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# BIOMASS PRODUCTION AS RENEWABLE ENERGY RESOURCE AT RECLAIMED SERBIAN LIGNITE OPEN-CAST MINES

by

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*The main goal of this paper is the overview of the scope and dynamics of biomass production as a renewable energy source for substitution of coal in the production of electrical energy in the Kolubara coal basin. In order to successfully realize this goal, it was necessary to develop a dynamic model of the process of coal production, overburden dumping and re-cultivation of dumping sites by biomass planting. The results obtained by simulation of the dynamic model of biomass production in Kolubara mine basin until year 2045 show that 6870 hectares of overburden waste dumps will be re-cultivated by biomass plantations. Biomass production modeling point out the significant benefits of biomass production by planting the willow Salix viminalis cultivated for energy purposes. Under these conditions, a 0.6% participation of biomass at the end of the period of intensive coal production, year 2037, is achieved. With the decrease of coal production to 15 million tons per year, this percentage steeply rises to 1.4% in 2045. This amount of equivalent tons of coal from biomass can be used for coal substitution in the production of electrical energy.*

Key words: *system dynamics, renewable resource, open-pit coal mines,*
*biomass production,*

## Introduction

The production of electrical energy in Serbia is highly dependent on coal, which participates up to 70% in annual production. In view of the global aspiration to reduce the emission of greenhouse gasses (GHG), this can represent a serious threat to sustainable development of the energy sector in Serbia.

As fuel for the production of electrical energy, coal is mined through open-pit exploitation, which results in the degradation of large land areas. On the other hand, after exploitation has ended, the re-cultivation of land is carried out, which represents a significant potential for the production of biomass. The close vicinity of consumers and adequate amounts of water for irrigation are especially favorable for the production of biomass. Due to the complex nature of the entire system, comprehensive reviews of this potential have not been done in the past. This,

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in turn, motivated the authors of this paper to analyze the possibilities of partial replacement of coal, as a fossil fuel, with biomass as a renewable source.

Open-pit exploitation of coal within large coal basins represents a very complex dynamic system. Open-pit coal mines cover large areas – several billion tons of coal and multiple times bigger amounts of overburden are being mined. Those activities cannot be carried out without the construction of the dynamic model of coal exploitation process, overburden dumping and re-cultivation of dumping sites. A simulation dynamic model has been constructed for the Kolubara coal basin, where 75% of total coal production within Electric Power Industry of Serbia (EPS) is carried out.

One of the first papers in the field of analysis of system dynamics in modeling energy is the model related to the exploration and production of natural gas [1]. Naill bases his model on the theory of life cycle of the process of exploration and production of petroleum and gas. In the next study [2, 3], Naill extended the borders of his natural gas model, in order to encompass all USA main energy sources (energy supply), as well as energy consumption (demand for energy in USA). He named his model COAL1, because his analysis revealed that the best fuel during the times of energy transition in USA is coal.

The improved and extended version of COAL1 model has been named FOSSIL1. US Department of Energy (DOE) has provided support for further improvement and extending of the FOSSIL1 model, in order to be used in planning the energy policy of the government. In 1989, DOE carried out a study of energy technology and policy, with the goal of reducing the emission of greenhouse gasses. The FOSSIL2 model has been used for this purpose. During the late 1970s, Sterman [4] worked on modifying and extending the FOSSIL1 model into FOSSIL2 model. Sterman constructed a dynamic model of energy system which included significant interaction between energy and economy. Sterman and  Richardson [5] and Pal *et al*. [ 6] have developed a petroleum exploration and production model which was similar to the model created by Naill, but with significant expansion and improvement.

In 1997, Fiddaman [7] developed a new dynamic model of climate-economic system under the name FREE (feedback-rich energy e  conomy model), which included a criticism of the existing non-dynamic economic models. The FREE model is the first energy economic model of any kind which explicitly examines the influence of limiting sources on the interaction between energy and economy. Rudianto [8] developed a model for the coal industry in the EU-15, under the name DCE (dynamic coal in Europe). By expanding the above-mentioned dynamic models of the system of fossil fuel resources [1, 2, 4, 5, 9, 10], the DCE model synthesizes the perspectives of several disciplines, including geology, technology, economy and the environment.

The main goal of this paper is the overview of the scope and dynamics of biomass production as a renewable energy source for substitution of coal in production of electrical energy. In order to successfully realize this goal, it was necessary to develop a dynamic model of the process of coal production, overburden dumping and re-cultivation of dumping sites by biomass planting.

## Mine plan of coal excavation in Kolubara coal basin

Open-pit exploitation of coal in Kolubara mine basin began in 1952, and so far $10^9$ tons of coal and $2.1 \cdot 10^9$ m$^3$ of overburden have been excavated. The remaining reserves of coal for exploitation amount to $2 \cdot 10^9$ tons of coal and $6.5 \cdot 10^9$ m$^3$ of overburden. The average annual production amounts to $30 \cdot 10^6$ tons of coal, which is for the most part (95%) used for the production of electrical energy. The area which is being exploited in Kolubara mine basin is around

16000 ha. At this moment, mining efforts (directly or indirectly) spread over 5730 ha. Figure 1 shows the map of Kolubara mine basin. Different colors, (1) to (7), are used for marking areas depending on what they are intended for, while tab. 1 shows the sizes of these areas.

**Table 1. Current relation of areas in MB Kolubara at the beginning of the year 2013**

|  | Waste benches [ha] | Coal benches [ha] | Dump site [ha] | Reclamed [ha] | Land acquisition [ha] | Total [ha] |
|---|---|---|---|---|---|---|
| Field A | 0 | 0 | 0 | 113 | 0 | 113 |
| Field B + C | 75 | 34 | 390 | 12 | 0 | 511 |
| Field D | 709 | 123 | 1217 | 658 | 96 | 2803 |
| Tamnava west | 159 | 135 | 702 | 0 | 998 | 1994 |
| Tamnava east | 0 | 0 | 1086 | 99 | 0 | 1185 |
| Veliki Crljeni | 111 | 105 | 0 | 0 | 0 | 216 |
| Field E + South field | 0 | 0 | 0 | 0 | 4165 | 4165 |
| Radljevo | 0 | 0 | 0 | 0 | 3075 | 3075 |
| Total | 1054 | 397 | 3395 | 882 | 8334 | 14062 |



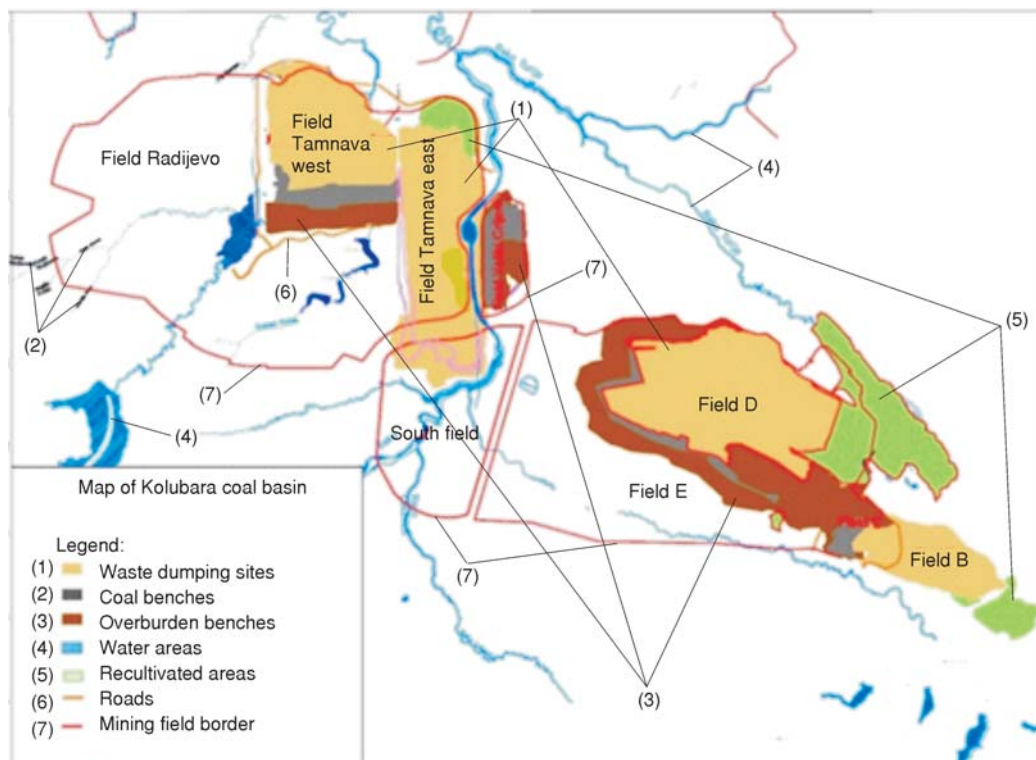**Figure 1. Ongoing mining works in Kolubara mine basin, with areas and intended use**
(for color image see journal web site)

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So far, one third of coal reserves and one fourth of total amount of overburden has been excavated in Kolubara mine basin, while re-cultivation has been carried out only on 882 ha out of the total of 3395 ha of overburden waste dumps. In order to reliably determine the time and scope of forming the final areas of dumping sites where re-cultivation can begin in this paper we had to plan for the mining activities in all open-pits in a longer period. For the planning of production in active open-pits, existing valid project documentation was used, while feasibility and pre-feasibility studies were used for planning the production in future open-pits.

A detailed and comprehensive overview was done for the next 30 years, which is a long and uncertain period. However, this was necessary since changes of exploitation conditions in this period are very intensive. The planned dynamics of coal and overburden production in the period 2013-2045 in Kolubara mine basin open-pits is shown in tab. 2, while the numerical values of re-cultivated areas favorable for the production of biomass are shown in tab. 3.

**Table 2. Planned production of coal and overburden in the period 2013-2045**

| Year | Field D | | Field B + C | | Field E | | Tamnava west field | | Field Radljevo | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Waste $10^6$ [m$^3$] | Coal $10^6$ [m$^3$] | Waste $10^6$ [m$^3$] | Coal $10^6$ [t] | Waste $10^6$ [m$^3$] | Coal $10^6$ [t] | Waste $10^6$ [m$^3$] | Coal $10^6$ [t] | Waste $10^6$ [m$^3$] | Coal $10^6$ [t] |
| Production period | 2013-18 | 2013-20 | 2013-20 | 2013-20 | 2021-45 | 2021-45 | 2013-39 | 2013-39 | 2014-45 | 2014-45 |
| Annual coal production | | 7 | | 5 | | 12/15 | | 12 | | 13 |
| Total production | 111.3 | 56.0 | 189.0 | 40.0 | 1139.5 | 318.0 | 765.3 | 321.1 | 1344.6 | 358.4 |

**Table 3. Available land for reclamation in the MB Kolubara in the year 2045 [ha]**

| | Plateau [ha] | Plane (Berm) [ha] | Bench slopes [ha] | Useful [ha] |
|---|---|---|---|---|
| Field D | 430 | 138 | 103 | 568 |
| East mine | 1890 | 473 | 178 | 2363 |
| Tamnava west | 937 | 474 | 216 | 1411 |
| Tanmava east | 1137 | 91 | 85 | 1228 |
| Veliki Crljeni | 268 | 0 | 0 | 268 |
| Raljevo | 1662 | 0 | 544 | 1662 |
| Total | 6324 | 1176 | 1126 | 7500 |

The results of the analysis reveal that the areas favorable for the production of biomass by the end of the year 2045 will amount to 7500 ha.

## Research method and system dynamics model structure

System dynamics, as a new methodology of modeling complex dynamic systems, was formulated in the mid-fifties and relates to the works of Forrester [11] from the Massachusetts Institute of Technology. System dynamics enables the formalization of the system dynamics model by means of computer simulation models, which can be used to simulate the behavior of

dynamic systems even when they are very complex. The construction of a computer simulation model of a dynamic system includes the following steps illustrated in fig. 2:
– problem identification – defining the point from which the system is observed, setting the borders of the system, defining the goals of model construction, *etc*.,
– system conceptualization – defining the elements and structure of the system, developing diagrams, setting dynamic hypotheses that explain the cause of the problem,
– model formalization – construction of a computer simulation model which reflects the essence of the problem,
– model simulation – testing alternative solutions of the problem,
– model validation – testing how much the model reflects the behavior of the real system, and
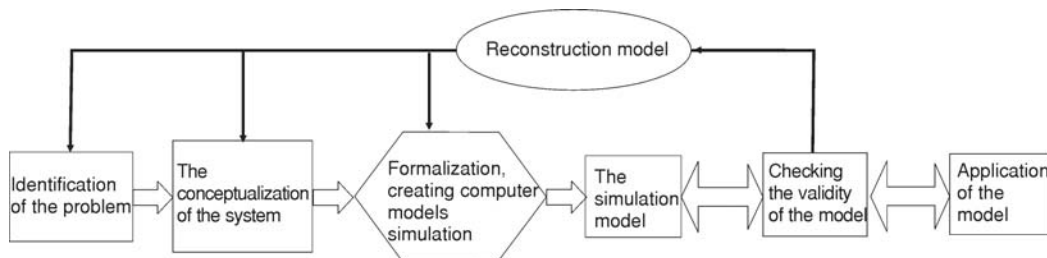– model application.



**Figure 2. Algorithm for constructing a simulation model of a dynamic system**

In the first phase of problem identification, the system is described and its borders are defined, paying special attention to proper identification of the time-varying values, as well as their causal effects.

In the second phase, system conceptualization, a structural model and flow diagram (fig. 3) are created. In this phase, it is im-



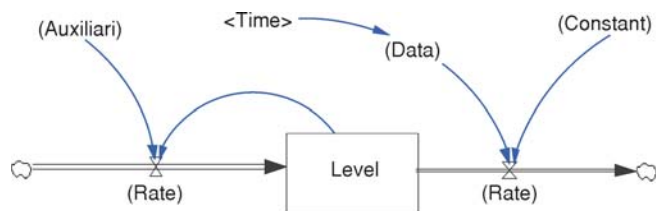**Figure 3. Flow chart for an elementary dynamic system, created using a program package for visual modeling – VENSIM**

portant to identify the most important material and information flows which lead to changes of the system state.

There are five basic types of functions in system dynamic, which are used in software packages for creating dynamic system simulation models.
(1) Level function – determines the dynamic behavior of the system and represents the accumulation (integration) in which all changes of the system state are accumulated (integrated).
(2) Rate function – represents the input/output rates of relative changes of the observed level.
(3) Auxiliary function – is used to define the auxiliary activities which, directly or indirectly, affect the level and rate functions.
(4) Constant function – define the constant values which are not time-varying.
(5) Data function – has values which are time-varying, but is not dependent on any other function in the model (except possibly on other data).

Figure 3 illustrates a flow chart of a simulation model of an elementary dynamic system which includes symbols for all of the most important types of functions. When creating a simulation model, after the flow chart has been constructed, it is necessary to define the mathematical relations between the interlinked system functions.

The dynamic model of biomass production (DMPB) was developed using the VENSIM (Ventana Systems, Harvard) [12-15] software package for visual modeling. In the first phase of model construction, individual, dynamic models of coal production, overburden dumping and re-cultivation of dumping sites were developed for each open-pit. In the next step, all these models were combined into one integrated model. The integrated model was used to model the production of biomass in re-cultivated dumping sites and its comparison with the overall production of coal.

Figure 4 shows the diagram of a dynamic model of coal production, overburden dumping and re-cultivation in one of the open-pits, "Field E".
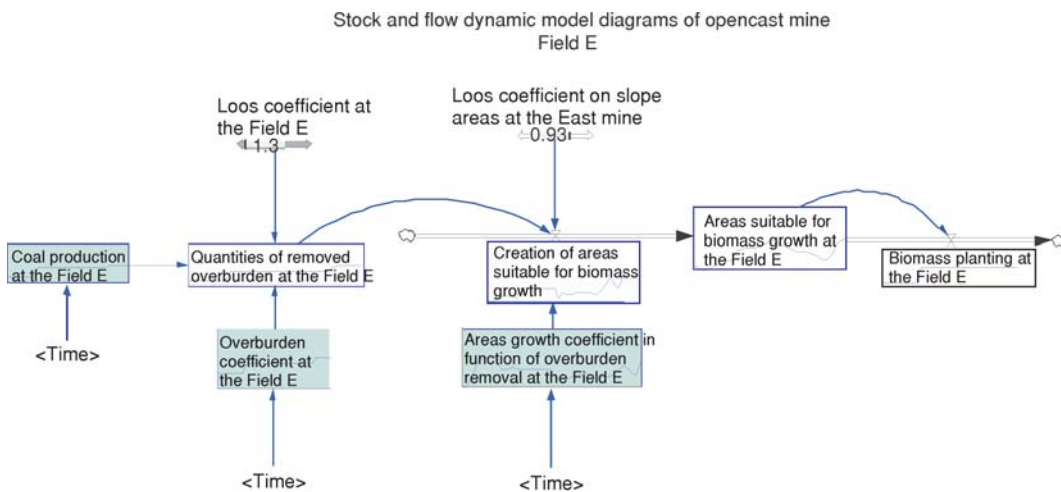


**Figure 4. Diagram of the dynamic model of the open-pit "Field E"**

The time-varying variables, shown on the diagram in turquoise fields, were model as Lookup tables (functions) on the basis of data extracted from project documentation on open-pit "Field E". The variable "production of coal in Field E" can vary depending on the needs for coal, but this does not apply to the other two functions, "stripping ratio" and "ratio of area increment", because they are defined as the consequence of changeable geological conditions in the mine and the planned technology in the open-pit. The input values "ratio of looseness" and "ratio of area loss due to increased slope" are defined and constants. The variable "area favorable for cultivation of biomass" has been modeled as dynamic level variable (Level), and the variables "creating areas favorable for cultivation of biomass" and "biomass planting" were model as rate variables, since they directly influence the increase and decrease of the level variable "area favorable for cultivation of biomass". The model timeframe is the period 2013-2045, and the time step is one year. The diagram in fig. 4 shows curves on modeled variables, which are the result of dynamic model simulation. The diagrams of models for the remaining open-pits have not been shown due to limited space in this paper.

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Individual models for all four open-pits where coal exploitation and preparation of area for biomass planting will be carried out have been integrated into one model. The integrated model integrated the production of coal and the production of biomass in all four open-pits. Figure 5 shows the diagram of this model (DMPB). The production of coal and planting of biomass for each open-pit were taken from their individual models and integrated into variables "planting of biomass in Kolubara mine basin" and "production of coal in Kolubara mine basin". The variable "planting of biomass in Kolubara mine basin" directly influences the increase of the value of the Level variable, "total planting of biomass in Kolubara mine basin". By multiplying this variable with the two constants, "calculated production of biomass into coal" is obtained. The production of biomass calculated in this manner can be compared with the planned production of coal, and the positive effects of partial compensation of coal with biomass in the existing thermal power stations can be analyzed.
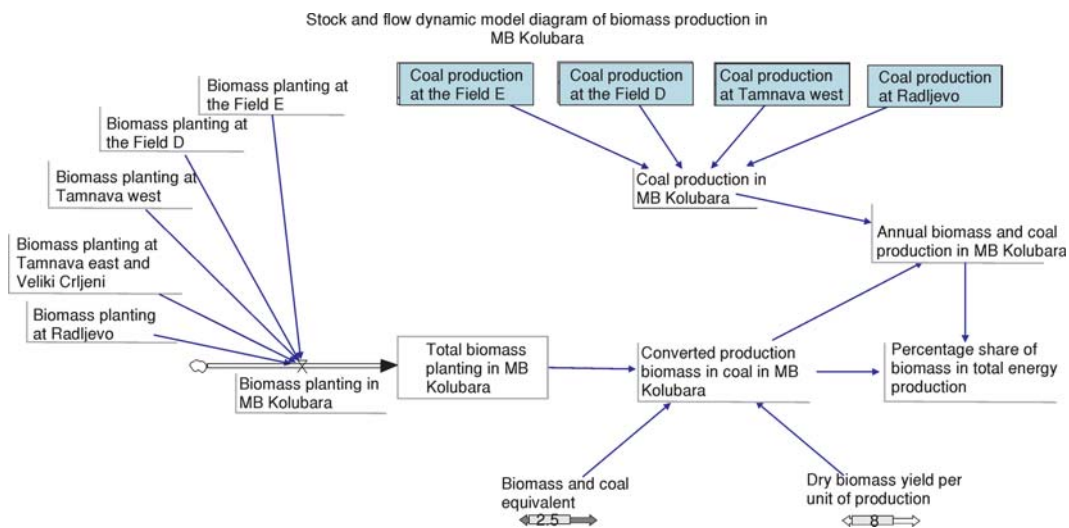


**Figure 5. Diagram of the integrated model of biomass and coal production in Kolubara mine basin**

## Analysis of the simulation results

The developed dynamic model offers the possibility of running an unlimited number of simulations by changing some of the input parameters. Running a large number of simulations offers the possibility to optimize the process. This paper is focused on the production of biomass, and consequently the rest of the paper analyzes the production of biomass with the planting of the chosen plant species.

The significant increase in the $CO_2$ content in the atmosphere, which occurs mainly as a result of combustion of fossil fuels such as coal and oil, significantly contributes to the effect of global warming. For this reason, it is necessary to describe and examine possible alternative energy sources that would significantly reduce $CO_2$ emissions. Plant biomass provides a cleaner products of combustion of gases compared to fossil fuels. Growing cycle of plants spent $CO_2$ in process of photosynthesis, so the power production from this biofuel is almost $CO_2$-clean. It is thus expected that biomass becomes one of the key energy resources combat global warming and depletion of reserves fossil fuels. Annual production per hectare is equivalent to the value of 400 GJ for C4 crops, 250 GJ for grains, and 70 GJ for oilseeds [16].

Perennial C4-grasses such as switchgrass (*Panicum virgatum*), miscanthus (*Miscanthus giganteus*), prairie cordgrass (*Spartina pectinata*), and others are being developed as sources for bioenergy due to many positive features [17]. All of these plants have characteristics that put them into the possible candidates for biomass production and remediation of soil. C4 perennial crops are suitable bioenergy crops because of efficient use of available resources, retaining carbon in soil, have a high degree of efficiency of water use, not an invasive species, and have little requirements for nutrients. Above ground tissues of these grasses became death at the onset of winter, in the temperate regions of the world such as Serbia, while crowns and rhizomes will stay dormant until spring [18]. Reserve stored in underground organs drive growth in the spring. The most studied grass in North America, switchgrass, can become productive in the first year of establishment and reach full capacity in second year of growth with addition of nitrogen. On that way, it is possible to maintain biomass yields for over 5 years [19]. The number of times, biomass grasses can be harvested, will be dependent on the genotype and environmental interactions. Under optimal conditions, the first harvest generally has the highest biomass yields [20]. So, numbers of yields are a major driver for biomass production and its quality. But, many studies support that a single harvest as an optimal for maintaining plant persistence in the field in a temperate climate because a certain minimal amount of C and N are needed for maintaining into the soil. For biomass grasses, even a small loss in yields can have a very big negative economic impact [21].

Phytomenagement aims at using non-food crops to increase environmental and health risks induced by pollutants, and at restoring ecosystem. Suitable plant species must be tolerant to contaminants, reduce their transfer into the food chain, and efficiently produce marketable biomass. Total harvest yields in the second year of the establishment can reach values of 6-10 t/ha, in the third year up to 12-17 t/ha or more. Crop yields reached a maximum after 3-5 years with total amounts of 20 t/ha per year [16]. Miscanthus (*Miscanthus sacchariflorus*) has gained attention as a potential bio-energy crop. It has very high growth rate as well as low nutrition requirements [22].This grass belongs to genus of the C4 perennial grasses. Because of that, it has advantages such as high biomass yield potential, high energy density, low water content, low establishment costs, and low soil erosion [23]. These features are, compared with other sources of biomass, far ahead. The harvested miscanthus can be used as crude fuel for heating or for electric power. This grass is very suitable for recultivation of soil in the ash dumps and soils affected by erosion [24]. Results of the mentioned researches suggested that the domestication and production of *M. lutarioriparius* in China hold a great potential for carbon sequestration and soil restoration in this heavily eroded region. Miscanthus has capacity to sequestrate inorganic contaminants into the root system and to induce dissipation of persistent organic contaminants in soil and for that, these plant species are favorable for phytostabilization and phytodegradation [25]. Some energy grasses (*Arundo donax* and *Miscanthus sacchariflorus*) had strong tolerance and high accumulating ability for Zn/Cr, and therefore, they are promising candidates for the phytoremediation of Zn-/Cr-contaminated soil [26]. Those authors stated that the Zn/Cr concentration in the grass roots was two to seven times of that in the shoots, while both of them were positively correlated with the Zn/Cr concentration in soil. Miscanthus advantage compared with other raw materials for the production of biofuels, such as agricultural residues (corn trees and wheat straw), is that miscanthus can be cultivated in polluted areas, or arable land of low quality, inadequate for other crops. Grass remediation is very convenient because physical and chemical remediation technologies are usually expensive, applicable for a small area, and sometimes could produce secondary pollution [27]. Energy plants/grasses could be promising candidates for remediation and hyperac-

cumulation of heavy metals because they usually have large biomass, strong stress resistance and people do not use it for food but directly burned or converted into bioenergy [28].

Among miscanthus species, the non-invasive hybrid miscanthus × giganteus, with a high lignocellulosic content, is a promising biomass crop for the bio-economy, biorefinery, and bioenergy industries. Planting this species on contaminated and marginal land is a promising option to avoid changes in arable land.

Of particular interest for economy is the use of adapted populations. For switchgrass, the tetraploid southern adapted populations have considerably greater yield potential than the population of northern origin [29]. But, most these plants can suffer from winter-kill, and in the future it would be convenient to improve winter-survival along with increased biomass yields. Miscanthus giganteum from our laboratory has a low rate of survival during the winter (unpublished observations) and future researches works would be very significant for improving yields of this valuable economic grass.

Biochemical and physiological properties could be improved also with in vitro techniques (tissue culture). That considers repeated selection for increasing dry matter forage, because lower lignin content leads to decrease in winter survival [30]. In vitro approaches can give us informations about molecular and cellular changes that have occurred in the rizomes and above ground parts of plants. These studies will be applicable to related grasses which have utilization in biomass production.

One of the most popular methods for conversion miscanthus to fuel or chemicals is pyrolysis, which requires 350-550 ºC in the absence of oxygen [31]. The main product of pyrolysis process is bio-oil which could substitute fossil fuel. Those authors stained that miscanthus was composed of 72.1% holocellulose (cellulose and hemicellulose) and 24.9% lignin. This grass has a relatively higher lignin content compared to the most common lignocellulosic biomass, yellow poplar wood [32]. The relative amounts of these components are important factor in determining the chemical properties of bio-oil. Miscanthus has relatively high inorganic compounds content compare to other biomass. So, this grass can be converted to bio-fuel at relative low temperature of 350 ºC [31].

On the basis of past experience in re-cultivation of tailings dumping sites by planting trees [33], the hybrid willow *Salix viminalis* cultivated for energy purposes was chosen. This type of willow, selected in Sweden [34], is characterized by high plasticity and adaptability to various climate and soil conditions. It gives a constant yield during 25-30 years. Willow bioenergy production system has been in progress for more than 25 years in Sweden [34] and 15 years in North America [35]. Beginning from the second or third year, the annual yield is no less than 30-40 tons of biomass in the form of large splinters, twigs. Current recommendation for willow planting include effective weed competition control and planting trees in density of 10000 to 20000 cuttlings per ha [36]. Those authors stated that biomass production of willow was the highest during the warmest growing season and lowest during the coolest season. So, annual temperature is very important factor which could limited growth significantly. If advanced technology is implemented and adequate agro-technical measures are undertaken, the yield of 8-15 tone of dry weight per ha per year of biomass can be achieved [16].

The establishment of short rotation energy plantation of woody plants in Serbia has not gained importance. With increasing interest in this field and with development of so called "energy plantations" it would be possible to find the most suitable tree species and cultivation conditions in plantations with a large number of plants per unit area [37]. According to results of mentioned authors, management of "Kolubara" mining basin in Serbia decided to form black locust plantation an area of 5.67 ha in autumn 2008. Survival percentage of this tree was 95.67%

which was bigger survival rate than in three mines in Germany where similar researches have done. Black locust wood with a higher density, calorific value and ash content compared to poplar and willow wood proved to be a more suitable plant for biomass production [38]. Mentioned authors proved that black locust wood density were 602 kg/m$^3$, which was more than 1.5 times higher than willow wood density (336 kg/m$^3$). In contrast to results about wood density, the highest average values of growth rings were recorded for all examined poplar clones, while all black locust clones had the slowest growth. Those three studied wood species belong to the group of fast growing woody species and it is necessary to determine the yield of biomass per hectare and to estimate the quantity of energy that may be produced (potential quantity of energy for black locust ranging from 20.396 MJ/kg to 21.956 MJ/kg and this values are higher than for willow and poplar). The standards for biomass production must be established on the same soil types, under similar technological conditions, duration of the rotation cycle, the number of cycles, the way of stand regeneration after felling, supplementary nutrition and protection regimes, *etc*.
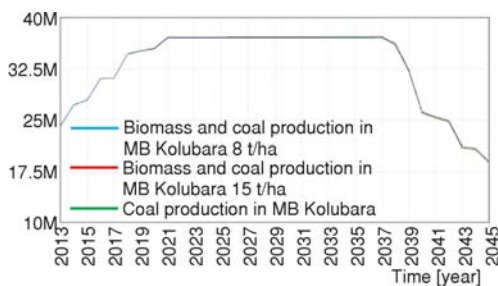


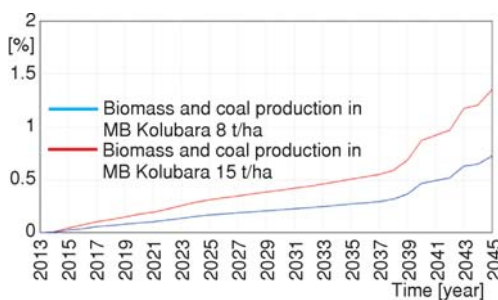**Figure 6. Production of coal and biomass in Kolubara mine basin with various biomass yield**



**Figure 7. Percentage share of biomass production in total production of energy sources for thermal power plants**

Using these characteristics, a series of simulations of the "dynamic model of biomass production" (DMPB) have been carried out, with the input variable "yield of biomass by unit of area" being changed, taking the values up to: 8 t/ha and 15 t/ha. The graph on Figure 6 shows the output results of these variations.

The calorific value of dry biomass was accepted as 18750 kJ/kg [39], which was 2.5 more than the average calorific value of Kolubara coal (7500 kJ/kg) [39]. This ratio was shown in the model as "ratio of re-calculating biomass into coal".

At the end of year 2045, the achieved production of biomass using the yield of 8 t/ha will amount to 0.14 Mt and using the yield of 15 t/ha will amount to 0.26 Mt.

Figure 7 shows the percentage share of produced biomass from tailings dumping sites in the total production of energy sources for the work of thermal power plants, and it varies from 0.7% using the yield of 8 t/ha to 1.4% using the yield of 15 t/ha.

The full implementation of all agro-technical measures, including irrigation, can be considered justified, because it results in doubling the yield of biomass. With the application of all agro-technical measures, the production of biomass would be 62000, 150000, and 260000 tons of coal equivalents during the 2020, 2030, and 2045 year, respectively.

Having in mind that Serbia is highly dependent on the production of electrical energy from coal, the contribution to the decrease in the emission of $CO_2$ is far more important than the relatively small percentage participation of biomass production in the total production. The

study [40] precisely defines the emission factor for Kolubara mine basin coal – for the average value DTE = 7.784 MJ/kg it amounts to:

$$CEF = 34.407 - 0.5891 \ DTE = 29.821 \ t \ C/TJ$$

where CEF [t C/TJ] is the coal emission factor and DTE [MJkg$^{-1}$] – the lowest coal heat effect.

By burning one million tons of coal mined from Kolubara mine basin, the following emission of $CO_2$ is produced:

$$Q_{CO_2} = Q_{coal}DTE_{coal}CEF \ K_{O_2} \ K_{CO_2/C} = 851,130,000 \ t$$

where $Q_{CO_2}$ is the mass of emitted $CO_2$ [t], $Q_{coal}$ – the mass of coal burned [t], $K_{O_2}$ – the oxidation factor (0.98), $K_{CO_2/C}$ – conversion factor (44/12; $t_{CO_2}/t_C$).

The EU has defined the strategy of $CO_2$ emission decrease by 2030 to 40% compared to year 1990. It is justifiable to expect that such an ambitious goal cannot be reached without dictating high prices for GHG emission, thus it is not expected that the price of one ton of $CO_2$ will drop below 30 EUR after 2020. Taking all the above into consideration, the following conclusion has been reached.

– The production of biomass in 2020 will amount to $0.062 \cdot 10^6 \ t_{ekv.coal.}$, and the value of $CO_2$ emission decrease will amount to $1.8 \cdot 10^6 \ €$.

– The production of biomass in 2030 will amount to $0.15 \cdot 10^6 \ t_{ekv.coal.}$, and the value of $CO_2$ emission decrease will amount to $4.5 \cdot 10^6 \ €$.

– The production of biomass in 2040 will amount to $0.26 \cdot 10^6 \ t_{ekv.coal.}$, and the value of $CO_2$ emission decrease will amount to $7.8 \cdot 10^6 \ €$.

## Conclusions

The results obtained by simulation of the dynamic model of biomass production in Kolubara mine basin until year 2045 show that 6870 ha of tailings dumping sites will be re-cultivated by biomass plantations. This area will increase by the end of exploitation period by 11.6%, that is, to 7770 hectares. The reason for such a small increase of re-cultivation areas in a relatively long time period is the fact that the open-pit mine is very deep, and that the quantity of overburden for filling the dug-up space is insufficient. Thus, the final phase of mining works will be re-cultivated by forming a lake of large size and volume. The time-frame for which the dynamic model of biomass production was developed can be considered valid for future analyses, since it covers the most important period of planting and production of biomass.

The results obtained by biomass production modeling point out the significant benefits of biomass production by planting the willow *Salix viminalis* cultivated for energy purposes, with the use of modern agro-technical measures. Under these conditions, a 0.6% participation of biomass at the end of the period of intensive coal production, year 2037, is achieved. With the decrease of coal production to 15 million tons per year, this percentage steeply rises to 1.4% in 2045.

Special benefits from initiating biomass production with GHG emission decrease, will be a constant topic when Serbia becomes a member of EU. The project of biomass production in Kolubara mine basin will most certainly be a leader for the development of biomass production, as an important and desirable energy source in the open-pit mines and thermal power plants environments on areas which are not suitable for agricultural production.

Those results can be used to determine the working time of existing and plan the construction of new thermal power plants, since it is obvious that, in the period after 2045, it will be necessary to plan the work of thermal power plants using the most modern ecological and tech-

nological solutions. That potential power plant would have only 16 million equivalent tons of coal-out of which at least 260000 t (1.4%) will come from biomass produced on re-cultivated overburden waste dumps.

This amount of equivalent tons of coal from biomass will represent a permanent renewable energy source of Serbia, which can be used for coal substitution in the production of electrical energy.

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