaces, hoisting shafts and machines, Industrial objects-monolith or with overhead cranes, public utility objects, e.g., hospitals, theatres, vaulted churches), river valleys, water reservoirs, main railways and stations, tunnels, vaulted bridges, main water-works unprotected against mining damage, huge houses of residence (longer than 20 m). Big cities.	Areas where partial protection of all objects is not profitable.
III	5.0 < N ≤ 10.0	12 > R ≥ 6	3.0 < D ≤ 6.0	Bigger damage to objects may occur without destroying them. The main roads, routes and small railway stations, industrial objects which are less susceptible to the movement of the subsoil (no overhead cranes), uncoated freezer rooms, high chimneys, smaller houses of residence (10–20 m in horizontal prospection), city sewage treatment plants, main collectors, sewage pipelines, gas pipelines, steel gas pipelines.	Areas requiring partial protection of objects (type of protection depends on the type of object, its sensitivity, subsoil properties, and magnitude of deformations.
IV	10.0 < N ≤ 15	6 > R ≥ 4	6.0 < D ≤ 9.0	Serious damage, objects are nearly destroyed. Stadiums, small houses, and other less important objects.	Areas requiring serious protection of objects.

Terrain category	Magnitude of expected deformations			Possible degree of damage: types of surface structures	Usability for spatial development
	N_{max}, mm/m	R_{min}, km	D_{max}, mm/m		
V	N > 15.0	R < 4	D > 9.0	Severe damage, objects are destroyed.	Areas not fit for spatial development.

Source: Vušović and Vlahović, 2020; Malinowska, Hejmanowski, and Dai, 2020

Unexpected land movements can occur even a considerable time after the end of mining. Abandoned mine shafts can suddenly and unexpectedly collapse. The potential hazards presented by abandoned shafts include the following (Donnelly, 2015):

- Collapse or movement of the ground, occurring suddenly or gradually;
- The discharge of acid or ochrous mine waters can result in the pollution of water courses and aquifers;
- Flooding of basements, buildings, and structural foundations;
- Emission of mine gases; and
- Accidental entry: injury or death is an inevitable consequence of falling down a shaft.

Flooded shafts compound the risk with the added danger of drowning, suffocation, or poisoning by gas. The collapse of the shaft is also possible once it is disturbed. Lecomte (2012) identifies seven causes of shafts collapse:

1. The collapse of an infilled shaft: The shaft fill material is abruptly remobilised downward, rushing into the old workings and causing the surface collapse (if no structure or protection was installed at the head of the shaft). The failure of the shaft filling material generally occurs after a slow degradation of the conditions of the filling material (e.g. due to rising water after the cessation of pumping). Other examples include the partial collapse of shaft-filling material into voids formed during the original shaft infilling.
2. Failure of the shaft head: Many shafts have been closed in the past using standards that would not be acceptable if applied today. For example, shafts closed by a single on-surface or near-surface wooden platform eventually completed to the surface by filling material on the shaft head but leaving the whole shaft column empty. Such structures could fail due to over-time degradation caused by moisture. Concrete slabs have also been used as shaft head, but these can break when they are subjected to excessive loads or when the surface ground materials on which they rest fail.
3. Failure of the shaft lining: The most frequent failures of shaft linings result from decreased resistance or increased pressure exerted by the surrounding ground. When the strength of the lining is exceeded, the lining (bricks, stone blocks, concrete, cast iron, and steel) deforms and eventually breaks. This results in a collapse in the shaft along with a part of the surrounding ground. The decrease of the mechanical properties of a lining material with time is an inevitable phenomenon resulting from the progressive ageing of the constituent materials. Shaft backfilling operations made

without sufficient precautions may also damage linings, and so will stones/blocks dumped from the surface that fall hundreds of meters and can damage lining sections.

4. Failure of stoppings located into the shaft galleries: Mine workings and tunnels connected to shafts may have been closed before the shaft was backfilled to avoid spreading the backfilling material into those tunnels. These structures generally consist of walls in hollow blocks, metal dams, or concrete plugs. A rupture of stoppings can allow filling material to spread into the tunnels, resulting in a collapse of the material in the shaft.
5. Effects of water: Influx of water, either due to rising water levels or infiltration because of the weather, can cause the failure of the filling material. The additional water within the column of the shaft adds weight. It may reduce the filling strength due to pore pressure generation, disturbing the equilibrium state within the column and generating failure of the shaft lining.
6. Rupture due to particular geological formations: The presence of specific geological formations, such as soluble horizons (gypsum/salt) or soil seams lacking cohesion susceptible to flow (sand, for example), may induce the creation of voids behind the lining. This void may destabilize the lining of the shaft and cause its collapse.
7. Subsidence due to remobilisation of filling material or surface development: Occasionally, slow and progressive remobilisation of the surface layer (shaft backfilling material and low cohesive ground material) occurs near a mining opening. Settlements occur within the backfilling materials as a result of compaction. In effect of outside disturbances (on-surface overload, vibratory stress) or due to remobilisation of filling materials, ground or backfill material can settle and induce low amplitude movements (generally, the maximum amplitude is a few decimetres). The results are mainly differential surface settlements that may affect buildings and infrastructure.

2.4.2 Mined lands subsidence in Albania

Surface deformation is caused by disturbance of the subsurface rock mass by underground extraction of minerals, creating void spaces. As a result, the rocks surrounding the mining area shift inwards to fill the voids left by extracted material, causing changes in the natural stress conditions in the rock mass. Continuous or discontinuous deformations develop at the surface depending on the mining depth. The former assumes the form of mild depressions in the ground, and the latter results in fissures, pits or escarpments. After the cessation of mining activities, as in Albania, this process gradually diminishes with time.

Secondary deformations, i.e. surface movements after the end of mining, are usually associated with the restoration of groundwater levels that causes swelling and reduction of everyday stresses in overlying rock layers or the effect of the destruction of shallow underground workings (subsidence). Substantial surface movements occur many years after mine closure and can threaten present-day development and the use of post-mining areas in Albania.

In the case of former mining areas, studies of present-day mining-related deformations can be carried out based on data acquired directly from field surveys, i.e. precise levelling (Blachowski et al., 2015) or satellite GPS measurements (Muntean et al., 2016). However, mining deformation surveys usually are not continued in the post-mining period, which is the case in Albania. Therefore it is impossible to determine the extent and the size of ground surface displacements resulting from the processes occurring in the underlying rock mass. In such cases, SAR (Synthetic Aperture Radar) data acquired by satellites orbiting the Earth since the early ’90s can be used. With a suitably large number of radar images, it is possible to determine surface displacements over large areas with millimetre accuracy (Milczarek et al., 2017).

2.4.3 Mined lands subsidence in Serbia

Surface subsidence due to underground mining and evaluation of subsidence-induced damages of objects are growing problems in Serbian underground coal mines. When comparing the experience in studying the process of mining subsidence with other countries, Serbia’s 40 years of experience can be considered relatively modest. The country is characterized by dipping seams, with a 10–20 m thickness at small and medium depths, an extremely steep relief, and a relatively small population of the mine area. In some underground coal mines, the protective pillars were excavated under the facilities of minor importance, such as the local roads and railways, smaller watercourses, and rural settlements. They, therefore, had the highest values of permitted deformations (Vušović, Vlahović, and Kržanović, 2021).

In active underground coal mines in Serbia, the dominant geological forms encountered are layered sloped structures with pronounced tectonic deformations, causing irregular shapes of limited exploitation areas and possible short lengths of excavation fields and panels with frequent changes in the strike and angles of seam dip. These phenomena are the result of complex post-tectonics in the deposits. The thickness of the seams ranges from several to 40 m, and the dip ranges from horizontal to steeply dipping. The basic physicomechanical properties of the working environment in Serbian underground coal mines are relatively unfavourable because the values of compressive strength of the seam roof and floor rocks are either lower or significantly lower than those of coal in the seam, which dramatically narrows the potential for application of large mechanized systems and concentration of production (Vušović and Vlahović, 2020). Regarding the depth of coal seams, most deposits belong to the group of mines with a medium depth of exploitation, up to 500 m. The geological conditions encountered in the deposits have a decisive role in choosing specific technological solutions for exploitation, excavation systems (methods and technologies), and security measures in underground mining facilities.

Complex geological conditions, including relatively high seam inclinations and the presence of faults, have a negative influence on subsidence. In such a condition, the prediction of the surface areas to be impacted by mining activities is more complicated than it is in horizontally deposited seams. The subsidence basin most likely will not be symmetric like in **Figure 1.4** (in section *1.6.2 Subsidence of mined lands hazard in Albania*), and it will have higher values of angular distortion on one side of the land and more favourable conditions on the other. Moreover, mining activities near faults increase the probability of discontinuous deformation even long after the stoppage of mining activities. Therefore, prediction of the future impact on the surface should be essential to the current mining operations and mine closure plans.

At the same time, in the case of Serbia, there are also positive factors related to the current and future subsidence. First of all, the surface of the mines is not highly urbanized. Therefore, potential destructive effects will not be as severe as in locations close to cities or heavily industrialized areas. Secondly, certain Serbian mines, such as e.g. Soko mine, use an underground mining system that is not highly concentrated (shorter mining workings, coal pillars between the extraction galleries) and, therefore, should cause lower subsidence values than regular mining with caving.

2.5. Waste stocks

Production of mining waste is inherent to the mining and enrichment of coal. Over the years, coal production in Albania and Serbia has left waste heaps characterized by varying composition and particle size distribution of the material. Over time, the conditions prevailing in the waste piles' solids change due to physical and chemical weathering processes.

2.5.1 Waste stocks in Albania

Over the years, the mining industry in Albania has created, through the opening processes (main mining workings), ore body preparation workings, exploitation of mining objects, and treatment of minerals in processing plants, large quantities of mining waste and tailings. They are estimated at over 45 Mt, of which around 10 Mt is coal waste, and they are geographically distributed throughout almost the entire country. Historically, many mines extracted and enriched coal at many different locations. However, virtually all of them are closed (except for two private mines with minimal output, as mentioned at the beginning of this document).

During the mines' lifetimes, coal beneficiation and its usage have produced approximately 14.5 Mt of solid wastes deposited around the mines from which they came (Goskolli, Genc, and Sushku, 2004). These wastes have a content of, on average, 3% coal, 2% sulphur, and 95% clays. The latter poses no environmental risks and can be used as a primary component of bricks.

Over time, the solid wastes have formed small hill-like structures that are now almost always covered with vegetation (Genc, 2000). They are unsystematically spread around the mines. Very rarely, some solid wastes are self-burnt, releasing a smelly smoke upon heat. Creeks that run through solid coal wastes are not potable but have been helping to water nearby agricultural vegetation. Forestation of mineral solid wastes and coal factories is strongly recommended (Genc et al., 2007).

2.5.2 Waste stocks in Serbia

Many years of coal mining in Serbia resulted in extensive areas occupied by waste heaps, with about 1.5 million m^3 of residues, almost 1/3 of which were generated in the RMU "Rembas" mine.

Mining waste heaps exposed to rainy weather conditions might be a potential source of chlorides, sulphates, and metals that penetrate the environment. The weathering of sulphur compounds (e.g., pyrite) present in the post-mining waste starts a series of geochemical processes resulting in the acidification of rainwater flowing down the slopes of the waste heap. Acidic surface water on heaps is a complex object of study and should be continuously monitored (Bauerek et al., 2017).

As presented in **Table 2.2**, in Serbia, the total area occupied by waste piles from underground coal mining is almost twice as large as the industrial estate areas related to underground coal mines designated for rehabilitation. That comparison provides a clear picture of how extensive the waste piles are in the country and how severe the problem of acidic surface waters is in Serbia.

Table 2.2 Summarises the areas for rehabilitation (industrial estate) and waste stocks in underground coal mines in Serbia.

Table 2.2 - **Area for rehabilitation and waste stacks from underground coal mines in Serbia (2006)**

Mine	Area for rehabilitation (industrial estate)		Waste piles	Total
	Area, m^2		Area, m^2	Area, m^2
RMU "Bogovina"	Bogovina-Zapad, 52,500	Bogovina-Istok, 2,500	Several locations: 153,800	208,800
RA "Vrška Čuka"	23,000		Four locations: 100,700	123,700
RKU "Ibarski rudnici"	89,900		80,000	160,900
RMU "Jasenovac"	35,500		2,000	37,500
RMU "Rembas"	79,000		Five locations: 377,700	456,700
RMU "Soko"	130,000		43,100	173,100
RL "Lubnica"	85,000		104,300	189,300
RMU "Štavalj"	87,000		73,300	160,300
Total	**584,400**		**934,900**	**1,510,300**

Source: Based on data provided by the national consultant, 2022

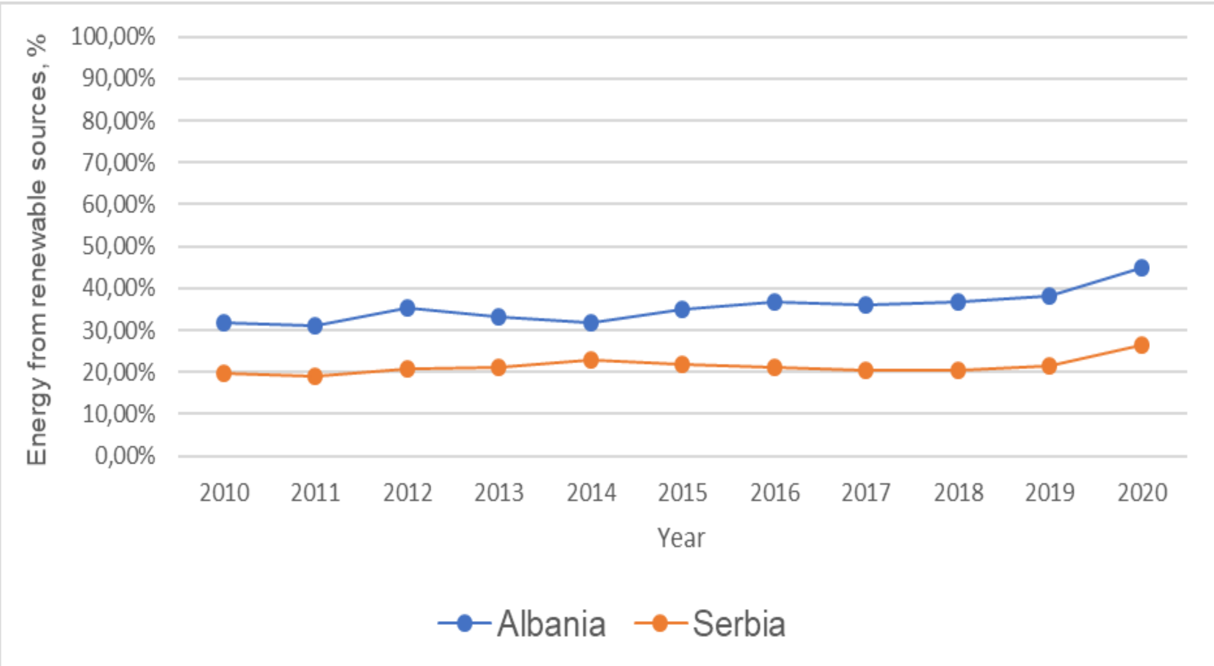
3. Analysis of the potential for repurposing mined land for future use in each beneficiary State

3.1. *Analysis of the current state of "green" energy in Albania and Serbia*

The closure of coal mines should be accompanied by transitioning to other types of energy - mainly renewable energy. Europe has steadily transitioned towards renewable energy sources for its electricity generation, making considerable progress over the last decade. In 2011, fossil fuels (oil, natural gas, and coal) comprised 49% of the EU's electricity production, while renewable energy sources accounted for only 18%. A decade later, renewable energy sources are nearly equalling fossil fuels, amounting to 32% of the EU's electricity generation, compared to 36% from fossil fuels (data from 2021, European Electricity Review, 2023). In the case of Albania and Serbia, which are not parts of the EU, a noticeable increase in the use of renewable energy at the expense of fossil resources can also be seen.

Figure 3.1 summarises the percentage of renewable energy in the total energy mix for both Serbia and Albania. Both countries have seen an increase in the share of renewable energy in the last ten years.

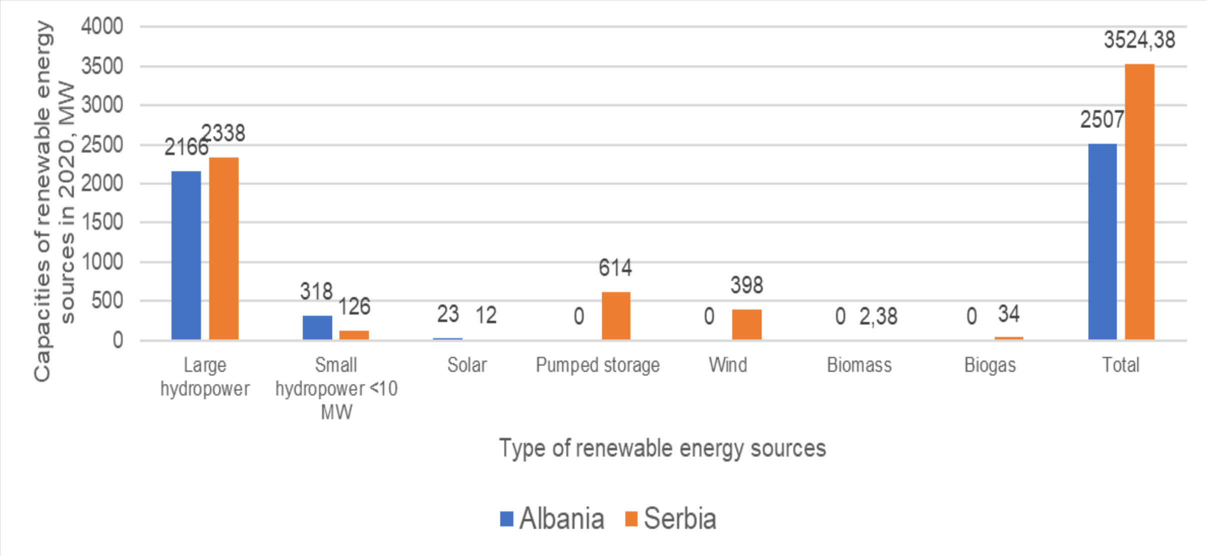
Figure 3.1 - **Energy from renewable sources in Albania and Serbia from 2010 to 2020**



Source: based on www.energy-community.org

Figure 3.2 shows the capacity of renewable energy sources (in MW) in Albania and Serbia in 2020. In Albania, green energy is produced from large and small hydropower sources. In Serbia, while large and small hydropower also constitutes a significant share of green energy produced in the country, the latter comes from pumped storage and wind.

Figure 3.2 - **The capacity of renewable energy sources in Albania and Serbia in 2020**



Source: based on www.energy-community.org/

At the same time, in Serbia, power generation from coal still constitutes the primary source of electricity, accounting on 2020 for approx. 51% of installed capacity and 68% of the total electricity production. Electricity generation from coal is run by the state-owned company "Elektroprivreda Srbije" (EPS), which operates two complexes. The first, "Termoelektrane Nikola Tesla," includes TPP Nikola Tesla A (6 blocks), TPP Nikola Tesla B (2 blocks), TPP Kolubara (5 blocks) and TPP Morava (1 block). The second one, "Termoelektrane Kostolac", consists of TPP Kostolac A (2 blocks) and TPP Kostolac B (2 blocks). Coal is primarily provided by EPS' open pit mines located in the proximity of its TPPs. In addition, EPS procures coal also from the underground coal mines owned by the state-owned company PEU "Resavica".

With 45% of the total primary energy supply (TPES), Albania has one of the most significant shares of renewable energy in the energy mix among South-Eastern European countries. Albania's primary renewable energy source is hydropower, which accounts for 95% of all generating capacity. The remaining locally produced energy comes from crude oil (4%) and solar (1%). While Albania has abundant solar and wind resources, they are almost entirely untapped (UNECE, 2021).

Heavy dependence on hydropower means that renewable energy generation in the country is sensitive to rainfall, which in recent years has been experiencing considerable annual variations and an overall steady decline. With the progressing climate change, the situation will likely worsen in the coming years (UNECE, 2021).

Apart from being sensitive to the changing weather conditions, Albania is also heavily reliant on its trading partners, as a large part of the country's energy supply comes from abroad (UNECE, 2021).

3.2. Mine closure procedures

Mine closure procedures commence following the decision of the relevant authorities (i.e., the mine company's management and the Ministry of Mining and Energy). Issues that need to be addressed throughout the process of closure are various and include:

- the legal and financial aspects of the endeavour;
- technical and practical matters related to the physical closure of the mine;
- environmental issues; as well as
- The social aspect includes mitigating burdens on the laid-out workers and the nearby communities hitherto dependent on the mine.

In terms of physical closure, the biggest challenge is posed by mine shafts. Mining shafts are among the most critical mine workings. In underground coal mining in Serbia, only four mines have coal seams accessed by shafts. Those are: RMU "Bogovina", RA "Vrška Čuka", RMU "Rembas" (Senjski rudnik), and RMU "Soko". Each shaft is linked with excavations that have various technological functions, such as:

- shaft inlets for shaft bottoms and coal seams,
- ventilation ducts,
- tubular and cable telescopes,
- old, not decommissioned overflow chambers,
- filling channels,
- compartment of skip measuring containers,
- walkways around the shaft,
- heating, escape channels, etc.

Due to the closure of a mine, these excavations require effective closure. Pits and shafts that are no longer being used should be closed due to threats they might pose to active mining excavations, ground and deep water, the surface with its artificial infrastructure, trees and crops.

Shaft closure is defined as:

- Filling the shaft pipe and shaft workings with non-combustible material and permanent protection of the shaft structure with a reinforced concrete slab,
- flooding the shaft after its isolation with water dams from the rest of the underground mine workings and placing the reinforced concrete slab on its hollow, or
- in some cases, filling the shaft is unjustified for technical and economic reasons, providing permanent protection of the shaft structure with a reinforced concrete slab.

The shaft closure, especially along its whole length, should be conducted only after a careful evaluation indicating whether:

- The given shaft heading, in addition to the exploited coal seams in the adjacent part of

the mining area, provides other valuable minerals,
- it is possible to adapt the shaft included in the decommissioning plans for other purposes, such as, e.g. a mine tank for backfilling material, drinking water, or industrial water intake,
- there is a possibility of adapting the shaft for storing materials that are burdensome to the natural environment.

Before proceeding to the detailed preparation of the decommission works plan, it is necessary to determine the following:
- The way the shaft components may be either used or wholly or partially recovered,
- The existing fixed shaft pipe equipment elements that can be used directly or with little adaptation during decommissioning works.

A detailed analysis of hydrogeological and gas conditions and shaft connections with other mine workings should precede safe and reliable shaft closure. Such analysis determines the method of closure and allows for defining a plan of work, which should be carried out individually for each shaft.

Shaft closure is a complicated process because shafts connect the surface area with a network of underground workings that disturb the hydrological and gas conditions in the rock mass. Therefore, the closure method must take into account both factors.

Shaft closure documentation should include the following:

a) essential documentation:
   - Application for shaft closure - justification for shaft closure, including the possibility of using it for purposes not related to mining operations, technical description of the shaft, technical data of the extraction device and other devices connected functionally with the shaft, description of water, gas, fire and old gobs conditions in the vicinity of the shaft, and additional documents providing data on the state of the shaft;
   - Technical (hydrogeological and geological-engineering) project for shaft closure - technical data of the shaft, description of the geological conditions of the shaft, technical parameters of rocks, prediction of shaft stability after its decommissioning, assessment of the possibility of using the shaft for non-mining purposes, and projected hazards during the decommissioning works of the shaft and after its closing.

b) operation and maintenance documentation:
   - the technology of performing works,
   - operating and record manual.

The above materials should be developed based on hydrogeological and geological-engineering conditions near the shaft, projected local mining hazards, and project implementation guidelines.

The technical shaft closure project should also include a list of anticipated local mining hazards, including in particular:

- water hazard,
- methane hazard, as well as
- ventilation and fire hazards.

The assessment of water hazards should include such factors as:

- location of aquifers,
- the amount of water entering the shaft from a given level,
- water chemistry,
- the degree of aggressiveness of water against the material of the shaft support,
- hydraulic connections of the shaft with adjacent workings or exploitation shafts,
- the possibility of water breaking through the shaft to active mining excavations, and
- the ability to reproduce the original hydrogeological conditions.

The methane hazard characteristics should include the following:

- location and amount of methane outflows,
- location of stoichiometric mixtures that pose fire and explosion hazards, and
- determination of methane hazard category.

The assessment of ventilation and fire hazard should concern the following:

- a propensity to self-ignition of coal seams cut by a shaft (endogenous fires),
- the degree of reconsolidation of old gobs after mining the deposit part inside the protective pillars for shafts, and
- the effectiveness of dams built around nearby fire fields (based on measurements of concentrations of fire gases in the enclosed space).

3.3. A possible implementation of actions (scenarios) developed under POTENTIALS and GreenJOBS projects in Albania and Serbia

The Central Mining Institute, which helped UNECE to develop this document, is currently working on two projects that address the 'second life' of coal mines, namely POTENTIALS and GreenJOBS.

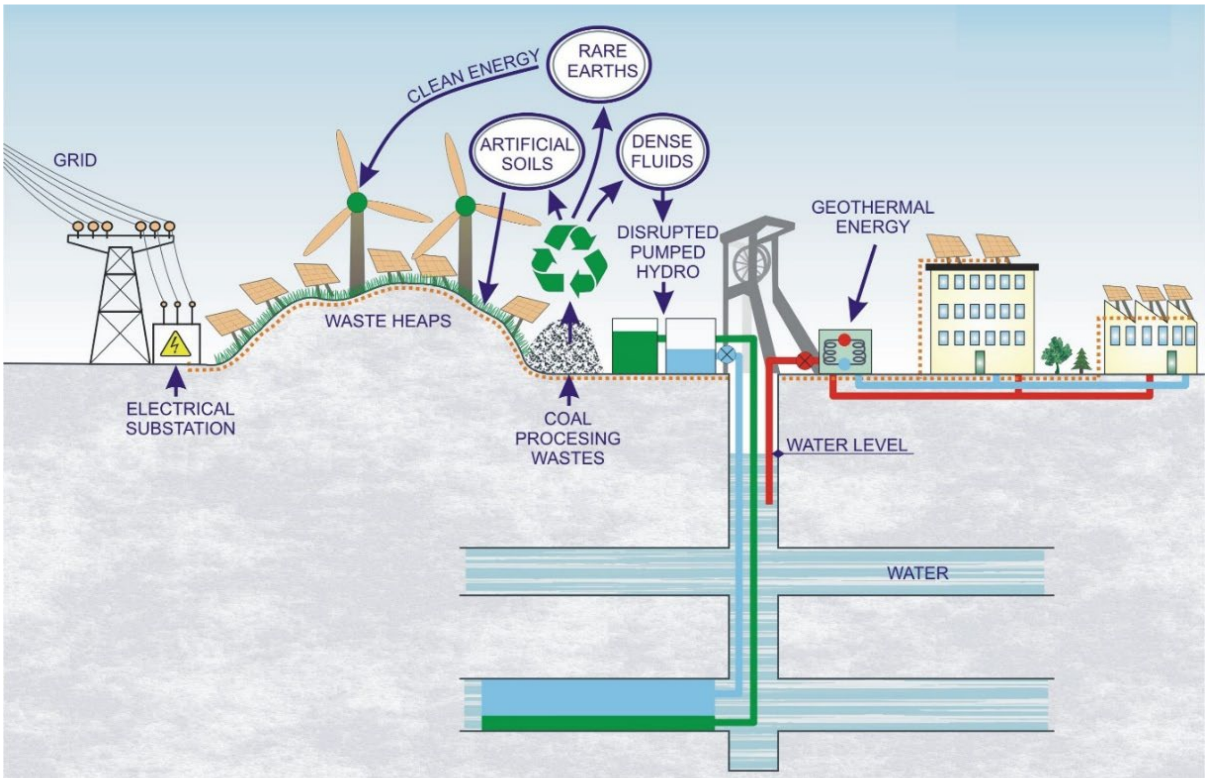
The POTENTIALS project focuses on the unique aspects of coupling end-of-life coal mine sites, coal-fired power plants, and closely related neighbouring industries. It takes advantage of their joint potential to stimulate new economic activities, developing jobs and economic value in coal regions in transition. POTENTIALS aims to identify and assess their synergistic opportunities employing a prospective analysis, enabling to develop business models that rely on renewable energy, contribute to the circular economy or scale energy storage, guaranteeing a sustainable and combined use of assets and resources, and support the update and re-adoption of territorial just transition plans. POTENTIALS' approach is premised on the notion that for stimulating new economic activities and jobs in Coal Regions in Transition, management decisions should be based on a prospective analysis of business models that rely on renewable energy, contribute to the circular economy or scale energy storage. Guaranteeing a sustainable and combined use of assets and resources, otherwise overlooked in these high-velocity environments of phasing out processes, is the necessary ingredient for sound decision-making.

The GreenJOBS project focuses on repurposing end-of-life underground coal mines by deploying emerging renewable energy technology and circular economy technologies to promote sustainable local economic growth and maximise the number of green, quality jobs. GreenJOBS aims to provide mining companies with two innovative business plans: a Virtual Power Plant where the energy produced will be sold to the grid or used to power electro-intensive industries or companies with constant energy consumption located close to mines, such as aluminium factories or green data centres; and a Green Hydrogen Plant where renewable hydrogen will be produced by electrolysis of mine water and electricity from renewable sources. The GreenJOBS approach is premised on leveraging five competitive advantages of underground coal mines:

- mine water for geothermal and green hydrogen,
- connections to the grid that can be adapted to inject the electricity produced,
- large waste heap areas for installing photovoltaic/wind,
- deep infrastructure suitable for unconventional pumped hydro storage using dense fluids, and
- fine coal waste for recycling into dense fluids, soil substitutes for restoration and rare earths.

Figure 3.3 presents a graphical abstract of the GreenJOBS project for the case of a Virtual Power Plant where the energy produced is sold to the grid or to power electro-intensive industries or companies with constant energy requirements that are located close to the mines.

Figure 3.3 - **Graphical abstract of the GreenJOBS project**



Source: based on www.greenjobsproject.eu

Possible examples of projects that could be developed under the POTENTIALS and GreenJOBS programs in Albania and Serbia include:

- Virtual power plant - production of renewable energy (solar photovoltaic and wind power on the waste heaps, unconventional pumped hydro storage using dense fluids, geothermal energy), which is to be sold to the grid or used to power companies with constant energy requirements located in the immediate area, such as factories or green data centres.
- Green hydrogen plant - a green hydrogen plant where renewable hydrogen is produced by electrolysis of mine water and electricity from renewable sources. It is a clear alternative to selling the surplus of generated renewable energy to the grid or power industries with constant energy requirements. The energy produced will be stored and used to power nearby electro-intensive industries.
- Eco-industrial park - an integrated alternative to legacy-industry complexes providing sustainable energy generation technologies and circular economy contributions at the industrial sites. The main objective of industrial parks is to reduce waste and pollution by promoting short-distance transport and optimizing material, resource, and energy flows within the industrial parks. Sustainable energy generation technologies comprise solar and wind energy production with energy storage and geothermal energy to provide cooling/heating to the companies/industries participating in the Eco-industrial park.

- Cultural heritage and sports/recreation areas using green energy - production of green energy at the coal mine and coal-fired power plant site combined with their adaptation for tourism purposes.
- Combined-cycle gas turbine (CCGT) power plant powered by natural gas uses coal-fired power plant infrastructure to combine-cycle plant works to produce electricity and captures waste heat from the combined cycle and open cycle gas turbines to increase efficiency and electrical output.
- Mine gas utilization for gas-powered CHP power units - use of mine gases for gas-powered CHP (Combined Heat and Power) units.
- Biofuel combustion energy plant - change from fossil fuel combustion power plants to energy production from processing biofuels.
- Molten salt plant - energy storage in tanks with heated molten salt. They allow smoothing of the fluctuation of renewable energies such as solar and wind. Nevertheless, they should be coupled with concentrated solar power (CSP) plants where a heat transfer fluid (HTF) such as oil absorbs the energy to achieve better efficiencies.

Below are possible actions that could be implemented, either in addition to or in combination with the above-listed project:

- Batteries provide ancillary services that run regulatory operations in the background, performing multiple functions - monitoring, balancing and repairing the energy infrastructure. In the event of a disturbance, these ancillary services restore values such as voltage and frequency to their normal range. They are, therefore, essential for maintaining a functioning electricity supply. They can be split into four ancillary services: operational management, frequency control, voltage control, and system restoration.
- Recovery of resources from coal mining waste piles - the circular mining technology based on waste pile materials recovery. It requires installing a material recovery plant, which must be permitted according to the territory development plant.
- Usage of methane from degasification units at closed coal mines.
- Circular mining technologies for pumped water material recovery. These require the installation of a mine water treatment plant and a lack of regulatory restrictions for land use.
- Large-scale IT infrastructure - power plant - uses a coal-fired power plant infrastructure for "mining" cryptocurrencies (bitcoin, etc.) and secure data collection and storage using green energy.
- Geothermal energy - use of closed coal mines for geothermal energy production.
- Recycling into dense fluids - an unconventional pumped hydro energy storage system employs a high-density fluid, such as a slurry, with a density greater than water.
- Underground hydro-pumping - producing and storing energy in the closed coal mine shafts using hydro-pumping (capacity less than 20 MW).

Since underground coal mining has already ended in Albania, using the post-mining areas for energy production - photo-voltaic and wind energy seems optimal. Given the country's geothermal water potential, its use should also be considered for producing renewable energy.

Given the conditions in active mines in Serbia, the possibility of coal mine methane- and, after decommissioning of mines, of abandoned mine methane-based energy production, should also be considered.

4. Technical, principle-based guidelines for designing and implementing national programmes for efficient, safe, and environmentally conscious mine closure in each of the beneficiary States

Planning for mine closure should start in the mine planning phase during feasibility studies. Development of detailed closure plans already at that stage should be required by the state and local authority's environmental permitting systems and operating licences. Such plans can and should be updated throughout the lifetime of the mining operation, reflecting changes in mining, expansion, and any unforeseen environmental impacts.

Local communities and other stakeholders should be engaged throughout the process, as the outcomes will affect them. According to the "Management of Environmental Risks During and After mine closure" - MERIDA project (performed under the European Coal and Steel Research Fund program), the objectives of the closure plan should be to (Duda and Krzemień, 2018; Fernandez et al., 2020):

- ensure that the site is physically and chemically stable and safe for humans and wildlife;
- encourage the re-establishment of a sustainable ecosystem;
- ensure the land suitable for subsequent use;
- minimise the economic loss to local communities and promote sustainable economic development;
- minimise the long-term remediation and monitoring costs;
- ensure adequate resources for timely and cost-efficient closure;
- ensure successful completion according to relevant authorities; and
- establish who is accountable post-closure.

When closing an underground mine, there are numerous hazards, including, amongst others:

- shaft failure,
- subsidence,
- mine gas,
- fires,
- water pollution,
- trespassing,
- rubbish dumping, and
- waste rock.

The site closure strategy should incorporate adequate measures to prevent such hazards from occurring. However, remediation and emergency measures must be implemented to limit the impact of those hazards in case they appear. In many instances, sites must also retain and maintain access to infrastructure (e.g. for re-establishment of mining, water level monitoring, and water quality monitoring).

4.1. Elimination of mining hazards occurring during the closure of the mine

Mining hazards, which may also arise when carrying out closure works in mines (shafts, drifts, workings) or even later, should be understood as a violation of water relations, methane and fire hazards, and the danger of water, dust, or gas getting into mine workings or impacting situation on the surface.

4.1.1. Water hazard and water treatment

Two variants of eliminating water hazards are available for consideration when closing shafts.

The first provides for the total shut-off of mining excavations adjacent to the shaft, using pipelines and shaft plugs with structures adapted to the projected hydrostatic pressure. This variant finds application in cases where dangerous water accumulation is possible in the liquidated shaft or its vicinity.

The second variant provides the water insulation of the shaft from neighbouring mine workings with the possibility of drainage that allows water to be discharged into active mining excavations and directed to the main mine drainage system. In this variant, the charging material must be water-permeable, and perforated filtering pipes must be installed in the discharge of water. This variant is used only when there is a certainty that water cannot accumulate in the decommissioned shaft and create a dangerous hydrostatic pressure, which can cause rapid displacement of the filling material to active mining excavations.

Any Acid Mine Drainage/Acid Rock Drainage (which coal mines are prone to producing) or water of a different composition than the natural water in the area must be treated before being discharged into local water courses. Untreated mine water pollution can reduce biodiversity along a watercourse, significantly reducing fish and invertebrate populations. Damage to a river population will also affect birds and mammals which feed on river species (Johnston et al., 2008). Treatment can be active, passive, or a combination of both. Generally, passive methods involve fewer ongoing maintenance costs but take up larger land areas because they need longer retention times to treat the water (Kleinmann, Hedin, and Nairn, 1998). However, some passive treatments serve additional purposes. Constructing wetlands can create a new bird habitat, increase biodiversity, and serve as amenity areas for the local population (Johnston et al., 2008). The typical active method is adding chemical reagents to increase pH and precipitate metals from the solution. This method's sludge must be separated and disposed of, which has high operating costs (Johnson and Hallberg, 2005). There is also an active biological method called sulfidogenic bioreactors. In this case, the alkalinity of the water is increased by biogenically produced hydrogen sulphide, and metals are precipitated out as sulphides. Such a system is more controllable and predictable than a passive biological system. It can also allow heavy metals to be selectively recovered and reduce sulphate concentration. While this process also occurs in passive biological systems, it is more efficient in active ones (Geller and Schultze, 2013).

There are many different types of passive biological methods to treat mine water. Suppose the water that needs to be treated does not have significant amounts of ferric iron or aluminium. In that case, it may be treated with an anoxic limestone drain (ADL), which is cheaper than wetland systems. In such cases, the water runs through an air-tight anoxic limestone gravel bed to raise the pH. The anoxia prevents ferric hydroxide from precipitating and armouring the gravel, reducing the limestone's ability to raise the pH. ADLs are often used with wetlands because they reduce the alkalinity, and the wetlands capture the precipitated iron (Johnson and Hallberg, 2005; Geller and Schultze, 2013).

4.1.2. Gas hazard

The methane hazard may occur both during the closure of the shaft and after its completion. In practice, the accumulation of gas mixtures with different concentrations of methane on the surface has been recorded at the shafts filled with loose material and even at the shafts whose heads were additionally sealed with sealing means. There were cases of zones with dangerous concentrations of gases within a radius of up to several meters from the shaft.

The gas hazard during the shaft closure can be limited by:

- conducting, for as long as possible, the closure of the shaft in an intensive current of active circulating or separate lute ventilation,
- continuous measurements of gas concentrations along the entire length of the shaft pipe,
- application of temporary breaks in backfilling, and
- tight sealing of mine workings connected with the shaft.

There are both active and passive methods of treating mine gas. Gas capture is an active treatment option. A vacuum is applied to the mine to prevent the gas from reaching the surface uncontrolled. This is typically a highly complex and expensive undertaking, and therefore it is generally used only in acutely problematic mines. The passive option is to create preferable pathways for the gas to vent at specific localities on the surface, fitted with flame arrestors and lightning conductors. Such conduits can include vent pipes in drifts/shafts or purposely drilled boreholes. If, for any reason, such methods cannot be applied (or are insufficient), then redevelopment of the site is often not advisable until stable (and acceptably low) gas emissions occur. Any infrastructure built over the abandoned mine should be designed to prevent gas entry, e.g. using gas sumps beneath buildings.

4.1.3. Ventilation and fire hazard

The backfilling process, regardless of the method of filling, does not guarantee a simple and effective way of sealing the shaft pipe. The coal seams cut by the shaft/drift may, under unfavourable conditions, be a potential fire source. Ventilation and fire hazards during backfilling should be eliminated by:

- circulating ventilation, maintained as long as possible, between a filled shaft and at least one exhaust shaft, above the deepest, still accessible level,
- separate ventilation, in the case of reduced efficiency of circulating ventilation,
- tight insulation of coal seam cutting zones prone to spontaneous combustion,
- incombustible filling material, and
- separation of the shaft from horizontal workings with permanent dams made of non-combustible materials.

Control of the shaft closure process

During the closure of the shaft, it is necessary to control the following:

a) Filling material in terms of:
   - reaction with water,
   - grain size,
   - the content of foreign bodies, e.g. metals, garbage, and
   - combustibility.
b) The state of the shaft's filling during capping by:
   - checking compliance between the delivered and the theoretically required amount of charging material,
   - measuring the state of the filling in the shaft (the measurement should be carried out with the frequency allowing for early identification of the formation of voids in the shaft and near the intersection of shaft inlets with the shaft), and
   - measuring the filling's level (it should be conducted each time after filling 50 m of the shaft pipe or restarting the work after stopping the filling for more than one week).
c) Methane evolution by continuous measurement of its concentration along the entire length of the shaft:
   - directly before starting the filling process,
   - after each prolonged interruption of backfilling,
   - after covering the next level,
   - each time there is a drop in atmospheric pressure by more than five hPa,
   - when the warning signal is triggered by one of the automatic methane detectors installed in the shaft.
d) Settlement of the charging material in the shaft after it has been filled, at least once a month for one year.

It is also necessary to control the outflow of the gas mixture. To accomplish this goal, the following devices are proposed:

- suction gas extraction device,
- a degassing device controlled by a sensor reacting to the pressure difference in the pipeline (windshield) and atmospheric,
- a degassing device with a conventional non-return flap valve.

Using the first of these devices allows the transport of the evacuated gas to the user.

Controlling the threat of methane outflow from a decommissioned shaft by employing a sensor-controlled gas pressure difference in the shaft and atmospheric air or by ordinary non-return flap valves (installed in tubes recessed in the closing covers of the decommissioned shaft) is intended to enable discharge into the atmosphere of such amount of methane that is necessary to prevent the pressure in the decommissioned shaft from rising, and thus also the methane flow to the surface.

In addition, fire hazards could be a significant threat also to waste piles. In the context of the countries that are the focus of this study, this observation is particularly relevant to the situation in the Serbian RMU "Soko" and the RMU "Štavalj" mines. Such hazards should also be carefully monitored, and preventive measures must be applied when necessary.

At the very minimum, measuring temperature at the depth of the waste heap and on its surface is recommended. The rapid development of UAV and infrared thermography cameras allows for cheap surface monitoring and early warning about elevated temperatures. Moreover, monitoring CO_2, CO, and O_2 at the depth of the heap is also advised.

Concerning preventive measures, several existing technologies, such as implementing additional sealing of the hotspots (e.g. with concrete panels and fly ash), serve as a concrete-like cover. However, such a solution is not feasible for large surfaces due to the high application costs. Therefore, the most common preventive measure is the greening of the waste heap, which stabilises the surface, minimises the oxygen migration into the heap, and thus reduces the fire hazard.

4.1.4. Records of decommissioned shafts

The mine must keep records of inactive and closed shafts, which should be maintained by a person appointed by the chief engineer of the mine. During the shaft closure, records should be kept by the person supervising the closure.

After completing the shaft closure, the principal and the contractor of the works should prepare a report featuring as-built drawings and updated maps of underground workings indicating the changes made and the remedial work.

Every shaft that has been sealed and for which as-built drawings have been prepared should be subject to an evaluation of the status of its protection once every six months. The inspection results and potential recommendations should be entered into the inactive and the decommissioned shaft registers.

The mines informed the state mining office about the closure and the method that was applied to execute it. The decommissioned shafts should be marked on mining maps.

All documentation related to shaft closure should be stored in the department of the head engineer for energy and machinery affairs.

4.1.5. Waste heaps

Waste rock can be used as a backfill. However, it might not be a desirable material if it is possible to recommence mine operations. Waste rock on the surface is often aesthetically damaging, can inhibit alternative land uses, and is hazardous as it might cause landslides, surface and groundwater contamination, and dust emissions. At the same time, waste rock might be used as aggregate and construction material. Therefore, to maximise the efficacy of its use, it should be sorted according to its material and environmental properties when it is produced. If a rock cannot be applied for backfilling, it should be reused in another capacity or disposed of appropriately.

Capping is a commonly applied approach to remediate waste rock for the following reasons:

- it limits erosion and dust emissions,
- it keeps the waste chemically stable (this is particularly important for sulphide-bearing waste rock, which can therefore produce ARD),
- it can enable the retention of water and soil mass, which in turn will encourage the establishment and growth of plant species and organisms,
- it can enhance the aesthetic image of the site if done appropriately.

The waste can be left uncovered if it is not a health hazard to humans or wildlife. It still needs landscaping to ensure slope stability and cope with erosion. It should be covered if the waste poses a risk to groundwater, surface water, wildlife, or human health. Covers can be ‘dry’ or ‘wet’. The latter involves an impoundment with water covering the waste. Oxygen diffusion rates are much lower in water than in air, making water covers more suitable for preventing oxygen infiltration into acid-producing rock waste/tailings. For a water cover to be practical, a sufficient amount of water must be available to ensure the stability of the water table and water chemistry.

Deeper water covers reduce oxygen diffusion most effectively. There also must be sufficient water depth so that wave action does not disturb the tailings. Using a water cover requires ensuring the long-term stability of the impoundment and water supply. The impoundment must have an outflow channel that can manage extreme flood events. A natural stream that provides the impoundment inflow can improve the barrier by depositing extra sediment and helping restore an ecosystem by introducing local biota and nutrients (Heikkinen et al., 2008).

A dry overburden layer can prevent Water infiltration, dust, and oxygen diffusion. A dry cover can also encourage plant growth. Before covering, tailings should be consolidated and dewatered, and therefore a temporary covering might be needed to prevent dust ablation during that time. Excessive acid production can be mitigated by adding lime, crushed limestone, or pulverised fuel ash before covering. An impermeable cover, preventing oxygen and water infiltration, can be made by spreading first a sealing layer (e.g. compacted impervious clay) and then a cover layer. The letter protects the former from erosion and desiccation and reduces its exposure to human interaction and wildlife. The dual layers impede upward capillary flow and help retain metal complexes transported in pore water. If there is no risk of water infiltration, the cover material can be spread without compaction or consolidation. These methods can also be used for tailings.

4.2. Closure procedure for underground coal mines in Albania and Serbia

Closure procedures can commence only upon the appropriate decision of the relevant authorities (company's management and Ministry responsible for mining affairs). As discussed previously, issues that need to be addressed throughout the process of mine closure are various and include:

- the legal and financial aspects of the endeavour;
- technical and practical matters related to the physical closure of the mine;
- environmental issues; as well as
- The social aspect includes mitigating burdens on the laid-out workers and the nearby communities hitherto dependent on the mine.

Physical closure of the mine starts with the development of technical documentation regarding:

- Disassembly and recovery of underground equipment, including steel support;
- isolation of all mine accesses – backfilling of shafts and construction of concrete slabs on shafts entries and construction of isolation dams on drifts entries;
- demolition of surface facilities;
- rehabilitation and reclamation of mine industrial estate.

Apart from two small private mines with insignificant output, Albania has no active underground coal mines. However, in Albania and Serbia, there is a need to monitor voids in the rock mass (essential for constructing new residential areas or industrial facilities in post-mining areas) and waste piles (for potential spontaneous combustion). Due to the presence of heavy metals originating from flotation plants in mine waters and soil, monitoring of these waters should be carried out (for example, the soil in the vicinity of the RKU “Ibarski rudnici” mines flotation plant at Baljevac is contaminated with arsenic (As = 88.1 mg/kg) and nickel (Ni = 260.4 mg/kg)).

The following are guidelines for closing underground coal mines in Serbia.

4.2.1. Closure of RMU "Bogovina"

Accesses to RMU “Bogovina” (Bogovina-Istok) are the ventilation shaft No.11 (depth 180 m, diameter 3.5 m, and volume 1730 m^3) and the main haulage drift GTN (cross-section area of 14m^2). There are also accesses to the abandoned mine – shaft No. 10 (hoisting shaft, with diameter 6 m) and drift, at the closed Bogovina-Zapad mine. These accesses have not been sealed either during the abandonment of the Bogovina-Zapad mine or ever since and, therefore, shall be included in the closure plan. The cross-section of the drift is approximately 12m^2. Since shaft No.10 is flooded, its present condition (depth) is not known. As a result, to develop a closure plan, its designed depth of 210 m, diameter of 6 m, and volume of 5,900 m^3 shall be taken as applicable measurements.

Waste stacked near the Bogovina-Zapad mine site can be used as a backfilling material for both shafts, but only after determining its properties and suitability for that purpose. Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

The level of ground waters is also not a factor that needs to be considered during the closure of the Bogovina mine. Applying rubble from demolished buildings as a material for backfilling shafts should be considered when preparing implementation plans.

There are two industrial estates at Bogovina Mine (Bogovina-Zapad and Bogovina-Istok), and both are currently considered for rehabilitation. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines).

4.2.2. Closure of RA "Vrška Čuka"

Mine accesses to the current production area are the Avramica drift (horizontal), the N4 drift (inclined), and the ventilation shaft VO2. In the location in question, over the past 120 years, numerous mines have had their own or common accesses, making it challenging to locate all excavations. The abandoned hoisting shaft Avramica, which is flooded, is near the mine's industrial estate. Neither this shaft's condition nor the installed equipment's situation is known. The Avramica drift has a cross-section area of approximately 16 m^2, while the cross-section area of the N4 drift is 10 m^2. The diameter of the ventilation shaft VO2 is 5 m, and the shaft depth is 138 m (the cross-section area of the shaft is 19,6 m^2, and the volume is 2,710 m^3). The diameter of the abandoned hoisting shaft Avramica is 5 m, and the depth of the shaft is 199 m (the cross-section area of the shaft is 19,6 m^2, and the volume is 3,910 m^3).

Waste stacked within the industrial estate of RA "Vrška Čuka" mine can be used as a backfilling material, but only after determining its properties and suitability for that purpose. Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

The industrial estate of RA "Vrška Čuka" mine should be subjected to environmental rehabilitation. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines).

4.2.3. Closure of RKU "Ibarski rudnici"

The RKU "Ibarski rudnici" includes two mining areas: Jarando and Tadenje.

The Jarando mining area is open with two drifts. The length of the GIN haulage drift is 815 m with a 14° inclination, while the Baljevac drift is horizontal with a length of 830 m. The cross-section area of both drifts is 12 m^2.

The Tadenje mining area is also open with two drifts, where the Tadenje drift is horizontal (360 m length), the main haulage drift is 16° inclined, and the total length is 66 m. The cross-section area of both drifts is 12 m^2.

Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

Areas planned for environmental rehabilitation at RKU "Ibarski rudnici" shall include industrial estates of mining areas, the industrial estate of the processing facility at Baljevac, and two waste piles. The function of the industrial estate at both mining areas is to provide loading run-of-mine coal at the cableway and supply the mine with materials and consumables. As a result, industrial estates of the mine consist of only basic facilities concentrated in relatively small areas. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines).

4.2.4. Closure of RMU "Jasenovac"

Accesses to RMU "Jasenovac" are the GIP drift, with a cross-section area of $12m^{2,}$ and the GVN drift, with two openings – one for the ventilation station and the other for the belt conveyor, both with a cross-section area of $12m^2$. Therefore, three dams will be required to isolate underground workings. Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

The area of the industrial estate of the RMU "Jasenovac", which is identified as a site for rehabilitation, is approximately 350 acres and covers all mining facilities apart from the management building located at Krepoljin city. During the operation of the mine and the processing facility in the past, waste was stacked in a single location neighbouring the mine's industrial estate. At that time, the mine had a processing facility based on dry screening and waste hand-picking; therefore, there were no waste fluids. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (e.g. photovoltaic farms or wind turbines).

4.2.5. Closure of RMU "Rembas"

The RMU "Rembas" includes three mining areas: the Senjski Rudnik, the Strmosten, and the Jelovac.
The Senjski rudnik mining area is open with hoisting and ventilation shafts connected to Resavica via South drift. The hoisting shaft is 230 m deep with a diameter of 6 m, and the ventilation shaft is 220 m deep with a diameter of 5 m, and it is equipped with a hoisting machine. The ventilation shaft also has an auxiliary connection to the surface. The volume of the hoisting shaft is 6,500 m^3, while the volume of the ventilation shaft is 4,300 m^3.

The Strmosten mining area has four accesses, all drifting, three of which are within the industrial estate of the mine. In contrast, the fourth one, the ventilation drift, is located outside the estate property. It should be mentioned that there is also a blind shaft in Strmosten (length 145 m and diameter 5 m), which is equipped with an operational hoisting machine. Cross-section areas of ventilation drift and auxiliary entrance to haulage drift are 10 m^2, while the area of entries to the GN-1 and the haulage drift is 15 m^2.

The Jelovac mining area has two accesses via drifts: an entrance to the Jelovac drift and an access to the Bučar drift. The cross-section area of the entrance to Jelovac drift is 15 m^2, while the entrance to Bučar drift has a cross-section area of 12 m^2.

Besides the accesses mentioned above, the North and South drift connect the workings at Resavica.

Waste from the RMU "Rembas" stack can be used as a backfilling material for the shafts at Senjski rudnik, but only after determining its properties and compliance for that purpose. Drift dams shall be constructed of solid material (concrete and brick) in such a way as to enable sampling of the air and water from isolated sites and offer the possibility of pumping water into the mine (flooding).

The areas planned for environmental rehabilitation at RMU "Rembas" shall include industrial estates of mines, the industrial estate of the mine at Resavica, and the waste piles.

The location of the Senjski rudnik, which also belongs to the industrial estate, is one of the oldest sites of the RMU "Rembas". Over time, the area around that site has developed into a village, the current centre of which is the mine industrial estate.

The industrial estate of RMU "Rembas" in Resavica comprises a processing facility, storehouses, workshops and central management offices (single site), the entrance to the South drift, and the rejects and coal fines pile.

Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines).

4.2.6. Closure of RMU "Soko"

The RMU "Soko" is open with two shafts (hoisting and ventilation). Access to various production areas of the mine is from the bottom of the shafts via long-term roadways. The hoisting shaft is 246 m deep with a diameter of 6 m (the cross-section area of the shaft is 28 $m^{2,}$ and the volume is 6,952 m^3). The ventilation shaft is equipped with a hoisting machine. The depth of this shaft is 156 m, and the diameter is 5.5 m (the cross-section area of the shaft is 24 $m^{2,}$ and the volume is 3,704 m^3). The connection between the ventilation station and the shaft is of a drift shape. Therefore, there is an additional opening. There is another drift, the GTN-1 (the cross-section area of the GTN-1 roadway is 17 m^2).

Waste from the RMU "Soko" pile can be used as a backfilling material for the shafts, but only after determining its properties and suitability. Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

Areas planned for environmental rehabilitation at the RMU "Soko" shall include the industrial estate of the mine and waste pile. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should consist of covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines). The economic use of methane from the mine should also be considered. In addition, it is essential to monitor waste dumps for fire hazards.

4.2.7. Closure of RL "Lubnica"

The RL "Lubnica" mine production occurs in the Stara jama mining area and on the development in the Osojno-South mining area. Although these two mines operate independently, they are connected, and in terms of ventilation and material supply, both mines can be treated as a single mine. The Osojno-South mining area is open with two capital drifts (the main haulage and the main ventilation drift), where fresh air is taken in through the main haulage drift. The connection between the Osojno-South mining area and the Stara jama mining area is by the N-3 roadway, which is used as the fresh air intake to the latter from the former. Outtake of the used air from the Stara jama mining area occurs via the N-2 haulage drift (area of cross-section is 10 m^2). Therefore, the Lubnica mine has three drift-type accesses. The cross-section of both entrances to the Osojno-South mining area is 17 m^2.

Drift dams shall be constructed of solid material (concrete and brick) in such a way as to enable sampling of the air and water from isolated sites and offer the possibility of pumping water into the mine (flooding).

Areas planned for environmental rehabilitation at the RL "Lubnica" shall include the industrial estate of mine, the industrial estate of the processing facility together with the local waste pile, as well as the waste piles at the now abandoned Lubnica open pit and the Osojno-South mining area drift entries location. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines).

4.2.8. Closure of RMU "Štavalj"

The RMU "Štavalj" is opened with two drifts – the main haulage drift (GIN-1) and the main ventilation drift (GVN-2). Both drifts are inclined and developed to the level below the coal seam. Other long-term roadways are developed from the ends of GIN-1 and GVN-2 towards the production areas. Main drifts have the same profile and a cross-section area of 13 m^2.

Drift dams shall be constructed of solid material (concrete and brick) to enable sampling of the air and water from the isolated site and offer the possibility of pumping water into the mine (flooding).

Areas planned for environmental rehabilitation at RMU "Štavalj" shall include the industrial estate of the mine, as well as active and non-active waste piles. The industrial estate of the mine covers all surface facilities, including all objects of the processing plant. Rehabilitation of the industrial estate of the mine and the land with the waste stacks should include covering them with soil and, e.g., creating a plant biotope or developing places for tourism and recreation. Those areas also offer good potential for producing renewable energy (by photovoltaic farms or wind turbines). The economic use of methane from the mine should also be considered. In addition, it is essential to monitor waste piles for fire hazards.

The following table (**Table 4.1**) summarizes - in a synthesized form - the mining parameters characterizing each of Serbia's underground coal mines.

Table 4.1 - **Synthetic summary of the mining potential of underground coal mines in Serbia**

No	Mine		Type of coal	Depth	Shafts	Drifts	Methane hazard	Production per worker, t/ 2017
1	RMU "Bogovina"		brown coal	240 m	Yes	Yes	registered appearance	38.2
2	RA "Vrška Čuka"		anthracite	up to 270 m	Yes	Yes	methane hazard	29.9
3	RKU "Ibarski rudnici"	Jarando	hard coal	150 - 470 m	No	Yes	methane hazard	135.0
		Tadenje		up to 100 m	No	Yes	non-methane	
4	RMU "Jasenovac"		brown coal	220 m	No	Yes	non-methane	125.1
5	RMU "Rembas "	Strmosten	brown coal	480 m	No	Yes	registered appearance	142.1
		Jelovac		160 - 200 m	No	Yes		
		Senjski rudnik		350 m	Yes	Yes		
6	RMU "Soko"		brown coal	450 m	Yes	Yes	methane hazard	141.1
7	RL "Lubnica"		lignite	200 m	No	Yes	registered appearance	147.9
8	RMU "Štavalj"		brown coal	280 m	No	Yes	non-methane	180.3

Source: Based on data provided by the national consultant, 2022

5. Conclusions and recommendations

1. Albania's economic development is making post-mining areas attractive to entrepreneurs. Therefore, those locations should be constantly monitored, especially regarding water quality, land deformation, and stability in the shafts' surrounding areas.

2. Underground coal mining in Albania was closed in the late 1990s and early 2000s, and today many post-mining areas belong to private owners. As a result, sufficient monitoring of the associated hazards is difficult or impossible.

3. Analysis of Albania's coal reserves, estimated at 130 million tons, shows that, in theory, restarting the extraction is possible. However, the complexity of geological and mining conditions and the history of underground coal mining in the country indicate that possibility of coal extraction at a level that guarantees economic viability is questionable.

4. The most promising direction for repurposing former mining land in Albania is dedicating them to green energy production, focusing on photovoltaic farms or agrivoltaics, as the local climate conditions for developing them are favourable. The Albanian government agencies work on preparing the national energy grid for greater green energy uptake.

5. Another way to utilise Albanian mining infrastructure is to create drinking water reservoirs, as the location of the local mines indicates that the areas on their surface can be used for urban construction or agricultural purposes. However, additional chemical analyses of these waters are required, as is the development of adequate rules for their continuous monitoring and treatment.

6. Coal mining in Serbia is carried out in 8 mines. All of them are characterized by natural hazards and complicated tectonic conditions, which question the possibility of improving mining efficiency in the country. As a result, it would be advisable to focus on only two or three most promising active mines, which could achieve long-term profitability with proper mining reorganization and additional investments. That would allow maintaining the production at the expected level and help avoid the costs of financing mines that are constantly loss-making. The conducted analyses indicated that only three of the currently active mines in Serbia, namely RMU "Soko", RMU "Štavalj", and RL "Lubnica", have coal reserves of a size that is sufficient for planning prolonged exploitation. In addition, during the restructuring and re-planning mining process it would be advisable to develop also comprehensive closure plans relying on forward-thinking land use possibilities and providing for waste stacking in a way that allows for additional repurposing alternatives.

7. As long as there are active mines in Serbia, the first step should be to recover and economically utilize coal mine methane (CMM). That would improve underground workers' safety and allow the development of a new business case after the closure. At the same time, mine closure plans and procedures should give particular attention to strengthening the abandoned mine methane (AMM) potential, thus providing a basis for long-term investments at these sites by utilizing the existing methane drainage system in the mine after its closure or drilling boreholes from the surface into the goafs).

8. The experience from other countries shows that the effects of coal mining may appear many years after the cessation of extractive activities. Therefore, continuous monitoring of post-mining areas in Albania and Serbia is recommended - exceedingly when residential buildings are foreseen or already constructed in these areas. Special purpose entities, such as the UK Coal Authority or SRK in Poland, may need to be developed to provide the services mentioned.

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Annexes

Annex A: Detailed overview of coal mining in Albania and Serbia

1. Detailed overview of coal mining in Albania

Coal production in Albania started in 1926 in the Mborje-Drenova deposits (Korca region) and in 1964 in Mëzezi and Valiasi deposits (Tirana region) (**Figure A.1.1**.) The history of underground coal mining in Albania could be divided into three stages:

- Before 1944: In 1922, the geological map of Albania, which was the first of its kind in the Balkans, was drafted. Seven years later, in 1929, the mining law of the Kingdom of Albania was passed, paving the way for the research, discovery, and exploitation of minerals in the country.
- 1944 – 1994: The coal mining industry was entirely under State control. It was organized based on regional enterprises and mining sectors. The production was oriented mainly toward the domestic market and fulfilling the domestic economy's needs. Coal was utilized for heating, energy, and metallurgy. The Valias coal deposit was discovered in 1969. The project for exploiting and opening the Valias mine was prepared in 1970. The works for marking the industrial area of the mine began in 1971, while the preparatory works for deepening the vertical shafts began in 1972. The first level was prepared with horizontal works 157.6 m below the surface. The opening of the horizontal works from the ventilation shaft started in May 1974 and from the main shaft in August of the same year. Coal production started on 25.07.1978 and continued until 31.10.1994. During that period, Valias Mine produced 3,515,178 tons of coal.
- After 1994: The privatization process began. The new legal and administrative framework based on the free market rules, i.e., the Albanian Mine Law, was developed in 1994. and led to the liberalization of the process of awarding exploitation licenses, evaluation of all mines' assets, and closure of non-effective mines, including their subsequent monitoring.

In the Albanian coal deposits, underground mining was used. The individual mines developed the workings on two, three, or more seams. The horizontal extent spanned from three to more than ten kilometres. The Albanian coal seams' thickness ranges from 0.4 to over 3 metres in places where their inclination increased from flat lying to steeply dipping. The mines had a productive capacity of 0.2-0.6 Mt per year, and their exploitation fields ranged from a few square kilometres to more than 10 km^2. Mine layouts were of various sorts (shafts, drifts, inclines), and development works in main and working levels were compounded by haulage and development drifts, parallel headings, cross-cuts, raises and other drifts. The principal working system used in the coal mines was the wall system (long and short walls) by caving and rarely applied room pillar caving and working in mining using multiple lifts (Derinlikler, Tahkimatı, and Sauku, 1992).

Of over 20 of Albania's underground coal mines, the most extensive underground coal mines were the Valias coal mine and the Memaliaj coal mine (**Figure A1.1**).

Figure A.1.1 - **Exploited coal deposits in Albania**

Source: www.akbn.gov.al

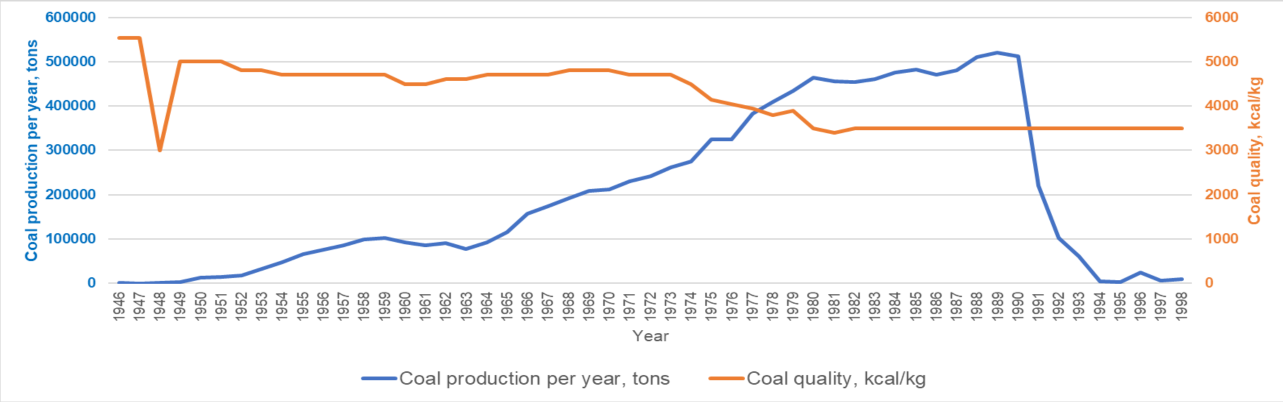
Valias coal mine was located in Tirana plain, about 15 km northwest of Tirana city. The coal layers belong to Upper Miocene deposits filling the Tirana syncline. The lithology section is constituted mainly of clay (44%) and siltstone (42%), and to a lesser extent by sandstone (7%) and by coal layers and coaly shales (7%). The maximal thickness of coal layers is about 1.50 m. The differently intercalated rock layers dip to the west by 10-12° and to the northwest by 3-4°. A thick Quaternary gravel layer covered by silt and clay lay above Upper Miocene deposits. In the Valias coal mine, the longwall exploitation was applied along the coal bed extension, causing the total roof to fall. The goafs created by the temporary coal exploitation were held with steel props. After removing steel props, the roof started to bend, and later the roof rocks began to fall (Eftimi and Amataj, 2003).

The general surface area corresponding to the Valias coal mine mining field is 14 km^2. In comparison, the surface on which the mine had developed its activity until its closure is 4.2 km^2 (420 ha). The Village of Valias is located above the Mborje-Drenova coal deposit. A dense network of regional and national highways describes the region. The opening of the Valias coal mine was carried out through vertical mining works (shafts), specifically: Main shaft, Auxiliary shafts No.1 and No. 2, and Air-shafts A1, A2, and A3. From 1973 to June 1978, 10,582 m of works were opened: 6924 m horizontal, 1873 m inclined, and 1785 m vertical works. After the deepening of the shafts to the first level (-113 m) in 1974, the opening of horizontal works began. Coal production started in 1978 and continued until 1994. During this time, 3,642,178 tons were produced with an average quality of 2,190 kcal/kg and a 47% impoverishment coefficient (percentage of coal produced from mining losses).

The Albanian Council of Ministers, by decision No. 139, dated 20.03.1995, determined that the mine should be closed and the mine's assets should be liquidated. It tasked the Institute of Mineral Extraction and Processing Technology (ITNPM) to prepare the Technical Project for the Closure of the Valias Mine to implement the decision. The study envisaged flooding the horizontal and steep works with water, filling all vertical shafts with material (fractionated limestone gravel), and building (if necessary) protections at their bottoms. This study, however, has never been implemented. The closing of the Valias coal mine was ultimately done following project No. 2916, developed by ITNPM in 2004. The latter had a budget of about 10,000,000 Albanian Leke (ALL), equivalent to around 84,000 USD (applying an exchange rate of 1 USD = 119 ALL). The implemented variant of closing the mine stipulated plugging the mouths of the shafts on the surface with metal pipes and concrete and surrounding them with walls standing in the perimeter calculated according to the technical requirements at that time.

The coal resource of the Memaliaj coal mine in the Tepelene district was discovered in 1914. In 1916, 8,000 tons of coal were produced. It was also exploited during the World War II. However, the first thorough research of the area was done only in 1950-1951. The investigation continued, and the geological reports on the prospect of coal retention in the Syncline of Memaliaj were prepared in 1974 and 1987. The Memaliaj Coal Extraction Mining Enterprise was established in 1949; since then, the production has increased yearly. In 1972, to maintain technological continuity, the Coal Enrichment Factory was put into operation in the proximity of Shaft No. 1. The coal from this mine, in comparison to other coal fields in Albania, has a relatively high calorific value but also a sulphur content greater than international standards, ranging from less than 1% to around 3%. The coal extracted in the Memaliaj mine was sold to various clients, such as e.g. industrial consumers, and it was used to produce building materials for metallurgical purposes, etc. When the demand from these consumers was at its peak, the Memaliaj mine reached the maximum production of over 500 thousand tons of coal per year, representing 25-30% of the Albanian total annual coal production (**Figure A.1.1**).

Figure A.1.1 - **Total production of coal in Memaliaj coal mine 1946-1998**



Source: based on information provided by national consultants

The following are the crucial facts about the closure of the Memaliaj coal mine:

- According to the order of the Albanian Ministry of Public Economy and Privatization No. 215 dated 09.06.1999, the project was developed to close mining works in Mines No.1 and No.2 of the Memaliaj Coal Company - Tepelene.
- Depending on their characteristics, the most suitable closure method was designed for each work, and the corresponding cost estimate accompanied it.
- The vertical shafts (eight in total) are temporarily closed by a plug with metal construction in their mouth and surrounding their area. The closing estimates for mines No. 1 and No. 2 were calculated at 12,680,000 ALL, and mine No.3 at 8,000,000 ALL, which gives 20,680,000 ALL (around 175,000 USD). That amount includes underground and surface disassembly expenses, ventilation, transport, power work, etc.
- Within the surface area of the underground exploitation influence, it was recommended not to carry out constructions of any category, and the existing structures are subject to monitoring.

Many coal mines that operated in Albania in the past are currently abandoned or dormant. In an attempt to revive the Albanian coal industry, the government still considers reopening coal mines such as Memaliai, Pogradec, Tirana, Korca, and Mborje-Drenovo to use their coal as a fuel for the country's thermal power plants. Such a step was supposed to ease the social burden on the local population by shutting down mines and the resulting power shortage.

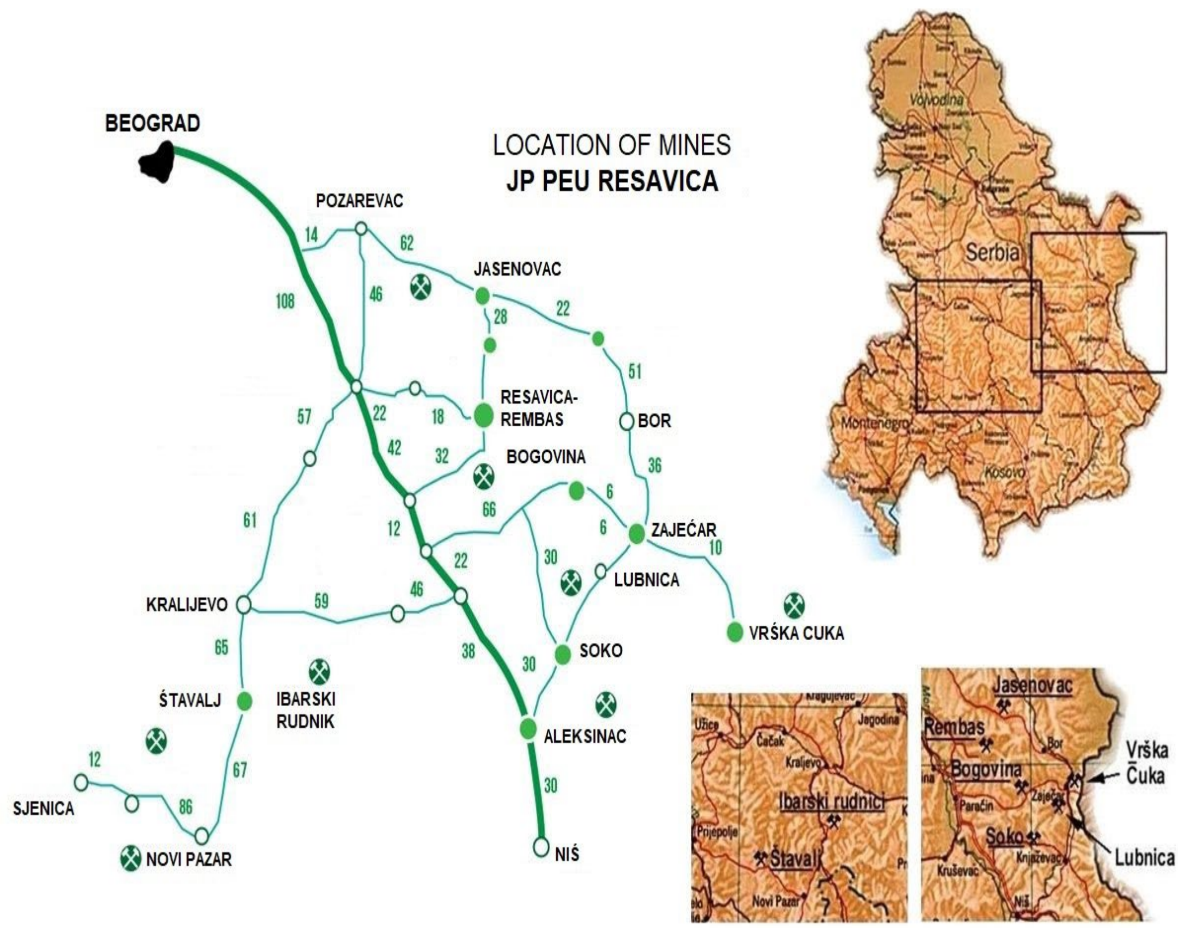
Many negative factors speak against reviving the coal industry in the country. First, most Albanian coal resources are found in the Tirana basin, close to residential areas. Consequently, many environmental issues must be resolved to bring the mines back to operation. Secondly, efficient mining operations would be complex since the coal seams are unstable and generally thin (typically no more than 1 m wide). Furthermore, coal in Albania is usually lignite with a high sulphur content of 5% and a low calorific power of 3,520 kcal/kg, which prevents its direct use for power generation (Shibata 2010).

Considering the facts presented above, it can be concluded that a return to coal mining in Albania in an economically justified and environmentally (ecologically) safe manner would be challenging, if possible.

2. Detailed overview of coal mining in Serbia

The location of currently active underground coal mines in Serbia (all belonging to JP PEU Resavica) is presented in **Figure A.2.1**.

Figure A.2.1 - **Localization of JP PEU Resavica underground coal mines**



Source: based on www.jppeu.rs

While in RMU "Bogovina", RA "Vrška Čuka", RMU "Rembas" (Senjski rudnik), and RMU “Soko” coal deposits are accessed through shafts and drift, in RKU "Ibarski rudnici", RMU "Jasenovac", RMU "Rembas" (Strmosten and Jelovac), RL "Lubnica", and RMU "Štavalj”, they are accessed through drifts only (**Table A.2.1**).

Table A.2.1 - **Exploitation methods and technologies used and access to the deposit in underground coal mines in Serbia**

Mine		**Access to the mine by shafts (deep/diameter, m)**		**Access to the mine by drifts (cross-section area, m^2)**		**Additional information**
RMU "Bogovina"		Ventilation shaft No. 11 (180/3.5)		Main haulage drift GTN (14)		There are also accesses to the abandoned mine – shaft No. 10 (210/6) and drift, at the closed Bogovina-Zapad site.
RA "Vrška Čuka"		Ventilation shaft VO2 (138/5)		Horizontal Avramica drift (16)	Inclined N4 drift (10)	In the proximity of the industrial estate of the mine, there is the abandoned hoisting shaft Avramica (199/5), which is now flooded.
RKU "Ibarski rudnici"	Jarando	None		Horizontal Baljevac drift (12)	Inclined GIN haulage drift (12)	Until recently, the mine operated three mines. In 1998-1999 the third mine, Ušće, was closed. Jarando & Tadenje mining areas are entirely separated production units.
	Tadenje	None		Horizontal Tadenje drift 360 m (12)	Inclined GIN haulage drift 66 m (12)	
RMU "Jasenovac"		None		Horizontal GIP drift (12)	Inclined GVN drift (12)	
RMU "Rembas"	Strmosten	Blind shaft (145/5)		Three drifts - industrial estate (10, 12, 12)	Ventilation drift - dislocated (10)	Although the mines of the RMU "Rembas" mine are separate, a connection between the mines exists to a single processing facility located at Resavica.
	Jelovac	None		Entrance to Jelovac drift (15)	Entrance to Bučar drift (12)	
	Senjski rudnik	Hoisting shaft (230/6)	Ventilation shaft (220/5)	South drift - connection to Resavica		
RMU "Soko"		Hoisting shaft (246/6)	Ventilation shaft (156/5.5)	Drift GTN-1 (17)		
RL "Lubnica"		None		Osojno-South - two capital drifts - main haulage (17) and main ventilation drift (17)	Stara jama N-2 haulage drift (10) and N-3 roadway (the connection between mines)	Mining activities at Lubnica mine are in production in two mines: Stara jama and Osojno-South. Although these two mines operate independently, they are

Mine	Access to the mine by shafts (deep/diameter, m)	Access to the mine by drifts (cross-section area, m^2)		Additional information
				connected; regarding ventilation and material supply, both mines can be treated as one mine.
RMU "Štavalj"	None	Main haulage drift GIN-1 (13)	Main ventilation drift GVN-2 (13)	During the operations of the Štavalj mine, there was at least one mine, which is now abandoned.

Source: based on information provided by national consultants

Table A.2.2 summarises the primary information about the mine infrastructure and the equipment used in Serbian mines.

Table A.2.2 - **General information about infrastructure and equipment in underground coal mines in Serbia**

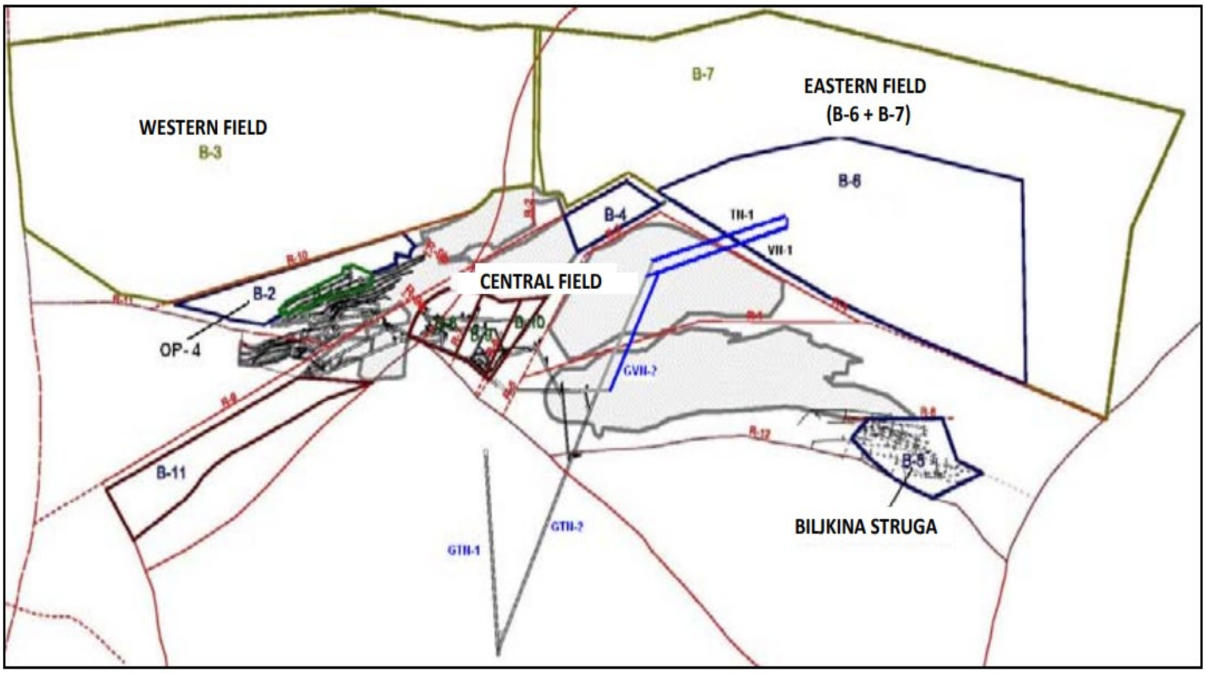
Mine	The infrastructure of the mine	Equipment
RMU "Bogovina"	Hauled run-of-mine coal is transported from bunkers at Bogovina-Istok to the processing facility at the Bogovina-Zapad site by trucks. The length of the transport route is 2 km in one direction. Both sites have an electricity supply (industrial-high and low voltage) and water supply – industrial (technical) water and water for human consumption.	Belt conveyors, chain conveyors, monorail, trucks (surface), ventilation equipment (fans), dewatering equipment (pumps)
RA "Vrška Čuka"	Underground haulage comprises chain conveyors, belt conveyors and wagons (winched-floor rail and mine rail). Locos for mine rail are of battery type. Run-of-mine coal is transported to a processing facility commissioned in 1992. The processing facility was initially designed with a flotation unit and gravity concentration unit, but the flotation unit was never finalized.	Belt conveyors, chain conveyors, monorail, underground railway (locos, wagons, winches), trucks (surface), ventilation equipment (fans), dewatering equipment (pumps)
RKU "Ibarski rudnici"	Jarando and Tadenje mining areas are equipped with underground coal haulage systems based on chain and belt conveyors. At the surface, these systems are connected to the main transport system that hauls run-of-mine coal toward the processing facility in Baljevac by cableway. Material supply to the working areas at both mining areas is by winch-powered cable monorail directly from the surface. The monorail route is via main ventilation roadways.	Belt conveyors, chain conveyors, monorail, cableway and railroad (surface), ventilation equipment (fans), dewatering equipment (pumps)
RMU "Jasenovac"	Run-of-mine coal is hauled to the surface through the main hauling roadway (GVN) and transported via belt conveyors to the processing facility. Transport of coal from the mine is only by trucks. Mine access infrastructure is in poor condition, causing problems, particularly in winter. There is no railroad connection.	Belt conveyors, chain conveyors, monorail cableway, railway (loco, wagons), ventilation equipment (fans), dewatering equipment (pumps)

Mine	The infrastructure of the mine	Equipment
RMU "Rembas" - Senjski rudnik	Each mine has an independent coal haulage system with chain and belt conveyors. However, these systems are connected to the main transport system that hauls run-of-mine coal toward the processing facility in Resavica. The main transport system from the Senjski rudnik is via South drift by mining rail with a transfer point from the mine's belt conveyor to wagons. Production from the Jelovac mine is directly loaded to belt conveyors of Jelovac drift by-pass and main transport, which hauls coal via the remaining part of Jelovac drift and subsequent Bučar and North drifts toward Resavica. Production from Strmosten mine is hauled to the surface at Vodna, where it is loaded into wagons and transported by mine rail into Jelovac drift up to the transfer point where it is loaded on belt conveyors of Jelovac drift by-pass, which is later connected to the main transport.	Belt conveyors, chain conveyors, monorail cableway, hoisting machine, ventilation equipment (fans), dewatering equipment (pumps)
RMU "Rembas" - Strmosten		Belt conveyors, chain conveyors, monorail cableway, hoisting machine, ventilation equipment (fans), dewatering equipment (pumps)
RMU "Rembas" - Jelovac		Belt conveyors, chain conveyors, monorail cableway, ventilation equipment (fans), dewatering equipment (pumps)
RMU "Soko"	Underground coal haulage system based on chain and belt conveyors hauling run-of-mine coal to the bunker at the bottom of the hoisting shaft. Coal from the bunker is loaded into wagons and hoisted to the surface and processing facility.	Hoisting machine, belt conveyors, chain conveyors, monorail cableways, wagons (underground, surface), ventilation equipment (fans), dewatering equipment (pumps)
RL "Lubnica"	Underground coal haulage system based on chain and belt conveyors hauling run-of-mine coal to the bunker at the surface. Coal is loaded into trucks from the bunker and transported to the processing facility at Grljan.	Belt conveyors, chain conveyors, monorail cableway, ventilation equipment (fans), dewatering equipment (pumps)
RMU "Štavalj"	Underground coal haulage system based on chain and belt conveyors hauling run-of-mine coal to the bunker at the surface. Coal is directed toward the processing facility from the bunker – dry screening and coal washing. Material and consumables are transported to the mine via main ventilation drift (GVN-2); for this purpose, the mine is equipped with a cable monorail.	Belt conveyors, chain conveyors, monorail cableway, ventilation equipment (fans), dewatering equipment (pumps)

Source: based on information provided by national consultants

RMU 'Soko' is one of the country's more modern mines and has a relatively large (as compared to other local mines) coal output. The coal basin "Soko" is part of the Sokobanja tertiary coal basin. It is characterized by a complex tectonic structure, as its deposits are characterised by a significant number of faults of different directions and dimensions, which divide the basin into three tectonic blocks - exploitation fields (**Figure A.2.2**).

Figure A.2.2 - **The division into exploitation blocks of the RMU "Soko"**



Source: Denić et al. 2014

Since 1985 the "Soko" mine has employed the "pillar-chamber method by folding coal roof and coal roof caving". Maximum production of 224,650 tons of coal was achieved by this method in 1987. Currently, the mine operates with an annual capacity of about 125,000 tonnes. The increase in coal production by applying existing techniques would be possible using the simultaneous excavation of two independent districts. However, such change would inevitably lead also to a rise in the number of workers, a necessity of application of a large number of additional mechanical and electrical equipment, an increase in the cost of maintaining operating efficiency of the equipment, an increase in the cost of ventilation holes, and reduction in operating performance (Miljanović, Kovačević, and Tošić, 2013; Denić et al., 2014).

In general, the mines included in the Public Enterprise for Underground Coal Mining Resavica are poorly equipped, and their technology is obsolete. Coal production has been virtually constant for more than fifty years. Furthermore, in some mines, e.g. RMU “Bogovina” and RMU “Rembas”, the level of mechanization was higher in the 1960s than today. For financial and organizational reasons, no mechanized coal excavation or mechanized tunnelling has been utilised. The applied mining methods are also obsolete and of low productivity. Most of the mines use some variant of pillar mining, where coal is mined in narrow stopes by drilling and blasting. Chain conveyors haul coal from the coal faces, where further transport is organized through several belt conveyors.

Over the years, specific solutions have been applied in the Serbian underground coal mines based on pillar and pillar and room excavation with blasting technology, all of which had several certain common elements, such as:

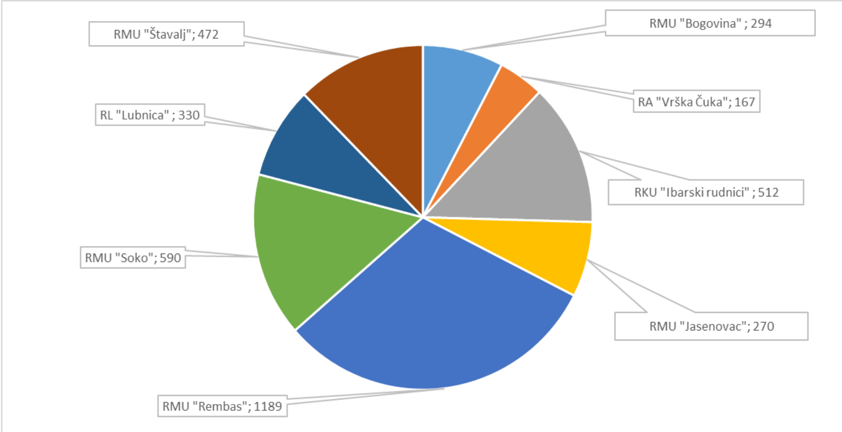
- applicability in the complex conditions of exploitation,
- possibility of conducting sustainable underground coal exploitation (deconcentrating of exploitation/mining works), and protection of the coal deposit,
- low excavation capacity, low productivity, and the need for a more significant number of excavation units,
- low degree of mechanization on excavation units, and
- high participation in constructing the preparatory rooms (Todorović, Tošić, and Trivan, 2020b).

Apart from the currently active coal mines in Serbia, in the past, there were many other mines of various sizes operating in the country. While for most of the closed mines, it is difficult to obtain precise and trustworthy detailed data, some basic information is available:

- Aleksinački Rudnik: coal mining started in 1883. The highest coal production was achieved in 1963 when 444,007 tons of coal were produced out of six shafts. The "Morava" shaft, with a depth of 750 m below the surface, was the deepest in Yugoslavia/Serbia. On 18 November 1989, the worst tragedy in the history of Serbian mining struck the mine: an underground fire at a depth of 700 m killed the entire shift of 90 miners, who suffocated from the smoke and carbon monoxide.
- RMU "Bogovina" (Bogovina-Istok): has access to the abandoned mine – shaft No. 10 (depth 210 m/diameter 6 m) and drifts at the closed Bogovina-Zapad mine (closed in the 1990s).
- In proximity to the RA "Vrška Čuka" industrial estate, there is the abandoned hoisting shaft Avramica (depth 199 m and diameter 5 m), which is now flooded.
- RMU "Rembas" operated three mining areas until 1999, when the Ušće site was closed. Currently, the remaining Jarando and Tadenje sites are separate production units.
- During the operations of the Štavalj mine, there was at least one site, which is now abandoned (unfortunately, there is no accurate data on that).

In 2017, the mines of JP PEU Resavica employed 3,824 workers (**Figure A.2.3**). The average age of an employee was around 40. Relatively low employment in the company's mines results in a small production. However, given the low degree of mechanization of exploitation, even a significant increase in employment will not meaningfully improve productivity.

Figure A.2.3 - **Employment in the mines of JP PEU Resavica, 2017**



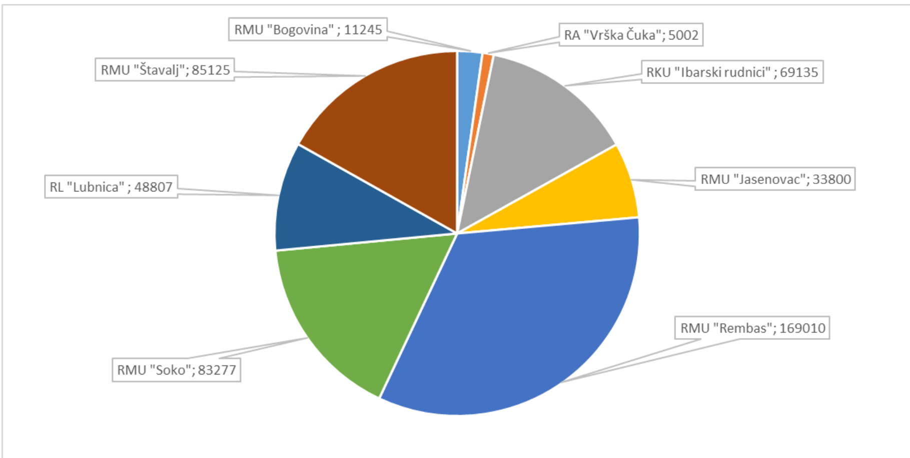
Source: based on information provided by national consultants

RMU "Rembas" mine, with its 1189 employees, leads in the number of staff, while RA "Vrška Čuka" is on the opposite side of the spectrum, hiring only 167 workers.

Many analyses of the JP PEU Resavica staff structure showed an excess of non-production (administration) employees and an insufficient number of production workers (Nikolic et al., 2016).

From the moment the company was created, its coal production, with some oscillations, has been regularly decreasing. From 960,973 t of excavated coal in 1992, the production fell to 560,651 t in 2015. It means that over 23 years, coal production declined by 400,322 t, or 42% (Nikolic et al., 2016). In the following years, however, the production re-bounced a bit, reaching over 500,000 tons of coal in 2017 (**Figure A.2.4**). Currently, JP PEU Resavica produces on average between 350,000 and 450,000 tons of coal per year: in 2018, it was about 433,000 tons, and in 2020 about 379,000 tons. Looking at the annual production throughout the last 30 years, a downward trend is evident (the Republic of Serbia, Security of supply statement, 2018; 2020).

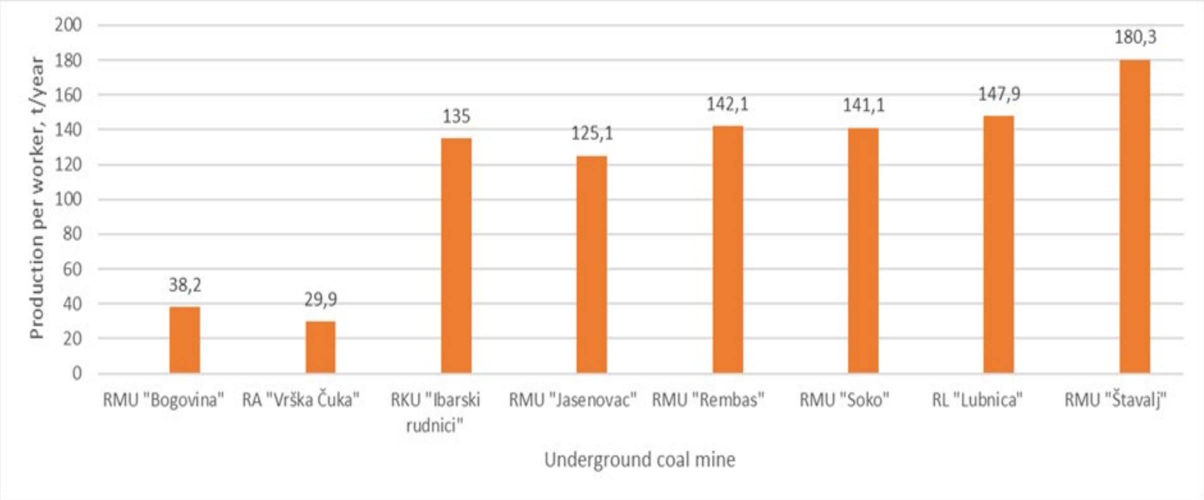
Figure A.2.4 - **Production of coal in mines of JP PEU Resavica, 2017**



Source: based on information provided by national consultants

Figure A.2.5 shows coal production per mine worker according to 2017 data. That indicator is very low at RMU “Bogovina” and RA "Vrška Čuka", which amounts to less than 40 tons/per year of coal per worker. The situation is significantly better at other mines, oscillating between 125 to 180 tons/year per worker. However, still far from the results recorded in other countries. For instance, the average rate in Polish underground mines is over 700 tons/year per worker.

Figure A.2.5 - **Production of coal per worker in mines of JP PEU Resavica in 2017**



Source: based on information provided by national consultants

In terms of type of coal that is extracted in Serbia, it is primarily lignite, brown, and hard coal (in RA "Vrška Čuka" and RKU "Ibarski rudnici" mines only) of which more than half is hauled to power plants Nikola Tesla A and B, as well as Morava, which are all run by the state-owned enterprise Elektroprivreda Srbije (EPS). The rest is sold to the industry, heating plants, schools, and private buyers.

As mentioned at the beginning of this section, all active underground coal mines in Serbia belong to JP PEU Resavica, a public company formed in 1992 by unifying nine underground coal mines operating at that time into a single enterprise. On 2 August 2007, the Government of the Republic of Serbia adopted the *Strategy for restructuring and privatization of 'Resavica' Public Enterprise for Underground Coal Exploitation (PE UCE)*. The main objective of that Strategy was to privatize PE UCE as a single enterprise after maximally reducing its liabilities. However, the Strategy mentioned above has not been implemented (Denić, Vušović, and Stojadinović, 2014).

At the end of 2011, a new strategy based on strategic partnerships or joint ventures in new enterprises with combined state and private capital was introduced (FACTIS, 2011). The investment of the strategic partners was to be directed towards improvements in thermal-energetic capacities and technological modernization of mines.

This strategy provided that the process of gradual mine closure will be initiated, starting from the mines with few coal reserves and poor mining conditions, in which a successful restructuring and privatization could not be expected (RMU "Bogovina", RA "Vrška Čuka", RMU "Rembas" – Senjski rudnik mine, and Jarando mining area within RKU "Ibarski rudnici"). Nevertheless, like in the former case, the objectives of this strategy also have not been achieved (Denić, Vušović, and Stojadinović, 2014).

On 6 August 2017, at the Miner's Day celebration meeting in Resavica, the company's management presented to the government and business partners the *Program of Reorganization and Consolidation of the Business of JP PEU – Resavica* (The Program). The phased implementation of the program was supposed to ensure the development and sustainability of the underground system of coal exploitation in Serbia. The program drew from the solutions indicated in the *Work and Business Consolidation Plan of JP PEU* adopted by the government. It introduced new ones, particularly in the field of organization and technological processes of exploitation.

Contrary to the expectations, the underground coal mines merged into a single state-owned enterprise (JP PEU), continued to show a negative balance in their operations and were able to survive on the market only thanks to certain State's investments and the critical social role that they had in the local communities (e.g. providing jobs, whether directly, or indirectly in mining-related companies).

The leading causes of the financial losses of the Serbian underground coal mines are the low price of coal, energy and raw materials price disparities, low degree of mechanization, and the chronic lack of the necessary investments in modernizing the equipment and infrastructure.

Due to long-term exploitation, many Serbian mines are on the verge of exhausting their reserves. That means that they cannot count on increasing their capacity and, at the same time, face ever-growing production costs. In addition, what exacerbates their already bad situation is the project of opening the new Poljana mine in the Kostolac coal basin (**Table B.2.4** *in Annex B*), which is projected to have a production capacity larger than all the current active mines combined. As a result, the Program set some old, almost fully exploited mines for a phased closure.

In contrast, an increase in production capacity was planned for the mines of the RMU "Soko", RMU "Štavalj", RMU "Rembas" – Strmosten mine, and RL "Lubnica". It was to be achieved by introducing modern equipment for constructing pit rooms, excavation, and transport. In terms of organization, centralized management, control, and supervision were to remain with the company.

The strategic goals of the first phase of the Program's implementation were:

- To continuously raise the level of production in the RMU "Soko", RMU "Štavalj", RMU

"Rembas", and RL "Lubnica" mines from 395,000 tons in 2017 to 600,000 t/year after the introduction of greater mechanization.

- To begin intensive construction work on the Poljana mine, with a production capacity of over 700,000 t/year.
- To start a program of a planned closure of mines of the coal reserves which are about to be exhausted.
- To increase the volume of coal deliveries for TENT Obrenovac and TE Morava up to 80% of the output of the underground mines.
- To reduce the number of non-production workers employed in the company.
- To procure new equipment, improve the technological processes of excavation and construction, optimize infrastructure, and modernize the equipment and facilities maintenance system to reduce production costs.

In 2018 Serbia's government planned to launch procedures for the closure of two unprofitable mines of JP PEU Resavica. However, the program has not been implemented.

The current Serbian energy sector development strategy through 2025, with projections up to 2030, is based on the national strategic priorities in the energy sector and the frameworks of the Treaty of Establishing the Energy Community (Ministry of Mining and Energy, Republic of Serbia, 2016). As a result, it aligns the national energy policy and legislation of the country with the energy and climate policy of the European Union. The document identifies strategic priorities for the energy sector development in Serbia, i.e., energy supply security, energy market development, and establishment of environmentally friendly energy generation.

In line with the national energy policy and legislation, the Strategy envisages a gradual transition towards a sustainable energy supply through increasing energy efficiency and greater use of renewable energy sources. Considering available indigenous lignite resources, electricity production in the upcoming period will continue to be based on coal-fired thermal power plants, operating alongside the local renewable energy sources, the share of which in the country's energy mix will steadily grow.

The Strategy provides for thoroughly refurbishing the existing coal-fired power plants and constructing new highly efficient generating capacities based on domestic lignite, compatible with the highest environmental standards. It stipulates intensive research of coal deposits throughout Serbia to substitute the existing mines soon to be exhausted with the new ones. As a priority, the Strategy sets out new surface lignite mines to meet the growing need for coal at the new thermal power plants. Since the existing law allows for the expropriation of private land for mining, flood control, and construction of oil and gas infrastructure, power plants, and distribution networks, the necessary legal framework enabling an expansion of the mining areas is already in place.

Annex B: General analysis of the local geological and mining conditions in Albania and Serbia

1. General analysis of the local geological and mining condition in Albania

Historically, coal production facilities in Albania included mines and beneficiation plants, and that industry was located mainly in the central, south-eastern, and southern parts of the country (**Figure A1.1** *in Annex A* and **Figure B.1.1**). According to closure projects data, the local coal reserves are about 130 million tons (**Table B.1.1**). They are situated in the following three prominent locations:

- about 86% of the reserves are in the Tirana area,
- about 10% of them are in the Korça-Pogradeci area, and
- about 4.4% in the area of Memaliaj.

Albanian coals are generally of the lignite type with an analytical calorific value of 2000–5400 kcal/kg (3200–3300 on average). Some of the coal can be enriched after mining, producing concentrates with a calorific value of up to 4500–5500 kcal/kg.

The coal discovered and exploited in Albania is of the lignite type. Through the mining works for exploration-prospecting, the geologists have found and documented fourteen coal-bearing deposits throughout the region, ranging from Tropoja to Saranda district.

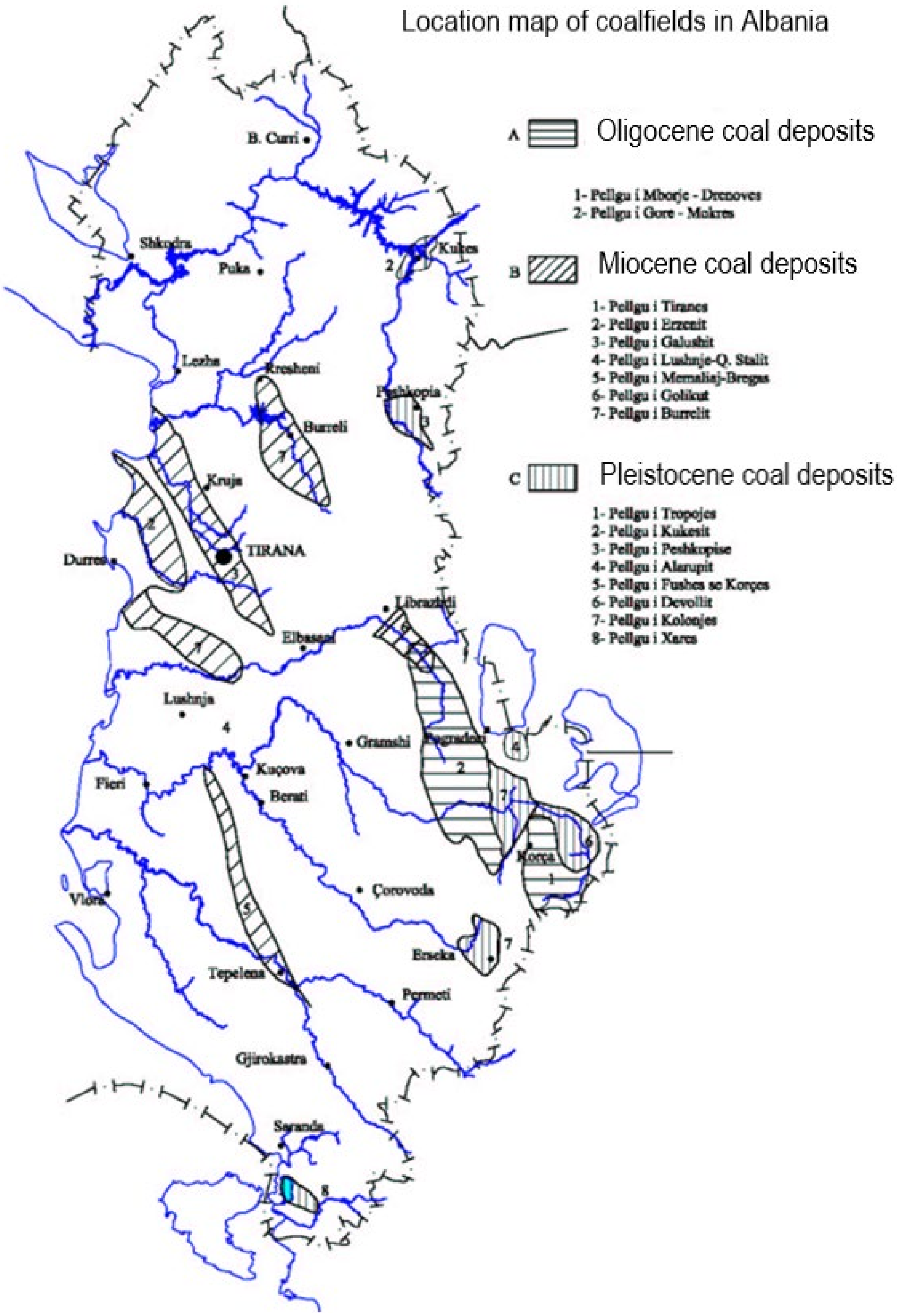
Nineteen coal deposits that were exploited up to 1995 are located in the coal-bearing deposits of Morava, Gorë Mokra, Tirana, Erzeni, Memaliaj, Bezhan and Alarupi (**Figure B.1.1**).

The coal-bearing deposits of Goliku, Galush, Burrel, Devoll, Fushë Korça, Tropoja, and Xara are limited and have mainly mineral occurrences with poor coals.

Coal occurrences are found in other places, as shown in **Figure B.1.1**. These occurrences have not been evaluated for their quantitative and qualitative features (http://www.akbn.gov.al)

The leading causes of the financial losses of the mines were: the low price of coal, energy and raw materials price disparities, low degree of mechanization, and chronic lack of the necessary investments in modernizing the equipment and infrastructure.

Figure B.1.1 - **Location of coal deposits in Albania**



Source: based on www.akbn.gov.al

One of the largest coal deposits in Albania is the Memaliaj deposit (area of the closed Memaliaj mine). Of the 12 seams found in fields 1, 2, and 3 of the Memaliaj coal mine, the 2nd, 4th, 5th, 6th, and 7th are considered industrial.

- Seam 4: It has an unstable roof and breaks easily into irregular blocks, while the floor is somewhat stable. Regarding other technical properties, they are similar to seams 5 and 6, which are described below.

- Seam 4a has an unstable ceiling; its bending occurs 5 m before the lava, while the collapse reaches 7-8 times the thickness of the coal seam.
- Seam 5: The thickness ranges from 0.48-0.87m, with a strength of up to 2. The ceiling consists of organic breccia with a strength of 3-4, not very compact with average cementation. Therefore, the roof's stability with plastic properties is not excellent, and the bending is done 3-4 m from the front of the lava. The thickness of the breccias is minimal, up to 0,1 m, which is lost in places, and the coal layer comes into direct contact with massive clays with a gradual transition to siltstone. The floor consists of compact clay and siltstone in some places.
- Seam 6: The thickness of the layer varies from 0.61-0.81 m with strength up to 3. It consists of one or two inserts from 0.10-0.27 m. The roof has no plastic properties; it is made of siltstone, clay in places and a false ceiling of 0.10-0.20 m. It first weighs down and then breaks into blocks at a distance of 2-4 m from the front of the lava. The floor is made of soft clays that swell and reduce the workspace.
- Seam 7: The thickness of the seam ranges from 0.58-0.76 m with one or two 0.10-0.27 m intercalations, with a strength of 3-4. The ceiling consists mainly of clay with a false top of 0.15-0.20 m. The floor appears solid and flat. The geological reserves of seams 5, 6, and 7 are 8,773,870 tons.

As described above, the Memaliaj coal deposit is characterized by thin coal seams with irregular shapes. Given that and the low calorific value of that coal, restarting mining in this deposit does not offer promising results, and therefore such plans are not economically justified.

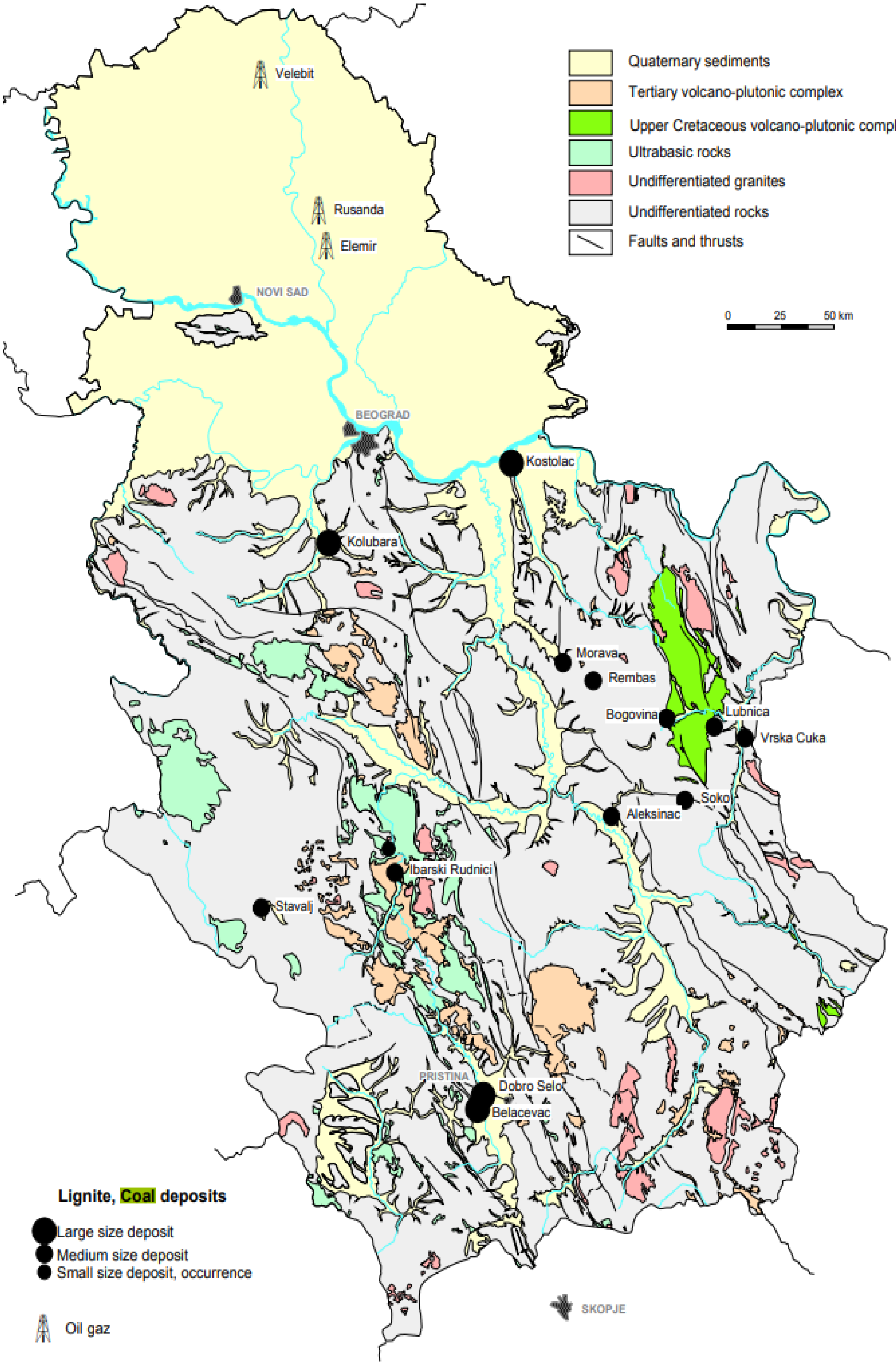
2. General analysis of the local geological and mining condition in Serbia

Generally, the coal basins in Serbia are of limnic or paralic types. Nearly all coal deposits were formed in intermontane basins, and only several are paralic (Despotovac and Bogovina East Field) (Ercegovac, Životić, and Kostić, 2006).

The brown coal basins in Serbia, shown in **Figure B.2.1** and **Figure B.2.2,** belong to the following three main metallogenetic provinces (Dimitrijević, 2000; Monthel et al., 2002):

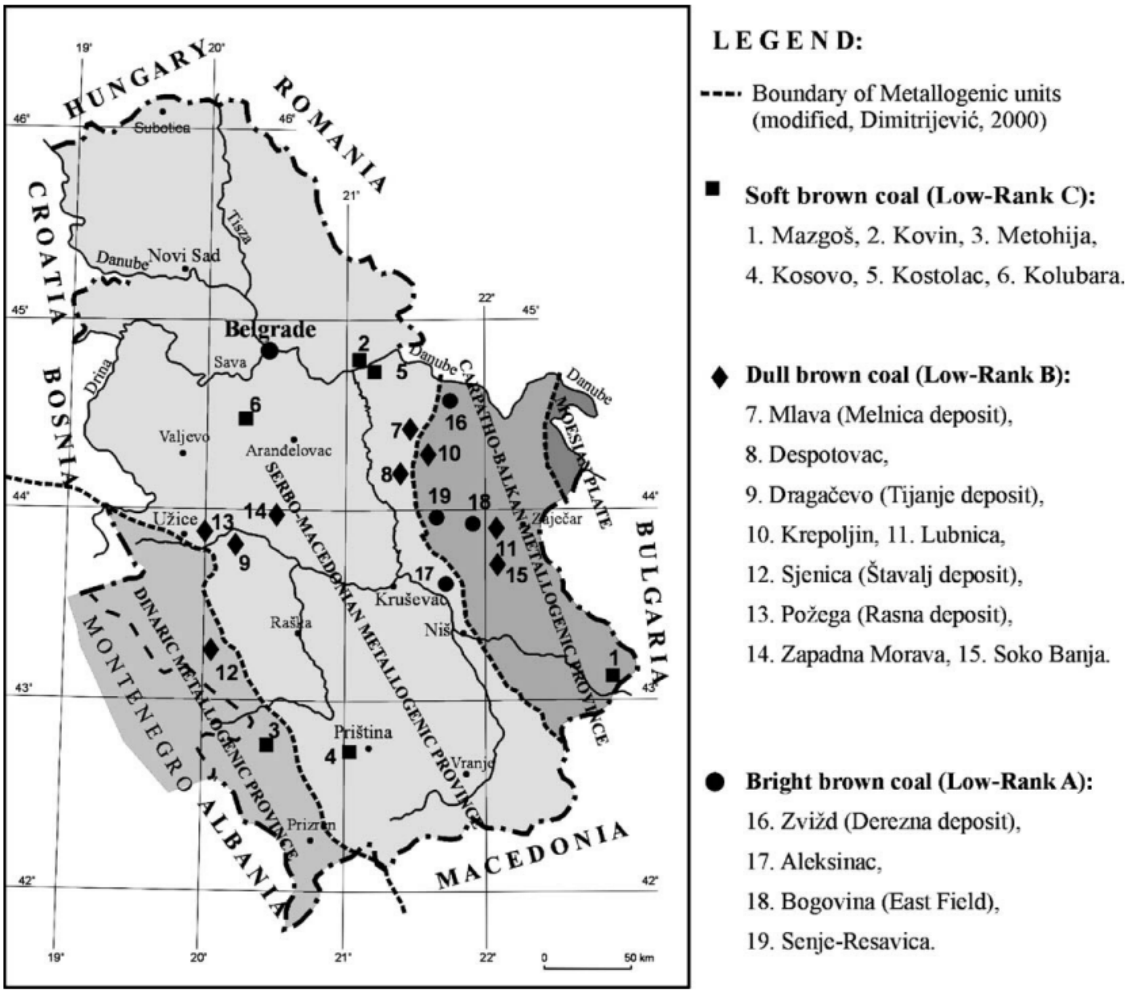
- Carpatho-Balkan, the eastern part of Serbia (which includes the Mazgoš, Krepoljin, Lubnica, Soko Banja, Zvid, Bogovina and Senje–Resavica basins);
- Serbo-Macedonian, the central part of Serbia (with the Kovin, Kosovo, Kostolac, Kolubara, Mlava, Despotovac, Dragačevo, Poega, Zapadna Morava and Aleksinac basins); and
- Dinaric, the western part of Serbia (with the Metohija and Sjenica basins).

Figure B.2.1 - **Coal deposits in Serbia on the background of the geological structure**



Source: Dimitrijević, 2000; Monthel et al., 2002

Figure B.2.2 - **The geographic position of investigated brown coal basins in Serbia**



Source: Dimitrijević, 2000; Monthel et al., 2002

The brown coals of Serbia vary in their quality and degree of coalification (Ercegovac et al., 2006). They developed in various clastic and terrigenous lithostratigraphic units (from the Lower to the Upper Miocene). Their rank has been defined based on the mean reflection of huminite/vitrinite (0.26-0.50%), the total moisture content (13.18-49.11%) and the net calorific value (21.2-28.1 MJ/kg, dry, ash-free basis).

Three groups of brown coals have been defined based on these parameters:

- Soft brown coals (lignite, Low-Rank C) are characterized by the huminite/vitrinite reflection of 0.26-0.30% Rr; high content of total moisture (43.41-49.11%); ash content, the as-received basis of 17.40-20.53%; ash content of 31.6-42.91% (dry basis); total sulphur content of 1.06-3.98% (dry basis); a net calorific value of 5.43-8.37 MJ/kg (as-received basis); net calorific value (dry, ash-free basis) of 21.22-24.68 MJ/kg. These coals have mild acid to very acid ashes, with melting point values of 1261-1366 °C. The soft brown coals are pale brown to dark brown in colour and are of heterogeneous composition with a predominance of matrix and xylitic lithotypes. The mineral-rich lithotype and doplerite coal appear in skinny layers. The most common macerals are textinite, ulminite, densinite and atrinite. Their vegetal structure is preserved, sometimes only slightly altered, and visible. The liptinite and inertinite content is low.

- Dull brown coals (Low-Rank B) are characterized by the vitrinite reflection of 0.31-0.4% Rr; a total moisture content of 17.05-37.59%; an as-received ash content of 12.87-25.74%; and an ash content on a dry basis, of 18.82-34.57%; total sulphur content of 1.44-4.06% (dry basis); a net calorific value of 10.51-16.97 MJ/kg (as-received basis); and a net calorific value, dry, ash-free, of 24.3-26.6 MJ/kg. These coals have mildly base to acid ashes, and the melting point varies from 1246 to 1318 °C. Dull brown coals are dark brown and often with banded structures. The most common macerals of the coals of this group are ulminite, textinite, densinite and atrinite. The liptinite content is comparatively low, except in some basins ranging from 10 to 15% (Lubnica Basin). The resources of dull brown coals are relatively large but are of secondary economic significance because of their complex tectonic and lithological composition and challenging conditions for exploitation.
- Bright brown coals (sub-bituminous, Low-Rank A) are characterized by black colour, banded structure and highly gelified tissue, with a vitrinite reflectance between 0.41 and 0.47% R_r. They have a total moisture content of 13.18-27.55%; ash content, the as-received basis of 12.54-22.53%; ash content, the dry basis of 14.70-26.71%; total sulphur content of 1.35-6.54% (dry basis); a net calorific value of 13.35-19.45 MJ/kg (as-received basis); net calorific value (ash-free, dry basis) of 25.26-28.05 MJ/kg; and mildly acid ashes. The melting point varies from 1220 to 1393 °C. The most common macerals are densinite, ulminite and gelinite. The liptinite and inertinite content is low, except in the case of the coal in the Aleksinac Basin, which has a high liptinite content, and Bogovina-Istočno polje, which has a comparatively high inertinite content.

The bituminous coals of Serbia played an essential economic role in former Yugoslavia until the 1970s, but numerous mines have been closed and abandoned since then. Many explored, exhausted, and abandoned deposits of Carboniferous, Jurassic, Cretaceous, and Neogene basins exist in the country. At present, bituminous coal is mined only in the Ibar Basin and at Vrška Čuka. The bituminous coals are divided into the following groups according to the degree of carbonification:

- Low-rank bituminous coals, with vitrinite reflection of 0.51-2.20% R_r, total moisture content below 10%, volatile matter content below 42% (ash-free, dry basis), the carbon content of over 75% (ash-free, dry basis) and net calorific value of 26-35 MJ/kg (ash-free, dry basis). The deposits belonging to this group, which are still being exploited, are all located in the Ibar Basin.
- High-rank bituminous coals, anthracite, with mean vitrinite reflection of over 2.20% R_r, total moisture content below 5%, volatile matter content below 10%, the carbon content of over 80% (ash-free, dry basis) and net calorific value of over 35 MJ/kg (ash-free, dry basis). The most crucial deposit belonging to this group, only one of which continues to be exploited now, is at Vrška Čuka.

The future explorations of coal in Serbia will be aimed primarily at the augmentation of the present reserves and a more thorough analysis of their quality. It is also necessary to carry out detailed geochemical analyses of the coal, coal ashes, and fly ash to forecast and estimate the harmful and potentially toxic elements. Only a comparatively small part of the complex geological explorations will be focused on areas with prospective new coal deposits.

A short geological description of eight active coal mines in Serbia is provided below and summarized in **Tables B.2.1** and **B.2.2**.

- **RA "Vrška Čuka"** – main seams (III) and interlayers occurring at a depth of up to 270 m, the productive horizon in Lower Liassic sediments (shale sandstones, clayey and quartz sandstones and coal seams);
- **RKU "Ibarski rudnici„** – Jarando mining area (two coal seams occurring at a depth of 150-470 m), and Tadenje mining area (four coal seams occurring at a depth of 10-100 m), Tertiary lacustrine coal basin, Miocene age with three horizons (sandstones, conglomerates, argillites, clays, tuffs and coal seams);
- **RMU "Rembas"** – Senjski mine (one coal seam at a depth of 350 m), Strmosten (one coal seam at a depth of 480 m), and Jelovac (one coal seam at a depth of 160-200 m), Senj-Resava Miocenelake coal basin (conglomerates, sandstones and red clays and sandstones);
- **RMU "Bogovina"** – two coal seams at a depth of 240 m, lake Oligocene (a narrow zone of tuffs, andesites and marls divided into the western and eastern part, one and two coal seams);
- **RMU "Soko"** – one coal seam at a depth of 450 m, freshwater Tertiary series of the Sokobani coal-bearing basin (marls, coal clays, conglomerates, sandstones and argillaceous sandstones overlying Upper Cretaceous limestone);
- **RMU "Jasenovac"** – one coal seam at a depth of 220 m, Kucaj-Beljanica autochthonous Jurassic and Miocene (clays, sandstones, sandy clays);
- **RMU "Štavalj"** – one coal seam at a depth of 280 m, Sjenica-Staval basins represents a deep tectonics basin, the coal-bearing sediments are of Miocene age, and consist of four characteristic lithological horizons (marls);
- **RL "Lubnica"** – two coal seams at a depth of 200 m, freshwater tertiary basin formations (conglomerates, sandstones, argillaceous, sandstones and clays).

Table B.2.1 - **Coal seams and their geological characteristics**

Mine	RMU "Bogovina"	RA "Vrška Čuka"	RKU "Ibarski rudnici"		RMU "Jasenovac"
			Jarando	Tadenje	
Coal seams	Two coal seams	Main seam and interlayers	Two coal seams	Five coal seams	One coal seam
Coal seam thickness, m	1-7.2 m and 1-4.5 m	0.3-3.0 m (up to 6.0 m)	1.5-12 m, and 1-2.5 m	4.4 m, 2.2 m, 1.95 m, 1.9 m and 2.4 m	5-29 m
Coal seam slope, °	12-14°	0-35°	10-40°	5-25°	20-33°

Mine	RMU "Bogovina"	RA "Vrška Čuka"	RKU "Ibarski rudnici"		RMU "Jasenovac"
			Jarando	Tadenje	
Hanging wall rocks (roof rocks)	Marls	Clayey sandstones	Marls	Marls, clays	Clays, sandstones
Footwall rocks (floor rocks)	Clays	Clayey sandstones	Sandstones	Marls	Sandy clays
Tectonics	Expressed	Very expressed	Expressed	Expressed	Expressed

Source: based on information provided by national consultants

Table B.2.2 - **Coal seams and their geological characteristics**

Mine	RMU "Rembas"			RMU "Soko"	RL "Lubnica"	RMU "Štavalj"
	Strmosten	Jelovac	Senjski rudnik			
Coal seams	One coal seam	One coal seam	One coal seam	One coal seam	Two coal seams	One coal seam
Coal seam thickness, m	7.7 m	4.5 m	7 m	up to 10 m	5-9 m and 2-5 m	10.0-14.0 m
Coal seam slope, °	10-20°	5-10°	10-25°	35-45°	20-33°	5-20°
Hanging wall rocks (roof rocks)	Marls and red sandstones	Red sandstones	Marls	Marls	Marls, clays	Marls
Footwall rocks (floor rocks)	Green sandstones	Green sandstones	Clayey marls	Coal clays	Sandstones and clays	Marls
Tectonics	Expressed	Expressed	Expressed	Expressed	Expressed	Expressed

Source: based on information provided by national consultants

In terms of the depth of the works, which determines the length of the airflow line, most of the underground mines in Serbia qualify as medium deep mines, with the deepest underground mines in the country being RMU "Rembas" – Strmosten mine (up to 480 m), RKU "Ibarski rudnici" – Jarando mining area (up to 470 m), and RMU "Soko" (up to 450 m) (Todorović, Tošić, and Trivan, 2020a).

Table A.2.3 summarises the coal reserves at each mine. The RMU "Soko" and the RMU "Štavalj" have the most extensive prospective reserves (Ivković, Tošić, and Dramlić, 2022).

Table B.2.3 - **Coal reserves in active mines in Serbia**

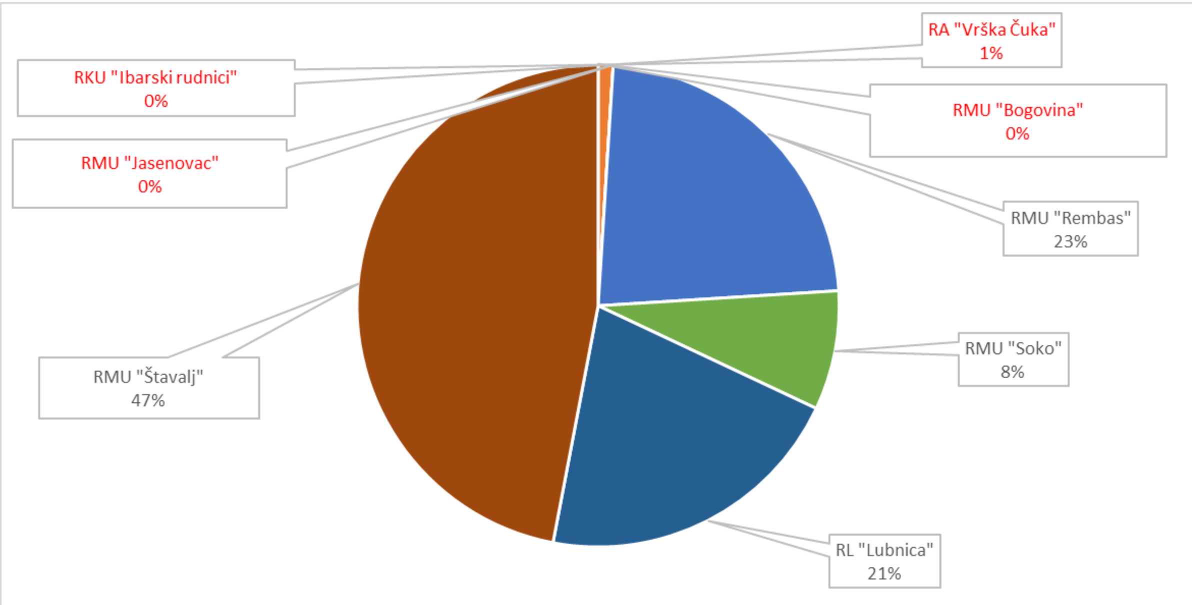
Mine	Balance reserves per category, t				Off-balance reserves, t	Type of coal
	A	B	C_1	$A+B+C_1$		
RA "Vrška Čuka"	25,687	626,383	1,624,608	2,276,678	350,000	Hard coal
RKU "Ibarski rudnici"	none	928,154	283,434	1,211,588	1,326,580	
RMU "Rembas"	710,275	2,187,052	4,531,823	7,429,150	581,590	Brown coal

Mine	Balance reserves per category, t				Off-balance reserves, t	Type of coal
	A	B	C_1	A+B+C_1		
RMU "Bogovina"	none	1,647,267	676,248	2,323,515	1,652,058	
RMU "Soko"	245,642	13,529,675	37,160,407	50,935,724	2,997,725	
RMU "Jasenovac"	none	176,744	none	176,744	25,960	
RMU "Štavalj"	1,477,710	99,326,316	84,197,469	185,001,495	7,423,342	
RL "Lubnica"	660,239	8,859,215	506,079	10,025,533	4,565,562	Lignite

Source: Ivković, Tošić, and Dramlić, 2022

Figure B.2.3 shows the balance of the Serbian coal reserves (proved reserves) of the highest A category (proved coal reserves). Only half of the underground coal mines in Serbia have such reserves (concerning total balance reserves). Those are RMU "Štavalj" (47% of all reserves in category A in JP PEU Resavica), RMU "Rembas", RL "Lubnica", and RMU "Soko".

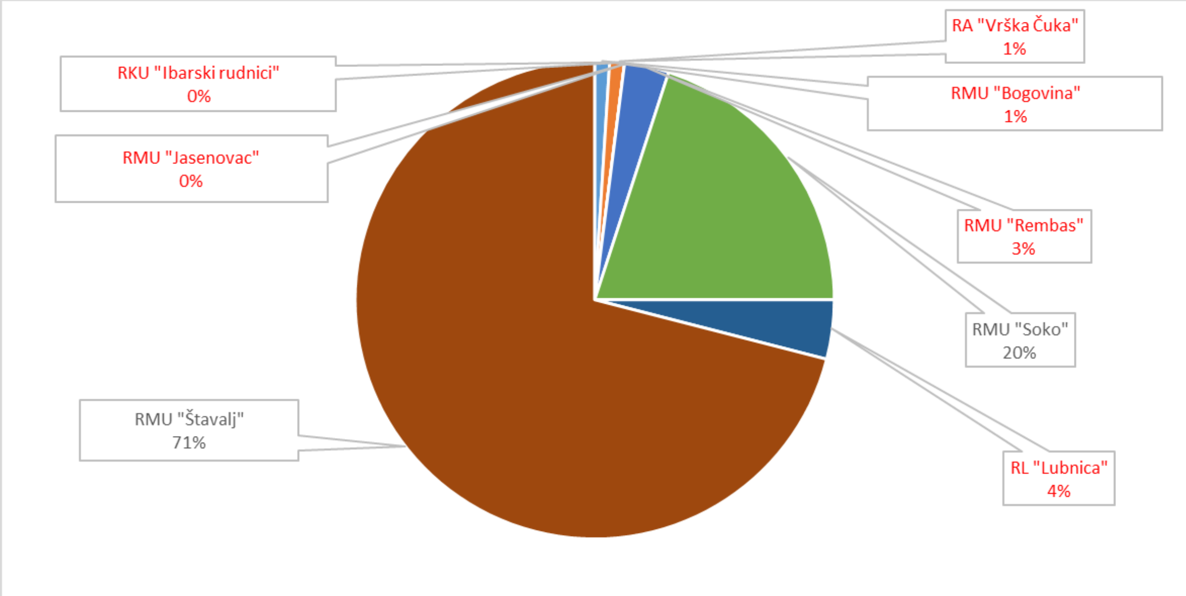
Figure B.2.3 - **Balance coal reserves per category A in JP PEU Resavica active coal mines, %**



Source: based on Ivković, Tošić, and Dramlić, 2022

Figure B.2.4 shows the balance of the Serbian coal reserves (proved reserves) of the second highest B category (proved coal reserves). Only two underground coal mines in Serbia have significant A and B categories reserves (concerning total balance reserves). Those are RMU "Štavalj" (71% of all reserves in categories A and B in JP PEU Resavica) and RMU "Soko" (20% of all reserves in categories A and B in JP PEU Resavica). The remaining six mines have only 9% of the total coal balance reserves in the discussed categories (**Figure B.2.4**).

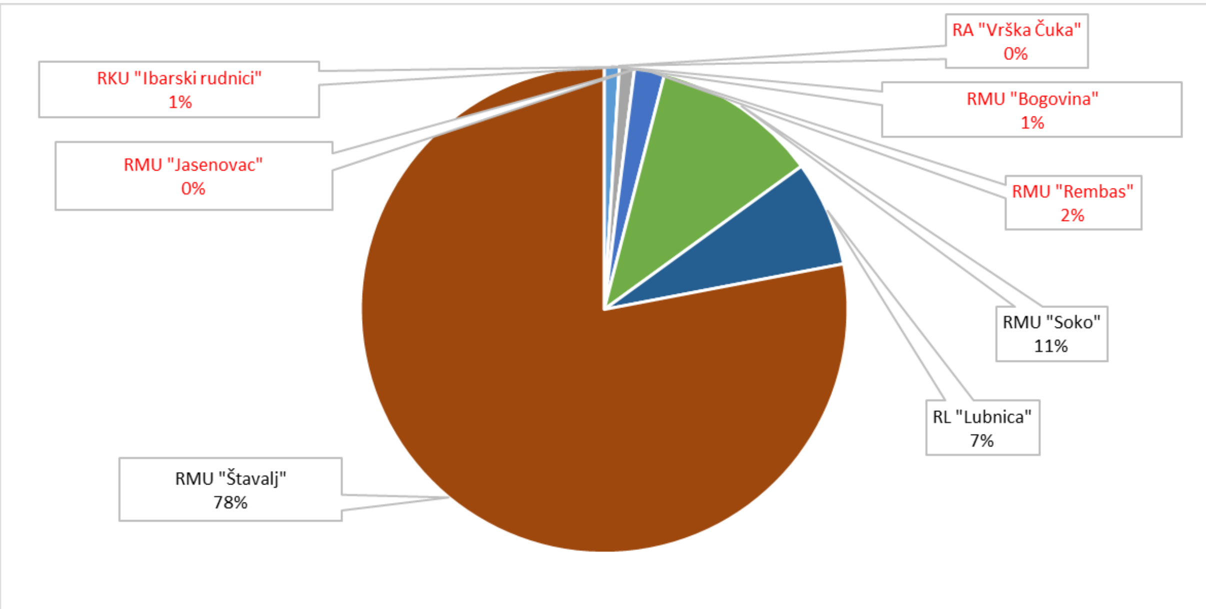
Figure B.2.4 - **Balance coal reserves per categories A and B in JP PEU Resavica active coal mines, %**



Source: based on Ivković, Tošić, and Dramlić, 2022

Figure B.2.5 shows the balance of the Serbian coal reserves (proved reserves) of the highest A and B categories (proved coal reserves) and the C1 category (probable coal reserves). Taking into account all the balance categories of coal reserves (proved categories A and B, and probable C_1 category), the RMU "Štavalj" has the most extensive resources of coal (probable and proven) – 71% of all Resavica mines coal reserves. RMU "Soko" (11%) and RL "Lubnica" (7%) also have relatively large amounts of probable and proven balance reserves.

Figure B.2.5 - **Balance coal reserves per categories A, B, and C1 in JP PEU Resavica active coal mines, %**



Source: based on Ivković, Tošić, and Dramlić, 2022

As a result, judging by the number of their resources, only three out of eight underground Serbian coal mines, namely RMU "Štavalj", RMU "Soko", and RL "Lubnica", have a potential for longer-term exploitation. Therefore, it seems reasonable to assume that if JP PEU Resavica were to invest in improving its exploitation capacity, the financial resources should be directed towards RMU "Štavalj" (lignite) and RMU "Soko" (brown coal), plus potentially towards RL "Lubnica" (lignite). Considering only the type and the quality of coal and not considering natural hazards, the best option would be to support mining operations in RMU "Soko".

Table B.2.4 summarises the coal resources in the reserve mining areas. These are potential areas for the development of new coal mines (Ivković, Tošić, and Dramlić, 2022)

Table B.2.4 - **Coal reserves in reserve deposits in Serbia**

Deposit	Balance reserves per category, t				Type of coal
	A	B	C_1	$A+B+C_1$	
Jerma	none	5,767,500	none	5,767,500	Hard coal
Melnica	none	21,121,761	8,899,908	29,921,669	Brown coal
Aleksinac	2,732,960	17,017,380	7,776,280	27,919,620	
Poljana	none	48,467,000	10,527,270	58,994,540	Lignite
Cirikovac	none	121,036,207	27,881,661	147,517,868	
Despotovac	none	15,080,000	9,710,000	24,790,000	
Zap. basen	none	72,111,343	21,792,492	93,903,835	
Dragacevo	none	none	62,000,000	62,000,000	

Source: Ivković, Tošić, and Dramlić, 2022

Category A (proved coal reserves) have only been recognised at the closed Aleksinac mine. The remaining deposits have been identified in categories B and C_1, meaning they should be considered potential.