NEW POST-EXPLOITATION OPEN PIT COAL MINES LANDSCAPES – POTENTIALS FOR RECREATION AND ENERGY BIOMASS PRODUCTION: A CASE STUDY FROM SERBIA

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Abstract

Selected results from research on landscape and functional transformations in one of the largest coal basins in Serbia are presented in this paper. Firstly, the site conditions of the Kolubara lignite basin are analyzed, followed by an overview of the success of planted coniferous and deciduous trees used in the process of biological re-cultivation by afforestation. Finally, the possibility of multifunctional uses of reclaimed deposols and of newly-created landscapes is considered, especially for recreation and production of biomass for energy in short-rotation plantations. The study of potential uses of newly created landscapes and ecosystems after coal extraction by open-cast mining and after technical and biological re-cultivation by afforestation, confirms the thesis on the feasibility of sustainable development. It is possible to create extraordinary anthropogenic forest ecosystems rich in biodiversity with multi-functional values that are suitable, inter alia, for recreation and energy biomass production.

Shrnutí

Nová krajina vytvořená na plochách vytěžených povrchových dolů – potenciál pro rekreaci a produkci biomasy: případová studie ze Srbska

Příspěvek přináší vybrané výsledky z výzkumu krajiny a jejích funkčních přeměn v jedné z největších uhelných pánví v Srbsku. V první části práce jsou analyzovány přírodní podmínky lignitové pánve Kolubara, poté úspěšnost výsadby jehličnatých i listnatých dřevin použitých v procesu biologické rekultivace zalesněním a konečně možnost multifunkčního využití rekultivovaných půd (deposolů) a nově vytvořené krajiny zejména pro účely rekreace a produkci energetické biomasy ve výsadbách s krátkým obmýtím. Tato studie potenciálního využití krajiny a ekosystémů nově vytvořených po těžbě uhlí v povrchových dolech a po technické a biologické rekultivaci zalesněním potvrzuje tezi o realizovatelnosti trvale udržitelného rozvoje. Je možné vytvářet jedinečné antropogenní lesní ekosystémy s bohatou biologickou rozmanitostí multifunkčních hodnot, které jsou mimo jiné vhodné i k rekreaci a k produkci biomasy pro energetické účely.

Key words: *open pit coal mines landscapes, biological re-cultivation, recreation, short rotation plantations, biomass for energy, Serbia*

1. Introduction

In Serbia, coal is the major energy raw material and the base of industrial and economic development. Low calorie coal – lignite is the most significant, because its share in geological (total) reserves is 85%, and even 94% of the exploited part. Nearly all lignite supplies are concentrated in several basins of which the most significant is Kolubara.

The Kolubara lignite basin was formed by the deposition and carbonation of plant materials occurring in the swamps and lakes of the Tertiary. It is located 50 km southwest of Belgrade. Geological contours of lignite deposits suitable for exploitation occupy an area of more than 500 km^2. In the Kolubara Basin (Fig. 1), lignite has been extracted exclusively by open cast mining, which results in multiple degradation of the environment. A drastic change of the landscape (Fig. 2) and ecosystems is unavoidable in the course of lignite extraction: artificital sterile mine spoil banks (tailings), immense holes – craters, areas without vegetation and with the destroyed soil cover, formation of lakes, pools and other artificial water bodies give a completely new image of the disturbed landscape.

As the result of different mining activities, especially opencast mining and development of industries, this region had been repeatedly damaged and transformed which seriously affected the landscape's natural balance and visual characteristics. The adverse changes, processes and consequences required parallel works on rehabilitation, i.e. revitalization, recultivation and, in general, works on the management of the disturbed natural units. Open cast coal mining requires the management of the entire space and overburden above the coal deposits. Rehabilitation and restructuring of land offer numerous possibilities of land restoration for the benefit of both human and natural communities.

2. Succesful examples of biological land rehabilitation

Mining has been pursued on a large scale in Central Germany for about 150 years (Hildmann and Wonsche, 1996). Thus it is not strange that Germany was the first country to recognize the importance of biological recultivation in the middle of the 19th century. Following this idea, USA and England made the first attempts for recultivation at the beginning of the 20th century. Real scientific research in this field of land management as well as a more extensive application of recultivation started after the Second World War.

Mining activities were carried out so intensively in the 1970s and 1980s in Germany that the reclamation could not keep up with the area devastated by mining (Hildmann, Wonsche, 1996). Political leaders had other priorities and subsequently state mining companies did not receive funds for remediation and reclamation (Dražić et al., 2011). Overburden consisted of sand and gravel and hardly any topsoil was the major remediation problem (Bismarck, 2000). A new soil cover had to be established and the interrupted nutritional chains had to be built up again to bring back plants and animals. By adopting rigorous legislation which dictated the method of extraction, permitted amounts of harmful substances, solution of social and other problems, and even selective overburden removal (Hildmann, Wonsche, 1996), Germany has managed to recultivate more than 40,000 hectares of mined land. Thanks to this largest European environmental program, established in the early spring of 1999, 65,370 ha of wasteland and dump areas, 27,280 ha of forests, 11,590 ha of agricultural land were reclaimed. Natural re-vegetation

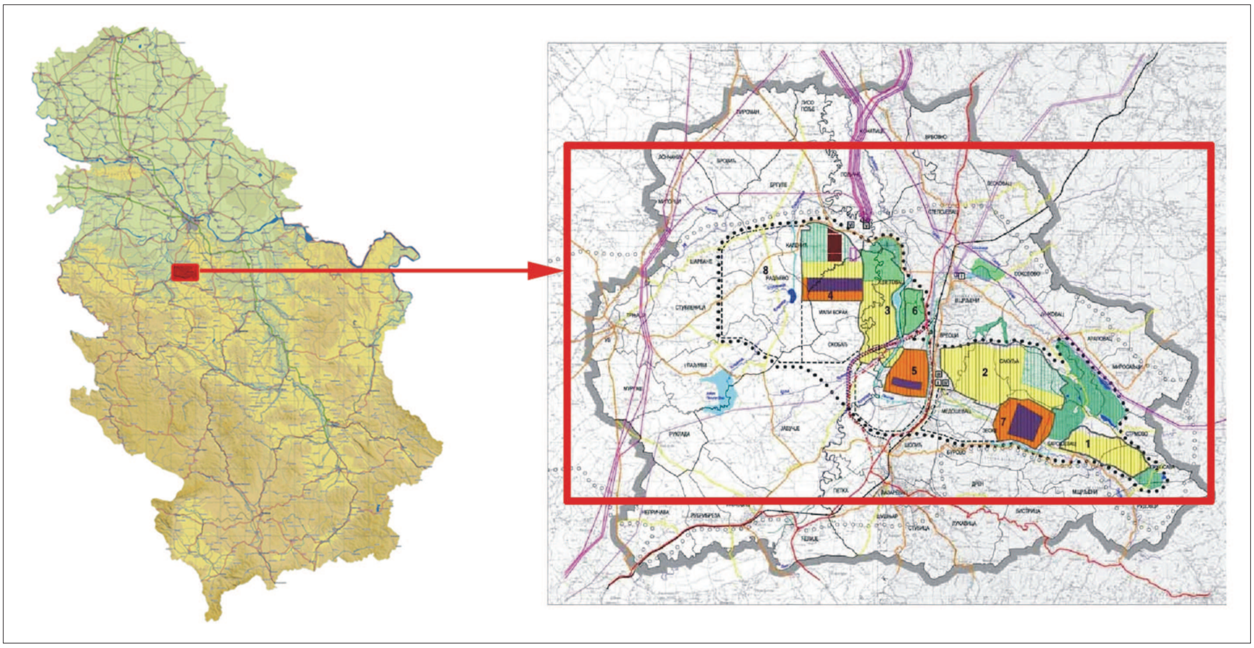


Fig. 1: The Kolubara lignite basin – geographical location in the Republic Serbia

Fig. 2: The Kolubara lignite basin – a panoramic view of the exploitation field "D" (photo: D. Dražić)

and controlled succession was carried out on 5,760 ha. New ecosystems are now established in order to bring the post-mining landscape on the path leading towards sustainable development and achieve the desired future land use – with many new lakes with water of bathing quality and you will also see thousands of acres of young forests and new agricultural land and areas protected for wildlife (Bismarck, 2000).

A particularly interesting idea is the establishment of short rotation plantations on disposal sites. Studies conducted at the disposal sites of open-pit mines in Germany showed that growth increment ranges from 5.3 to 19.6 tones of the dry matter/ha in 4-year old plantations grown even under unfavorable soil conditions (Bungart and Hüttl, 2001).

Germany was not alone in revitalizing the land degraded by coal surface mining and its subsequent multifunctional use, so there are many other examples of successful work. In the USA, thanks to legislation such as the Federal Surface Mining Control and Reclamation Act from 1977 (SMCRA), there are very good examples of successfully revitalized lands, after or in the course of surface mining of mineral ores: e.g. in West Pennsylvania (Ahharach and Hartman, 1973), South Indiana (Byrnes and Miller, 1973, Medvick, 1973, Miles et al., 1973), Pennsylvania (Davis, 1973), Ohio (Funk, 1973), West Virginia, mine Elkins (Hodgson and Townsend, 1973; Thurman and Sencendiver, 1986), and others (cf. Committee on Soil as a Resource in Relation to Surface Mining for Coal et al., 1981). The establishment of farms, reinstated by agro-melioration measures to the state of pre-mining productivity was the most usual practice in Midwest USA in the past. There are frequent cases of the restoration of natural "wildlife" sites nowadays. Very popular method of re-cultivation is the transformation of post-exploitation landscapes into wetlands. Valuable sites for birds resting during their migration are established in this way. It is believed that this aspect of re-cultivation is also financially feasible, because these ecosystems are natural purifiers and water filters to the level prescribed by standards. The establishment of forests and orchards is suggested in former forest regions. Some companies choose primary vegetation and meadows, enabling the natural succession of plant species to the level of climatogenic forest community.

Recently, very significant results have been achieved in the reclamation of regions damaged by mining in the past in Great Britain, especially in England and Wales as well as in Scotland. Only after signing a contract with the National Coal Board (NCB), a mining company can get the permission to open new open cast mines. Twenty-eight out of 65 articles of the contract refer to environment protection, landscape conservation and re-cultivation of damaged land. In this way, large areas are managed in Yorkshire, North Derbyshire and Doncaster (Lindley, Mansfield, 1979).

Inquiries carried out in Bulgaria by Hage et al. (1996) showed that the impact of mining on the environment could be reduced remarkably, if ecological aspects were considered. They suggest further development of open pit mines through the protection of landscape parts by changing the mining edges, a rapid shift from outside to inside dumping and early recultivation of outside dumps. Furthermore, they state that post mining landscapes in Bulgaria have numerous possibilities to create a reasonable environment. This includes among others: areas for agriculture and forestry use, integrated and special areas for nature conservation and development of areas for recreation.

In Poland, coal mining activity covers about 16,000 ha. The establishment of forest ecosystems has priority in post mining landscape. The first afforestation of dumps in Poland was performed in the Turow Mine in the early 1970s (Strzyszcz, 1996). Many leguminous and grass species were introduced and soil cover on slopes was made of trees such as black and grey alder, robinia red oak, larch, Scotch pine, ash, and poplar. The outer dump of the Adamow Mine in Poland, sized about 350 ha, was a second object subjected to afforestation in same period. Vegetation was slightly different, though. Besides leguminous and grass species, trees species such as black and grey alder, red oak, larch, poplar hybrid 275, Norway maple and mountain ash were introduced (Strzyszcz, 1996).

Of the former socialist countries (in addition to the former German Democratic Republic), the then Czechoslovakia was one of the leading countries in revitalization of land degraded by coal surface mining. Re-establishing agricultural ecosystems through recultivation on post-mining landscapes prevails in the northern-Czech Lignite Basin. The approach was regulated by law in 1957 (Strzyszcz, 1996). Forest recultivation is present in the Sokolovský Basin due to the quality of overburden materials. Near the city of Chomutov, an area of 480 ha was agriculturally reclaimed and 100 ha were recultivated by afforestation.

3. Methods

In the first part of the paper, site conditions (climate conditions, characteristics of deposols[1] at disposal sites of barren soil) of the Kolubara basin are analyzed, then the success of planted coniferous and deciduous trees used in the process of biological recultivation by afforestation. Comparative surveys are also conducted of the development of the present dendroflora at disposal sites of the open-pit mines in forest cultures established during the biological recultivation of the Kolubara-Tamnava coal basin. Finally, possibilities of the multifunctional use of reclaimed deposols (see e.g. Kostic et al., 1996) and newly created landscapes are discussed, especially for recreation and production of biomass for energy in short rotation plantations.

This paper also presents research results on the detailed monitoring and analysis of several species suitable for short rotation plantations (*Populus* x *euramericana* cv., *Salix* sp., *Pseudotsuga menziesii* Mirbel Franco, and *Larix decidua* Mill.) that were planted on sample plots on deposols. Total numbers of planted tree seedlings were as follows: 1,008 (European larch), 978 (Douglas fir), 651 (poplar) and 1,449 (willow). The seedlings were watered regularly, depending on meteorological conditions. One year after planting, in spring, initial supplementary nutrition was added at 30 g of NPK mineral fertilizer per seedling in order to provide the best possible thriving and start growth, whereas in the second year the supplementary feeding was added as waste sludge obtained during the process of coal processing.

Monitoring of important parameters until the end of rotation is essential for conclusions and determines optimum technologies for establishing the plantations, silvicultural measures, tending, and utilization of appropriate mechanization and harvesting of biomass obtained in this manner, as well as the assessment of realistically obtainable energy biomass quantities in the areas degraded by the surface exploitation of lignite coal.

In order to determine possibilities of biomass production at the disposal sites of barren soil (deposols), a comparative experiment was established with a number of fast-growing tree species. Trees were planted to determine optimal method and technology of soil preparation (deposols), initial supplementary nutrition by fertilizers and other growth stimulants, planting density and technology for each species, protective measures to be adopted in short rotation plantations against harmful insects and phytopathogens, effects of phyto-remediation, selection of suitable mechanical devices in all work phases and analysis of economic parameters of the establishment of plantations intended for the production of biomass for energy.

The experimental plot in Baroshevac was established at a waste disposal site of barren soil (deposol) within the Kolubara basin during 2006/2007. Parameters monitored on the experimental plot were as follows:

- average length of the above-ground part (m),
- length and diameter of the root collar (cm),
- mass of the above-ground part (g),
- mass (g) and volume (ml) of the root,
- dry matter of the above-ground part of extracted seedlings two years after planting(g),
- high and low calorific value (MJ/kg),
- health condition.

For the assessment of a potential capability of the study sites for recreation, a method developed by Cvejic (1989) was applied to evaluate the potential natural suitability for recreation. This method, as the result of research and detailed comparative analysis of previous methods by Kiemstedt (1969), Ruppert (1971), Schaneich (1972), Turovski (1972), Mrass (1974), Harfst (1975), Kastner et al. (1982) can be characterized by numerous advantages. It belongs to a group of quasi-total, user-independent quantitative methods. The method takes into account natural characteristics of the region and includes ecological and esthetic-psychological aims as well as the aim of potential suitability for outdoor recreation, conditioned by the climate. It should be emphasized that this method evaluates the potential zones for recreation and not the already formed recreation zones.

The method consists of three phases:

1. Elimination of evaluation units, based on elimination features,
2. Designation of potential recreation zones for all types of recreation, and
3. Assessment of a suitability of the land to accommodate recreation: water recreation and recreation in the landscape.

The evaluation was based on detailed aerial photographs made on a scale 1:10,000. The size of the evaluation units of quadrate-raster was 0.25 × 0.25 km. Within each raster, thirteen features were evaluated: relief, forests, waters, banks, meadows, presence of individual trees, hedges, orchards-vineyards, fields-arable land, agricultural, forest roads and walking paths, cultural and natural monuments, settlements, infrastructure, competitive land uses and accessibility, as well as 21 sub-features of the above principal features. A unique four-phase scale was implemented from 1 to 4, where four points represent the highest suitability.

[1] The term "deposols" has been used mostly in the post-Yugoslavian geographical space for a specific type of anthropogenic soils developed in consequence of the storage of surface layers in the process of coal mining and tailing (see e.g. Kostič et al. 1996, Ličina et al. 2012).

4. Results

4.1 Site conditions

The study area is characterized by temperate continental climate (Kerner), sub humid, moister type (Thornthwaite), with mean annual air temperature ranging between 11.0–12.0 °C. Annual rainfall ranges between 583.5 and 783.1 mm, with two maxima: in early summer and in late autumn, and two minima: at the end of winter and at the beginning of autumn. Mean annual relative air humidity is 69.0–76.9%. The most frequent winds are in ESE direction, then WNW, W, N and NW, while average frequency of calms is 629‰. During open cast mining, the previously natural soils in this area were replaced by mine spoil banks, originating from different geological layers. Pontian sands and heavy Pliocene clay are most often found on the surface of the spoil banks.

The plantations were established on very heterogeneous substrates (Figs. 4, 5), which are, after Antonovic (1980) in the class of anthropogeneous soils, special class of technogenic soils, type deposols, subtype deposols formed by open cast mining of lignite. They have very variable properties, which is the consequence of different initial characteristics of deposited materials (Fig. 3). Generally, all of them are characterized by very low amounts of humus and organic matter and by a weak acid to neutral reaction.

4.2 Development of different tree species

During the process of biological recultivation by afforestation, numerous species of trees and shrubs were planted, depending on the type of soil and other micro-habitat conditions (Tab. 1). The largest area is occupied by pure plantations of Austrian pine and Scots pine (27.7%), and by group selection mixtures

Fig. 3: Disposal of overburden tailings in Kolubara – substrates for biological reclamation (photo D. Dražić)

Figs. 4, 5: Cross-section through the substrate (deposols) in Kolubara on which forest plantations are established (photo D. Dražić)

Tree species	Total	
	hectares	%
Pure plantations of Austrian and Scots pines	262.00	27.7
Pure plantations of larch	33.00	3.4
Pure plantations of Douglas-fir	13.00	1.3
Pure plantations of Weymouth pine	21.00	2.1
Pure plantations of oaks	23.00	2.3
Pure plantations of maple	29.00	3.0
Pure plantations of black locust	82.00	8.4
Pure plantations of other broadleaves	78.00	7.9
Mixed stands of conifers	109.00	11.1
Mixed stands of broadleaves	93.00	9.6
Mixed stands of conifers and broadleaves	228.00	23.2
Total:	**971.00**	**100.0**

Tab. 1: Characterization of the area by tree species (Dražić et al., 2007)

of broadleaves and conifers (23.2%). The percentage of group mixtures of coniferous plantations is 11.1% of total afforested area, and mixed plantations of broadleaves account for 9.6%. Other broadleaves - lime, alder, Siberian elm, birch, etc., account for 7.9%, black locust 8.4% in total afforested area, while other species account for 1.3% to 3.4% of the total plantation area (Dražić et al., 2007). Besides the mentioned species, in the process of biological re-cultivation by afforestation, there were planted more than 15 species (Figs. 6 and 7).

In general, parameters of the development of the studied tree species in forest plantations (diameter, height) showed satisfactory results (Tab. 2). All tree species used in afforestation exhibited a high degree of survival after planting, very good dynamics of diameter, height and volume development, but there were differences between the species on the same deposols, and differences in the development of each species on different deposols.

4.3 Potential use of reclaimed lignite strip mine areas for recreation

Of the total evaluated area (1,143 ha) divided into 183 rasters (see Fig. 8), 31% (57 rasters, i.e. 356 hectares) was the first category of suitability for recreation, 56% (103 rasters, i.e. 644 hectares) was the second category of suitability for recreation. Only 13% (23 raster-areas or 144 ha) was the third category of suitability for recreation. No land was classified in the fourth category (Dražić, 2000).

Based on the above results, it can be concluded that the study area has an extraordinary potential suitability for recreation, because a significant percentage of the area is under forest, there are water bodies such as lakes, rivers and swamps, there are meadows, terrain dissection is also expressive although at a relatively low altitude. On the other hand, the percentage of fields, developed areas, infrastructure and competitive land uses is small. In the third phase of evaluation,

Figs. 6, 7: Forest plantations of different tree species established in the process of biological re-cultivation in Kolubara (photo D. Drazic)

Tree species	Deposol of lighter mechanical composition		Deposol of heavier mechanical composition	
	Diameter (cm)	Height (m)	Diameter (cm	Height (m)
GYMNOSPERMAE (CONIFERS)				
Alder (Alnus glutinosa L. Gaertn)	12.3	10.00	10.0	10.00
Larch (Larix decidua Mill.)	11.7	10.80	8.6	10.00
Weymouth pine (Pinus strobus L.)	8.6	6.85	9.2	8.00
Douglas fir (Pseudotsuga menziesii Mirbel. Franco.)	8.6	6.50	9.1	6.55
Scots pine (Pinus sylvestris L.)	8.3	7.10	6.7	4.50
Birch (Betula verrucosa Ehrh.)	11.9	9.40	-	-
Austrian pine (Pinus nigra Arn.)	7.3	4.60	6.7	4.85
Sequoia (Sequoiadendron giganteum (Lindley) J.Buchholz)	10.7	5.00	-	-
Sequoia (Sequoiadendron giganteum (Lindley) J.Buchholz)	10.7	5.00	-	-
Arizona cypress (Cupressus arizonica Greene.)	10.6	5.58	-	-
Bhutan pine (Pinus wallichiana A.B. Jackson)	10.4	5.05	-	-
Western yellow pine (Pinus ponderosa Dougl.)	9.4	4.00	-	-
Atlas cedar (Cedrus atlantica Man.)	7.3	6.00	-	-
Lawson's cypress (Chamaecyparis lawsonianna Murr.Parl.)	6.9	5.67	-	-
Incense cedar (Libocedrus decurrens Torr.)	6.3	4.03	-	-
ANGIOSPERMAE (DECIDUOUS TREES)				
Caucasian fir (Abies nordmanniana (Steven) Spach	4.8	3.00	-	-
Serbian spruce (Picea omorika Panc.Pyrkine)	4.4	5.05	-	-
Sibirian elm (Ulmus sibirica)	11.5	6.33	-	-
Red oak (Quercus rubra)	5.1	5.50	-	-
Tulip tree (Liriodendron tulipifera L.)	4.4	4.42	-	-

Tab. 2: Development characteristic of some tree species at the age of 10 years

we designated area parts that can accommodate water recreation (Fig. 9) and recreation in the landscape (Fig. 10). Of all evaluated units, water bodies occur in twenty-five percent of raster areas. The River Turija flows along the north-eastern boundary. There are also lakes of various sizes.

The rivers and lakes (Figs 11 and 12 – see cover p. 4) can be used for swimming, fishing, boating and the maintained beaches can be used for sun-bathing, leisure time and other aspects of recreation.

4.4 Sustainable development of renewable and non-renewable energy sources

Apart from lignite coal, which is undoubtedly the most important source of energy in Serbia, a considerably extensive area under coniferous and broadleaved tree plantations was established within the coal basin in the process of biological re-cultivation by afforestation. A significant volume of wood for energy is obtained in the process of regular maintenance of these forest crops (thinning, cleaning, etc.). However, much larger quantities of biomass can be produced in short rotation plantations on waste disposal sites (deposols). In this way, sharing of production and human resources, integrated production and use of renewable energy sources (hereinafter RES) and non-renewable energy sources (hereinafter NON-RES) is possible in the same space.

Biomass represents the most important renewable energy source in Serbia with a share over 60% among renewables (Stojiljkovic et al., 2011). The main reason is a high share of agriculture (arable land constitutes approximately 55% of the territory) and abundance of forests (approximately 30% of the territory is covered by forest and an increased level of forest coverage of 40% is planned). In order to reduce emissions of CO_2, renewable energy must replace fossil fuels. In countries with large forest resources and well developed forest sectors, wood is the primary source of renewable energy (Hakkila, 2000).

It is realistic to utilize energy of 1.0 Mtoe (Million Tons of Oil Equivalent) from the forest biomass and 1.4 Mtoe from the agricultural biomass. Total amounts of forest biomass are estimated at 7 million mł of fuel wood (55% from state forests) and 5 million

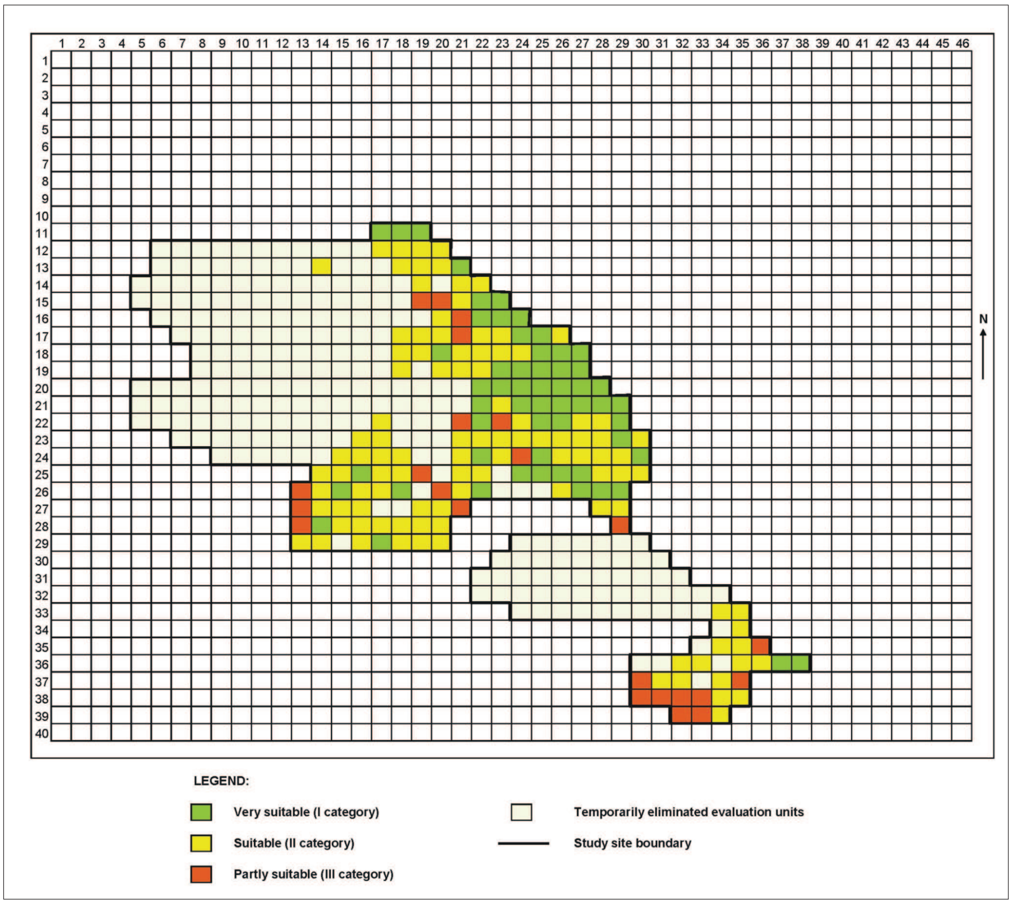


Fig. 8: II phase of evaluation – potential recreation zones on the study site in Kolubara

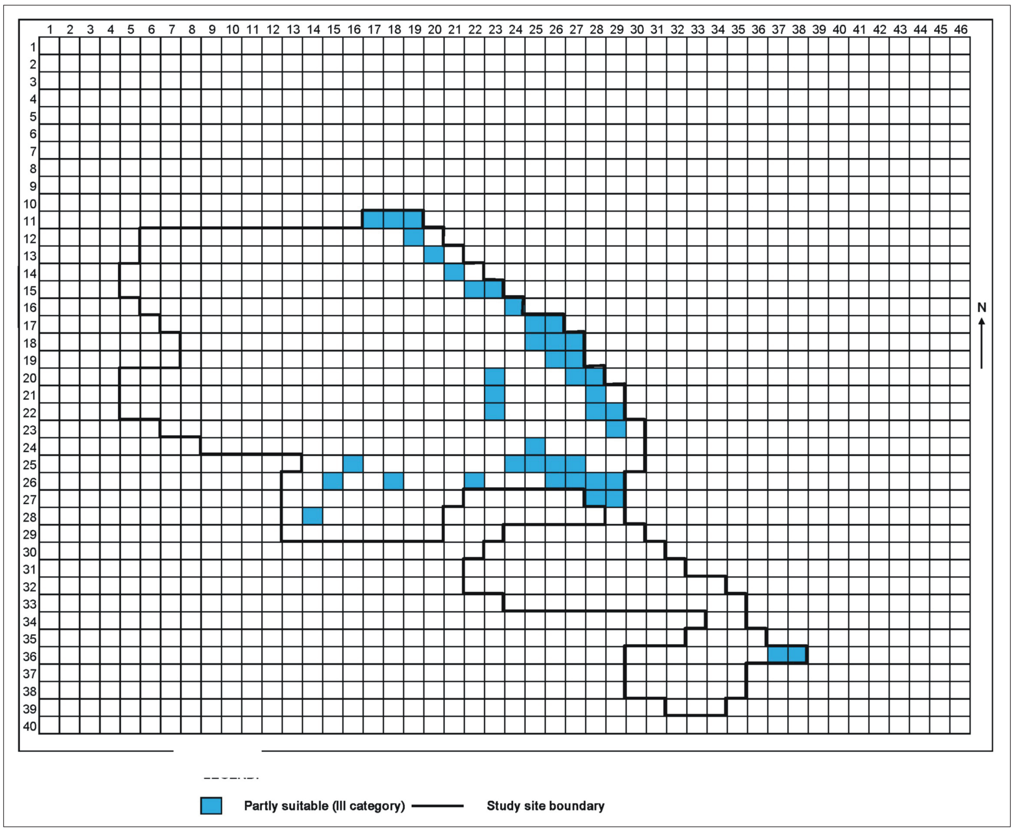


Fig. 9: III phase of evaluation – study site suitability for water recreation

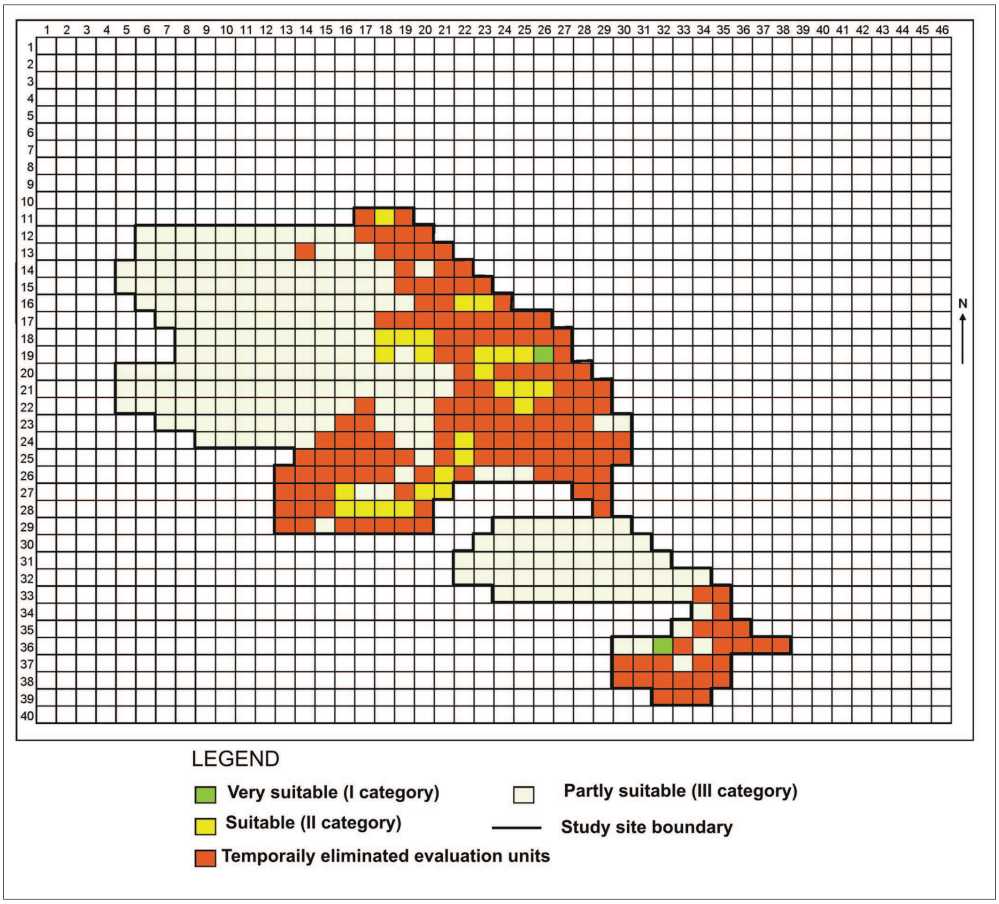


Fig. 10: III phase of evaluation – study site suitability for recreation in the landscape

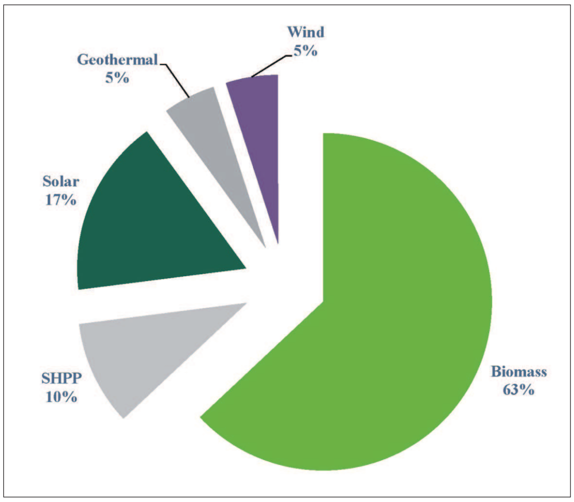


Fig. 13: Potential share of different forms of RES in Serbia

mł of wooden waste. There is an opportunity in Serbia for growing so called "energy forests" on the area of 200,000 ha of untilled land, on which fast growing forests could be planted and further used for energy purposes. The research has shown that 15 to 20 tons of wood biomass per hectare could be obtained per year, which is between three and four million tons of wood biomass. The use of biomass in Serbia has already found its application in heating households with the use of forest biomass briquettes and palettes.

4.5 Biomass production in short rotation plantations on overburden deposits (deposols)

Short rotation plantations for biomass energy production are one of the realistic alternatives, primarily because of their ecological advantages which are as follows:

- Renewable production,
- They emit very small amount of carbon into the atmosphere (1/10 CO_2 in comparison with other fossil fuels),

- Locally, the plantation can reduce the erosion process, provide funds for degraded land restoration, neutralize air pollution and local effect of fossil fuel energy production(for instance SO_2 and NO_x) and reduce further threat to existing woods,
- Different types of dendroflora can be used for a double purpose – biomass production and land decontamination from various pollutants – phyto-remediation,
- Woody plants account for 63% of the total number of short rotation plantations. Poplar trees, willows and alders dominate in moderate climate zones. They are characterized by annual productivity of more than 10–12 t/ha of dry wood and bark, relatively equal quantity of yield for energy capacity provision and cost of less than 50 $ per dry ton,
- For setting up a plantation, selected, fast growing types of trees are used, depending on local conditions – willows, poplar trees and others,
- They are characterized by very high planting densities (poplar trees 6–12,000 plants/ha, willows 10–12,000 plants/ha), and they are harvested every 3 to 10 years,
- In the USA and Europe, hybrid poplar trees and willows are in most cases more suitable than natural species in spite of the fact that some fast growing natural clones have been identified. In some moderate agricultural regions herbaceous crops, grass and others have been researched. One of the advantages of that type of crops is that they can be planted and collected by means of existing agricultural mechanization, without new investments into special forestry equipment,
- Topography, soil, humidity condition variations dictate to use a larger number of different plants in order to optimize sustainable production. From the ecology point of view, it is desirable to have mixed plantations with different types of trees, bushy and grass plants, since that type of plantation provides habitat for different animal and bird species. Besides woody plants, stands of grass, herbaceous, semi-herbaceous vegetable species, such as *Phragmites communis* or *Miscanthus* sp., which behave as long-lived species when planted for this purpose, can be set up, and
- Good plantations on good locations in tropical and moderate climate zones can achieve 2–10 times higher yield compared with natural forests.

Box 1: Legislative framework of renewable energy development in Serbia

There are several government institutions in Serbia responsible for development of renewable energy sources, including biomass – Ministry of Agriculture, Forestry and Waterpower Engineering, Ministry of Science and Technological Development, Ministry of Environment and Spatial Planning, Ministry of Mining and Energy, Ministry of Economy and Regional Development, Agency for Energy Efficiency and Regional Centers, Council for Sustainable Development, etc.

One of the EU membership requirements that Serbia has to comply with is adoption of a series of laws concerning environment protection, based on European standards and their implementation. Until now, Serbia has adopted a so called "Green Package of Laws" which includes the Air Protection Law, since, until recently, carbon dioxide emission in Serbia were double those of countries of similar gross national income.

The "Energy" legislative framework primarily refers to:

- Energy Law (2004);
- The Republic of Serbia Energy Development Strategy by 2015 (2005) which determines the following priority directions in this sector:
- Energy Development Strategy Implementation Programme of the Republic of Serbia 2007-2012 (2006), with amendments and supplements (2009);
- The Republic of Serbia has signed the Treaty of Establishing South-East Europe Energy Community and EU, by ratification of which it assumed the obligation of implementation of directives concerning increased use of renewable sources (2001/77/EC and 2003/30/EC), stating that 20% of the total energy production must be from renewable sources by 2020.
- The Kyoto Protocol Ratification (2007);
- Regulation on conditions concerning acquirement of the status of favoured electric energy producer and criteria for condition compliance assessment;
- Regulation on measures encouraging electric energy production by using RES and combined production of electric and thermal energy;
- The Republic of Serbia has become a founding member of the International Renewable Energy Agency (IRENA) on 26th January 2009, which is the first international (inter-governmental) organization focused exclusively on renewable energy and it will continue to participate actively in its work in accordance with the Agency Statute and its own interests in the area of activating and using renewable energy sources, and
- The Serbian Government has adopted the Regulation on measures encouraging electric energy production by using renewable energy sources and the combined production of electric and thermal energy. The policy of encouragement involves guaranteed purchase price for all electric energy produced in mini hydroelectric power plants, plants using biomass, wind power plants, solar power plants and power plants using biogas, waste or sewerage gas, in the period of 12 months after production start.

Although natural arable lands are most suitable for setting up plantations, lands with moderate limitations can be used, too, with previously resolved problems of water, erosion and lack of fertilizers.

Besides the biomass produced in forest cultures formed in the process of biological re-cultivation by afforestation, the research conducted in surface mine tailing ponds in Germany showed that, even under unfavourable soil conditions, the yield accounted for 5.2 to 19.6 tons of dry matter/ha at the age of four years. Biomass produced in this way is characterized by low concentration of heavy metals, high caloric value and favourable characteristics of ash with the high concentration of macronutrients. Use of ash for land improvement can recompense for the loss of soil nutrients after harvesting biomass. The experience from Germany and some other countries suggested the possibility for the establishment of the plantations of fast-growing woody species at the disposal sites of barren soil (deposols) of open-pit coal mines.

The Government of The Republic of Serbia, via The Ministry of Science and Technological Development, within the framework of the National Programme for Energy Efficiency, supported the projects EE273015 and TR18201 "Opportunities for biomass energy production from wood short rotation plantation within the framework of electro energy systems in Serbia", led by The Institute for Forestry – Belgrade, and with a collaborator, beneficiary and participant: P. K."Kolubara" and S. E. "Srbijasume", whose objectives and research content are the following:

- Biomass volume production increase in fast growing dendroflora plantations in surface coal mine tailing ponds in Serbia,
- Increased share of energy generated from biomass in our country and enabling partial fossil fuels substitution according to the Kyoto Protocol regulations, The Davos summit conclusions and other international treaties,
- Determining the ecologically and economically most suitable tree species,
- Determining optimal technologies for setting up plantations,
- Determining care, protection and supplementary nourishment measures with the aim to obtain the largest possible amount and best quality biomass,
- Determining the opportunities for use of waste mud from coal processing as a rational and accessible growth primer (fertilizers),
- Phyto-remediation of contaminated substratum,
- Determining the economically most acceptable solution,
- Employment of local inhabitants and surplus work force, which will emerge in the process of public company restructuring in the energy sector.

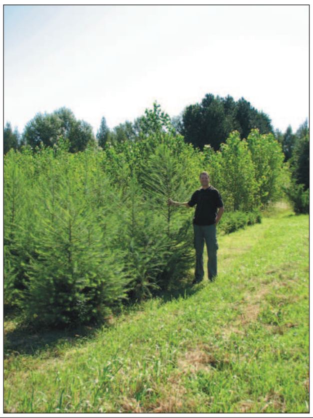
The successful biological recultivation in the Kolubara basin was conducted in the area of about 1,300 ha. Forest cultures of different coniferous and broadleaved species account for 75% of it. The species are very vital and show good growth and development despite the unfavourable site conditions (Dražić et al., 2006).

The research has shown that the potential of the expected production of air-dry biomass in Kolubara basin is very significant and it is estimated to be about 200,000 tons per year, i.e. over 1,200,000 tones in the six year rotation period (Dražić et al., 2005). The experimental plots (Figs. 14–17) with few species of dendroflora (*Populus* x *euramericana* cv. – poplar, *Salix* sp. – willow, *Pseudotsuga menziesii* Mirbel. Franco – Douglas fir and *Larix deciduas* Mill. – common larch, Tab. 3 and 4) have brought evidence to the fact that the establishment of energy plantations for the specific purpose, in which a significant biomass volume of good energy characteristics will be provided, is a feasible project.

Thereby, the production of dendro-biomass for energy will be unified in the influence zone of the open-pit mines of lignite coal, with the capacity of coal processing and thermal power plants, which is important both from the economic and ecological point of view.

There are significant tailing pond areas in Serbia which are not used at present. Similar new areas are created daily. These areas are located primarily within the surface lignite mines (Kolubarsko-tamnavski basin, Kostolački basin and others), surface non-ferrous metal mines, clay, stone and other raw materials exploitation sites. It has been estimated that, in Serbia, an area of approximately 1,000 km^2 will be degraded due to the exploitation of surface minerals and other raw materials. Part of these areas can be used for setting up short rotation plantations for energy biomass production. Lignite deposits in our country stretch across the area of more than 1,000 km^2 and account for 83% of the total reserve of fossil fuels energy potentials. However, due to the fact that it is non-renewable energy source, it is considered that we will exhaust the reserves of this potential in 50 years.

The present experience shows that in the process of the biological re-cultivation of tailing ponds, the ratio of forest to agricultural re-cultivation is most frequently 60:40, which means that in the final phase we can expect the forest ecosystems to be established on 600 km^2 while agricultural areas, urban ecosystems and infrastructure will cover 400 km^2 (Drazic et al., 2005). Taking into account the current experience concerning achieved production effect of ten year old forest cultures set up on deposol soils

Figs. 14, 15, 16, 17: Experimental plots with different fast-growing tree species on deposol in the Kolubara basin (photo D. Dražić)

Analyzed parameters		Species			
		Larix decidua	*Pseudotsuga menziesii*	*Populus sp.*	*Salix sp.*
Length of the above-ground part with the main sprout (cm)		60.0	55.0	351.0	276.0
Length of the above-ground part without the main sprout (cm)				326.0	
Length of the main sprout (cm)				24.0	
Length of the root (cm)		32.0	21.0	54.0	43.0
Diameter of the root collar (mm)		9.9	13.8	34.8	15.9
Mass of the above-ground part (g)	Stem	36.3	19.6	860.3	150,0
	Twigs			189.2	
	Leaves			485.3	20,7
	Leaves + twigs	144.0	62.8		
	Total	180.3	82.5	1534.8	170,7
Dry mass of the above-ground part (g)	Stem	11.8	6.5	447.7	80,7
	Twigs			86.7	
	Leaves			176.7	8,2
	Leaves + twigs	68.3	23.5	711.0	88,9
	Total	80.1	30.0		
Mass of the root (g)		46.7	35.2	523.0	41.7
Dry mass of the root (g)		13.9	9.4	246.3	22.2
Volume of the root (ml)		36.7	25.0	444.3	60.0

Tab. 3: Average values of above-ground part length, root collar length and diameter, mass of the above-ground part, mass and volume of the root and dry mass of the above-ground part of extracted seedlings two years after planting

Tree species and tree part	High and low heating value (MJ/kg) for the analyzed species			
	Laboratory values		Values according to literature data	
	High heating value	Low heating value	High heating value	Low heating value
Douglas fir stem	19. 288	18.313	19.18	15.20
Douglas fir needles with twigs	18. 752	17.827		
Poplar stem	17.443	16.468	17.26	13.52
Poplar leaves	17.329	16.404		
Willow stem	17.385	16.410	17.58	13.65
Willow leaves	18.044	17.119		
Common larch stem	18.927	17.952	16.98	14.86
Common larch needles	19.888	18.963		

Tab. 4: High and low heating value (MJ/kg) for the analyzed species

in external surface lignite mine tailing ponds in the Kolubara basin, in extensive plantations without prior technical re-cultivation and application of management measures, it is realistic to expect that the intensive plantations with the previously conducted technical re-cultivation, with the application of optimum agro-technical and agrochemical measures, with the spacing of plants 1.2 × 0.8 m in the short rotation of 6 years, would achieve total potential production of about 1,145,735 tone/year dry biomass on 6,000 hectares.

5. Conclusions

The study of potential uses of newly created landscapes and ecosystems after coal extraction by open-cast mining and after technical and biological recultivation by afforestation confirms the thesis on the feasibility of sustainable development (Dražić and Bojović, 2004).

The research has proven that it is possible to create multi-functional areas of anthropogenically formed aquatic and terrestrial forest – meadow and agricultural, multi purposed ecosystems rich in biodiversity and suitable, inter alia, for recreation and energy biomass production. Significant quantities of biomass can be produced in short rotation plantations on waste disposal sites with deposols (Drazic and Veselinovic, 2006). In this way, in the same space, sharing of production and human resources, integrated production and use of RES and NON-RES is possible.

The data presented above point to the significant, until now unused, woody biomass potential from the existing and future forest and non forest biomass resources, which could be used for energy purposes. Their share in the total energy potential could account for 25–40%, which could be exceptionally beneficial from the economic and ecological point of view, taking into account the fact that carbon dioxide (CO_2) emission in kg/kWh during burning of wood pellets is only 0.03 which is significantly less than coal (0.29) and other types of fuel.

Biomass is of outstanding importance for the Republic of Serbia since, apart from the fact that it represents environment-friendly fuel, which can make significant contribution to efforts aimed at CO_2 emission reduction, it is a renewable energy source, provided that the measures for sustainable forest management are applied. Its intensive use will contribute to decrease dependence on imported energy products and to ensure economic development in rural areas, which is of vital importance for every country.

According to the data from the Ministry for Mining and Energy, biomass could be the source of one fourth of the total energy produced in Serbia. If only one fourth of the above mentioned biomass (more than 2.8 million tons) were used for energy purposes, we would acquire energy that could satisfy all needs of low temperature energy stationed energy systems (heating, product finishing in processing plants, drying in smaller hothouses and others, even cooling machines), of the country's agricultural complex.

The adoption of the Regulation on measures supporting electric energy production from renewable energy sources and combined production of electric and thermal energy will significantly contribute to attract investments in this sector. For that reason, commercial banks, international financial institutions and state development funds are becoming involved in that issue by providing favourable credits.

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