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Towards just transition of coal regions - Cultivation of short rotation copies and dedicated energy crops for biomass co-firing vs photo voltaic power plants

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ABSTRACT

In developing countries, which dominantly produce electricity by burning coal, energy transition represents a significant challenge. Short rotation coppice and dedicated energy crops could be a promising raw material for production of biofuel and its further usage for electricity and heat generation. This work assesses possibilities and elaborates on the sustainability of cultivation of short rotation coppice type willow and dedicated energy crop Miscanthus on former areas of coalmines belonging to the largest power utility in Bosnia and Herzegovina, namely JP Elektroprivreda BiH d.d. – Sarajevo. Abandoned coal mine areas were mapped and, by settled criteria, dedicated either to future photovoltaic power plants integration or the cultivation of energy crops and their further use in the considered generation portfolio mix. In order to assess the contribution of both photovoltaic power plants and biomass in the upcoming energy transition process, an adequate method has been developed in this article and specific sustainability indicator groups determined to further calculate the sustainability ratio. The paper focuses on economic, environmental and social indicator groups, which were used to perform the aggregated economic analysis and the multi criteria analysis. Performed aggregated economic analysis lightly favours the construction of photovoltaic power plants over the use of willow as fuel. In this analysis, Mischantus is lagging far behind due to its lower yield compared to willow. The multi criteria analysis on the other hand, valorises the social indicator adequately and the sustainability ratio results are much closer for both considered renewable sources types. This shows the importance of a comprehensive approach and definition of appropriate methods to enable decision-makers to draw appropriate conclusions.

Introduction

Combatting the greenhouse effect caused by humans and associated global warming is one of the most important task in preserving the lives of future generations. That's why the EU Commision proposed, as part of the European Green Deal [1], the 2030 climate and energy framework which includes EU-wide targets and policy objectives for the period from 2021 to 2030. The key targets for 2030 are at least 40 % cuts in greenhouse gas emissions (compared to 1990 levels), at least 32 % share for renewable energy and at least 32.5 % improvement in energy efficiency. To realise the climate target set in the Paris Agreement, a profound transformation of the global energy landscape is essential. Such a transformation is possible with the rapid replacement of conventional fossil fuel like coal with low-carbon and renewable energy sources. The degree to which coal regions manage this transformation and shape their future will depend on having the institutional support, technical capacities, and funding necessary to protect people and the environment.

Currently, 41 regions in 12 EU Member States are actively mining coal, providing jobs to about 240,000 people: about 185,000 in the mining of coal and lignite and about 53,000 in coal and lignite fired power plants [2]. Most of these people have limited opportunities to find alternative employment due to a lack of skills or a lack of alternative jobs in their regions. The same is true in Bosnia and Herzegovina (BiH), as it can be considered a coal region. It is necessary to make sure that the transition process devoted to the miners is just [3]. In 2006 BiH became a contracting party in the Energy Community. The Energy Community Ministerial Council adopted the Recommendation 2018/01/EnC-MC in November 2018. The Recommendation urges the Contracting Parties to "prepare the analytical, institutional and regulatory preconditions for the development and adoption of integrated national energy and climate plans for the period from 2021 to 2030". National Energy and Climate

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Nomenclature

AEA	Aggregated Economic Analysis
ASPID	Analysis and Synthesis of Index at Information Deficiency
BC	yearly balancing power costs
BiH	Bosnia and Herzegovina
CAPEX	Capital expenditures
E	yearly energy produced
EcIn	economic indicator groups
EnC-MC	Energy Community Ministerial Council
EnIn	environmental indicator groups
EPBiH	JP Elektroprivreda BiH d.d. Sarajevo
EU	European Union
EU ETS	European Union Emissions Trading System
GHG	Greenhouse gas
MCA	Multi Criteria Analysis
NECP	National Energy and Climate Plans
N_{kept}	number of people necessary to maintain the newly implemented solutions
N_{tot}	total number of employees
OECD	Organisation for Economic Co-operation and Development
OPEX	operating expenditure
PPCA	Powering Past Coal Alliance
PR	yearly profit gained from electricity generation
$PRCO_2$	profit gained from selling the certificates on the market
PVPP	Photo-voltaic Power Plant
RES	Renewable Energy Source
RET	cost of the worker retraining
RMU	Brown Coal Mine
RU	Coal Mine
ScIn	social indicator groups
SR	Sustainability Rating
SR_{AEA}	Sustainability Rating for the aggregated economic analysis
SRC	Short Rotation Coppice
SR_{MCA}	Sustainability Rating for the Multi Criteria Analysis
UK	United Kingdom
$WAGE_{mon}$	gross monthly wage
wf_{ec}	weighting factor for the economic indicator group
wf_{en}	weighting factor for the enviromental indicator group
wf_{sc}	weighting factor for the social indicator group

Plan for B&H is currently a work in progress. It is expected that the proposed reduction of CO_2 emissions from coal power plants operated by national power utility JP Elektroprivreda BiH d.d. – Sarajevo (EPBiH) will be set to around 15–30 % in 2030 (in reference to the base year of 2014) and that the cap on greenhouse gas emissions will be decreasing up to 1.5–3 % every year [4].

In order to gradually shift from coal towards a carbon–neutral energy production, EPBiH is planning to phase-out production from coal power plants. It is necessary to find a transition solution that will be just, both in the social and economic context, along benefits to the environmental and climate saving aspects. Having this in mind, together with the fact that seven coalmines with a large number of employees are part of EPBiH concern, a suitable development plan is very challenging to define.

State of the art

EU policies have long supported restructuring in coal regions and energy-related training, research, inovation and infrastructure. More recently, the themes of energy transition and decarbonisation have become prominent through the EU's Horizon 2020 programme. European Policies Research Centre is cooperating with 14 partners in the Horizon 2020-funded TRACER project [5], which aims to support nine coal-intensive regions to agree Smart Specialisation Strategies and to facilitate transition towards sustainable energy systems. TRACER aims to mobilise a wide range of stakeholders (from business, research/education, government/policy, and civil society) to come together in order to discuss and agree on a shared strategic vision and priorities for energy reasearch and development in coal transition regions, and to move forwards with accessing investment and implementing these strategies and priorities. Its goal is to analyse best practice examples of transition processes in coal intensive regions. Furthermore, the Initiative for transition of coal regions in the Western Balkans and Ukraine was launched in December 2020 and aims to help countries and regions to move away from coal towards a carbon–neutral economy.

To meet the Paris Agreement, the coal phase-out is needed by no later than 2030 in the OECD and EU, and by no later than 2050 in the rest of the world [6]. The EU would have to cut its coal consumption to almost zero by 2030 to fulfil its already agreed upon climate protection commitments [7]. Several western European nations have formally announced a deadline to end all coal burning. In 2017, the UK and Canada launched the 'Powering Past Coal Alliance' (PPCA) [8], a coalition of governments, organisations and businesses seeking to establish a phase-out of coal for electricity generation by 2050 at the latest. The UK was the first large user to set a drawdown [9], scheduling the last fires to go out by 2025. This was propelled even faster by an increased carbon tax [10]. France, a small coal burner, will phase it out altogether by 2022. The Netherlands and Italy have also proposed plans to close their coal-fired power plants by 2030 and 2025, respectively. Netherlands adopted a law prohibiting the use of coal for the production of electricity as of 1 January 2030 at the latest [11]. Germany, the EU's largest economy and a perceived champion of clean energy through its Energiewende program [12], remains Europe's largest coal burner. The question of a "coal exit" is being hotly debated by the country's new coalition government, and most experts don't expect a phase-out to fully take place until 2030 at the earliest [13]. Just the same, recent figures show that hard coal-fired generation in Germany fell by 53.2 % in the year ending in 2018, while lignite coal generation dropped by 6.6 %. Canada in November 2016 announced regulations to phase out coal generation by 2030. Coal made up a paltry 7 % of its total power capacity in 2014 [14].

While in Germany all major parties have accepted the necessity to phase out coal and differ only in how fast and at what cost this should be done, the main Polish political parties [15] agree on the necessity to keep the coal industry alive and differ only in how explicitly they support the industry and how fiercely they oppose EU climate policies. In the Czech Republic [16], all major parties either have an unclear stance on coal, or are split across the industry–environment internal cleavage.

Coal extraction from surface and underground mines changes the natural landscape. The impacts derived from the mining activity must be corrected in the final phase of restoration, returning the landscape to an aspect similar to the original one, prior to the mining exploitation [2]. Mine site reconversion to renewable energy generation can provide economic value and contribute to energy security after the closure of a mine. Many renewable energy projects are already in place or have been proposed at coal mining sites. Former mine sites with favourable sun exposure can make good locations for solar power generation. Mine sites often cover extensive areas with flat landforms reshaped by the mining activity, and also include artificial slopes and ridges at higher elevation formed by the accumulation of tailings and other mine waste. The development of such projects benefits from the existence of infrastructures in place which would avoid additional capital costs [17].

One of the proposed green energy options for coalmine region is the coal-to-biomass conversion. That conversion will be depended on

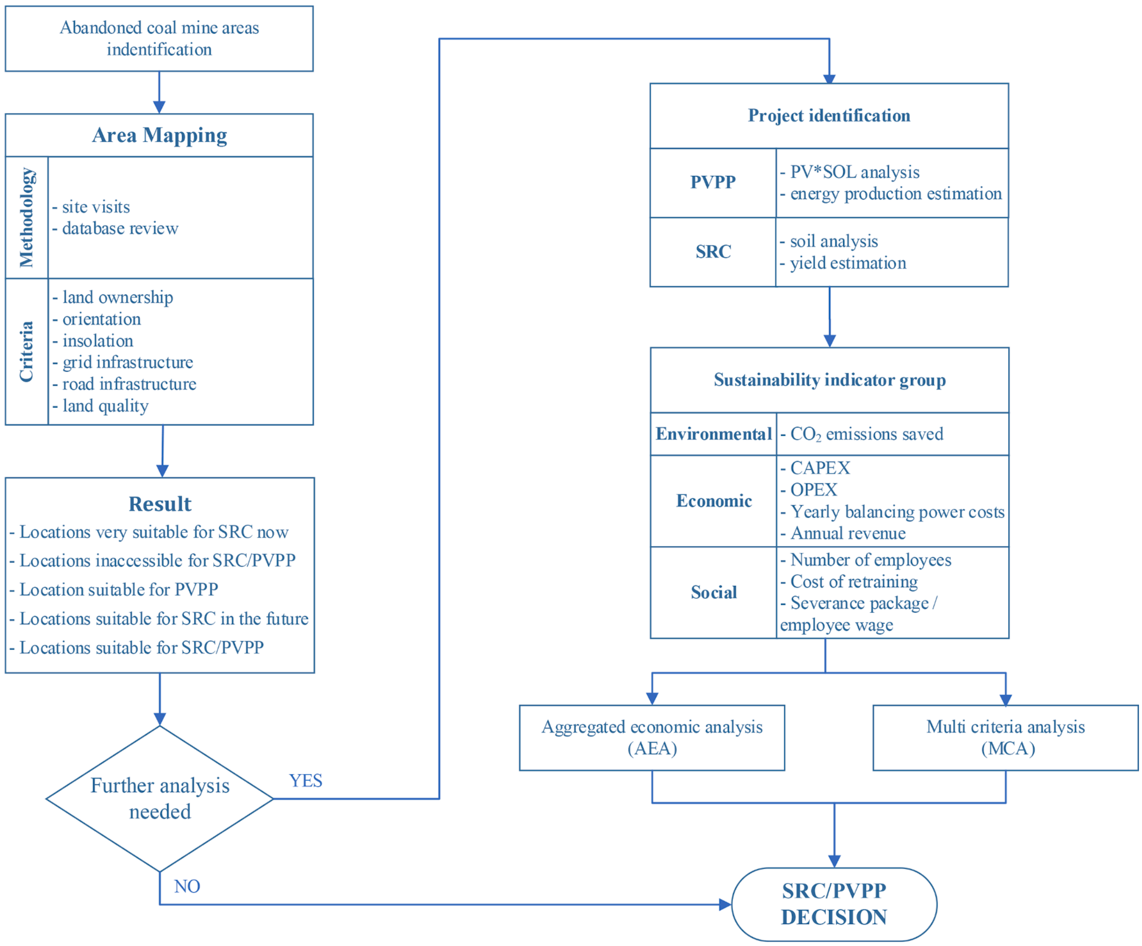

Fig. 1. Flow chart of the method applied.

proven sustainable, secure and long-term efficient feedstock supply. One of the solutions is to use the abandoned mine sites for biomass planting. The soils generated in the restoration present extreme conditions (e.g., nutrient poor and polluted soils) for their use for the production of forest biomass, so it is essential to search for species that adapt to the conditions of the environment. Biomass materials are often described as "carbon-neutral," because they release the same amount of carbon when burned as they remove from the atmosphere while growing. In theory, the CO_2 released during the combustion of biomass materials will be recaptured by the growth of these same materials, creating what is described as a "closed-carbon cycle" [18]. Biomass sources have a great potential as renewable feedstock to be converted into useful forms of energy with a wide range of conversion technology and process options with different scales. Type and quantity of biomass feedstock used is therefore important. Some of the energy crops that are specifically produced to create feedstock for energy generation include switchgrass, poplar and willow [19].

Willow is a type of short rotation copies (SRC) cultivated with the aim to produce high biomass yields in a short period that can be used for energy purposes. "Coppice" is characterized by the ability of the selected tree species to re-grow with new sprouts after the plant is cut down (poplar and willow). SRC presents an alternative to annual energy crops because it is a low-input agricultural practice that generally implies low GHG emissions due to limited applications of chemicals. The use of pesticides is negligible and the need for fertilizers is small compared to conventional agricultural crops: fertilization of trees is not common practice, and the crops are perennial and grown for several years before harvest. Harvesting cycle is every 1 to 4 years and the estimated productive life is around 20 years [20]. It grows to 3.5–5 (m) in height [21].

Miscanthus is a woody rhizomatous C4 grass species which originated in Southeast Asia and was initially imported to Europe as an ornamental plant. Plants with C4 photosynthesis have the potential to out-yield plants with C3 photosynthesis because of higher radiation, water and nitrogen-use efficiencies, but they require warmer conditions than C3 plants to initiate growth in spring time. It is a perennial plant with an estimated productive life of around 20 years. It grows to 3–4 (m) in height and the stems and leaves can be harvested annually but maximum yield is achieved after 3 to 6 years. It is a dedicated energy crop that. Controlling weeds in new plantings of giant Miscanthus is necessary to develop a quality establishment [22].

Otherwise, abandoned coal mine areas can be reclaimed in a variety of ways and, along for green energy purpose, used for many other different useful human and economic activities such as tourism, recreation, industry etc. In this paper, however, it is reasonably assumed that the establishment of green energy options on abandoned coalmine areas and thus keeping the core business of a power utility which owns and operates the coal mines and thermal power plants (TPPs) in the coal region, is of high priority in order to secure energy supply while exiting from coal. The previous research works have been mostly focused on one predetermined renewable energy source alternative for an active coal region. In the context of energy transition, this means either installation of power units based on variable RES such as solar or wind or the land usage for planting of biomass (SRC, energy crops) and its further use as energy source instead of coal. Unlike in previous research, in this paper, as a novelty, different RES based alternatives to the coal (in this case biomass and solar) were considered simultaneously, on the same abandoned coal mine plot. The model was developed to evaluate energy yield and sustainability of the options under consideration by using variety of economic, environmental and social parameters. A broad spectrum of sustainability indicators was considered to strengthen the evaluation of specific sustainability criteria, i.e. specific indicator groups (economic, environmental and social). Chosen RES technologies that were mutually compared within this paper are quite different (variable vs base load operation, labor requirements, etc.). In order to fairly and equally evaluate their outcome, the analysis was expanded using untypical single indicators such as yearly balancing power costs, cost of employee retraining and severance packages / employee wages. In addition, the proposed model includes an assessment using both aggregated economic analysis (AEA) and multi criteria analysis (MCA). This approach fulfils the gap in sense of lack on decision making works, articles and methods, for RES selection options to be implemented on former coalmine area, maintaining the core business on energy generation.

Such a comprehensive approach contributes to the scientifically grounded selection of appropriate RES option for the specific abandoned coal mine plot, in this specific case SRC and energy crops versus PVPP. It has been shown that such an approach leads to making a more informed decision.

Method

Just transition processes of coal regions may offer different options of human and economic activities restored from closing of coal mines and decommissioning coal-based power stations in a coal region. In order to keep security of energy supply, green energy options might be prioritized and other transition options get narrower but still kept valuable, taking into account that quite large former coalmine land is usually available. The paper put focus on using the solar energy for driving photovoltaic power plants as one RES option. The global weighted-average levelized cost of electricity (LCOE) of utility-scale photovoltaic (PV) plants declined by 85 % between 2010 and 2020. By the end of 2020, over 707 GW of solar PV systems had been installed, worldwide. This represented>16-fold growth for the technology since 2010 [23]. There are a lot of approaches when it comes to planning the locations of potential power plants [24]. As the other RES option, SRC and energy crops planting is assumed for biomass growth, to run biomass cofiring instead of coal. To assess the contribution of both PVPPs and biomass, an adequate method has been developed and specific sustainability indicator groups determined to further calculate the sustainability ratio.

Method description

Fig. 1shows the flow chart of the method applied, and the obtained results presented in Chapter 3 demonstrate the importance of a comprehensive approach to enable decision-makers to draw appropriate conclusions.

As starting point, abandoned former coalmine locations need to be mapped (step Area Mapping, Fig. 1) in order to identify available area convenient for repurposing and implementing RES options. In general, not all such locations can be used for the purpose since some other important factors, such as the existing infrastructure, or the power grid capacity at the locations, also play a role and should be taken into consideration. Furthermore, different technical criteria like land ownership, land quality, orientation or insulation, define the choice for further activities.

Based on aforementioned criteria, the land is preliminary categorized for further use and eventual further implementation of the two considered RES technologies (step Results, Fig. 1). By further assessments, as well as using some professional software tools or soil sampling, specific projects can be identified with their expected energy generation yield (step Project identification, Fig. 1). But, in order to make the better RES repurposing option choice, a specific sustainability assessment has been developed and implemented within this research article. Specific sustainability indicator groups have been recognized and adequately addressed (step Sustainability indicator groups, Fig. 1).

Table 1
Specific sustainability indicator groups.

Indicator group	Single indicators	Unit
Environmental	CO_2 emissions saved	AEA - €/MWh MCA - t/MWh
Economic	CAPEX OPEX Yearly balancing power costs Annual revenue	AEA and MCA - €/MWh
Social	Number of employees Cost of retraining Severance package/employees wage	AEA - €/MWh MCA – number of employees

For the main technical parameter, the average annual electricity generation in both RES options has been considered. To perform an economic analysis, many economic parameters such as CAPEX or OPEX need to be taken into consideration. Additionally, since PVPPs like all variable RES require a specific approach when it comes to the balancing of the power system, economic analysis included the balancing cost. On the other hand, having in mind the nature of biomass usage, this service is not required for operating facilities burning biomass. Impact on the environment was analysed by reduction of the emissions of CO_2. Furthermore, coal mines employ a large number of people and it is necessary to valorise the social impact of any transition scenario, being either the construction of large-scale PVPPs or the growing of biomass. Number of coal miners that would still be employed, after the retraining, was taken into the account. It is worth noting that the analysis only included the workers directly related to the coal mine industry sector that could be retrained and not the administrative employers (economists, lawyers etc.).

Finally, the costs were divided into three categories: economical, environmental and social. Economic costs included the profit from electricity generation, CAPEX and OPEX, as well as balancing power costs for PVPP operation, while the environment cost consists of the money saved from the reduced CO_2 emissions. Social costs are considered by the number of employers retained. In the end, the analysis was expanded by applying AEA and MCA, as a strengthening decision making tool.

Analysis of sustainability rating (SR) has been performed twofold and consists of AEA and MCA. Namely, specific environmental, economic and social sustainability indicator groups, shown in Table 1, are defined and estimated on the basis of measurable input data and software tool applied for PVPP design.

In the AEA, the focus was on the economic parameters of all three specific indicator groups. Here, all values were expressed in euros [€] in relation to the average annual electricity generation. In the MCA, each of the specific indicator groups were considered separately and weighting factors were introduced. The MCA, used in this paper to assess the sustainability of energy system under consideration, is previously used by many authors, and usually based on “Analysis and Synthesis of Index at Information Deficiency” methodology which also includes the system of stochastic model of uncertainty. For the analysis, it is necessary to make a selection of sustainability indicators and specific criteria, adopted by weighting factors. With linear function of indicators multiplied by weighting coefficients the agglomerated General sustainability index is obtained [25,26].

Aggregated economic analysis

SR for the aggregated economic analysis (SR_{AEA}) has been done taking into account identified and calculated economic (EcIn), environmental (EnIn) and social (ScIn) indicator groups. All three indicator groups for both RES types have been elaborated for the time frame of 20 years, given that this period coincides with the life cycle of selected fast-growing biomass types, and is contained within the approximate

Table 2
Mine area mapping.

No	Coal Mine	Plot	Area (ha)	
1.	RMU Bila	Plateau 1	0.9	3.3
		Plateau 2	2.4	
2.	RMU Zenica	Mošćanica	4.0	33.6
		Landfill “Bare” Stranjani	20.9	
		PK Stranjani	3.4	
		PK Podbrežje	5.3	
3.	RMU Breza	PK Gornja Breza	21.0	80.9
		PK Kolovaj	3.9	
		Vratnica	28.3	
		Koritnik – izbod	14.0	
		Smrekovica – Sutješčica	6.9	
		Area in front of gas station	1.7	
		Bare	0.8	
		Taložnici	4.3	
4.	RMU Đurđevik	Completed part of landfill PK “Višća II”	27.0	62.1
		Landfill – “Bedrok”	9.7	
		Taložnjak	7.4	
		Location 4	6.3	
		Location 5	11.7	
5.	RU Gračanica	Block 1	15.9	67.5
		Block 2	51.6	
6.	RMU Kakanj	Location 1 – PK Vrtilište	1.9	22
		Location 2 – PK Vrtilište	2.3	
		Location 3 – PK Vrtilište	0.5	
		Location 4 – Plateau 1 of landfill Bijele Vode	8.5	
		Location 5 – Plateau 2 of landfill Bijele Vode	4.3	
		Location 6 – Plateau 3 of landfill Bijele Vode	4.5	
7.	RU Kreka	PK Šićki Brod – Kalajevo – Location 1	65.8	597.0
		PK Šićki Brod – Kalajevo – Location 2	13.8	
		PK Šićki Brod – Kalajevo – Location 2 - additional	50.0	
		PK Lučavačka Rijeka – Location 3.1	42.0	
		PK Lučavačka Rijeka – Location 3.2	49.4	
		PK Lučavačka Rijeka – Location 3.3	18.1	
		PK Lučavačka Rijeka – Location 3.4	17.3	
		PK Lučavačka Rijeka – Location 3.5	90.6	
		PK Plane, PK Zagorje, PK Huskići, PK Pašići, PK Lukavac and PK Karići	>250.0	
TOTAL				866.4

114 ha	Locations very suitable for SRC plantations now
18.8 ha	Locations inaccessible for SRC plantations/ photovoltaic power plant (PVPP)
98.8 ha ha	Locations declared suitable for construction of photovoltaic power plant (PVPP)
>517.4 ha	Locations that could be suitable for SRC plantations in the future
117.4 ha	Locations suitable for SRC plantations/photovoltaic power plant (PVPP) – further analysis required

lifetime of photovoltaic power plants. The EcIn was calculated taking into account the yearly profit gained from electricity generation (PR_i), total investment (CAPEX), yearly operation and maintenance costs ($OPEX_i$), yearly balancing power costs (BC_i) which are needed for the PVPP operation and the yearly energy produced E_i.

The adopted calculation is presented in equation number 1 and is expressed in €/MWh.

$$EcIn = \sum_{i=1}^{20} \frac{PR_i - CAPEX - OPEX_i - BC_i}{E_i} \tag{1}$$

The EnIn took into account the CO_2 emission savings through the profit gained from selling the CER on the market ($PRCO_{2i}$), divided by the yearly energy produced E_i, as presented in equation number 2. By expressing the EnIn in €/MWh, the contribution to decarbonisation is valorised through monetary profit for the investor.

$$EnIn = \sum_{i=1}^{20} \frac{PRCO_{2_i}}{E_i} \tag{2}$$

As addressed earlier in this paper, special attention has been made to adequately define and calculate the ScIn, considering that this elaboration aims to adequately valorise the contribution to the preservation of jobs through retraining of people who have been employed in coal mines before. The number of people necessary to maintain the newly implemented solutions (N_{kept}) was determined by estimating man-hours for maintenance of PVPP and man-hours required for biomass planting, maintenance, harvesting, transport, preparation and the co-firing

Fig. 2. Kreka coal mine area for PVPP (left) and for willow (right).

process itself. The number of employees (N_{tot}) in this context covers the generation segment only. In this regard, the social indicator took into account the amount of money needed to retrain workers. On the other hand, the costs of severance pay, or payment of salaries to workers who do not contribute significantly but cannot be laid off for social reasons, had also to be taken into account for more workers in the case of PVPP, compared to the biomass cultivation case. Thus, gross monthly wage ($WAGE_{mon}$) needs to be determined, together with cost of the worker retraining (RET). In order to calculate the social indicator, all identified social costs have been further divided by the yearly energy produced Ei, and expressed in €/MWh, as the previously calculated other two indicators.

$$ScIn = \sum_{i=1}^{20} \frac{(N_{tot} - N_{kept}) \cdot 12 \cdot WAGE_{mon} + N_{kept} \cdot RET}{E_i} \quad (3)$$

The SR_{AEA} has been then calculated for all considered RES types taking into account the following equation (4):

$$SR_{AEA} = EcIn + EnIn + ScIn \quad (4)$$

Multi criteria analysis

In order to perform a more detailed analysis, the weighting factors were introduced. Once the costs are divided, by using weight factors the impact of each category can be assessed. Since there are a number of parameters involved in making a decision, like economic, social and environmental, it is inevitable that some will be more important than the other. One method that can be used in this case is the MCA which takes into account all the criteria at the same time by using respective weighting factors[27]. First of all, it is necessary to form the vector of input attributes that are needed to evaluate all considered options [28]. In this paper, input attributes are the EcIn, ScIn and EnIn. Then, all the indicators are normalized so they can be more easily compared. Finally, with the introduction of the weighting factors, the results obtained is expressed by means of additive aggregate function.

Here as well, the SR for the multi criteria analysis (SR_{MCA}) has been then calculated for all considered RES types and for the two locations for PVPP installation taking into account the weighting factors and the following equation (5):

$$SR_{MCA} = wf_{ec} \times EcIn + wf_{en} \times EnIn + wf_{sc} \times ScIn \quad (5)$$

Here, wf_{ec} is the weighting factor for the economic indicator group, wf_{en} is the weighting factor for the environmental indicator group and the wf_{sc} is the weighting factor for the social indicator group.

Results and discussion

The developed method has been demonstrated on a particular case study of former coal mine areas of EPBiH power utility, the largest power utility in the country.

Case study description

EPBiH has made its strategic goal to increase the production from RES, especially wind, solar and biomass. Today EPBiH's generation portfolio structure involves 1,165 MW in TPPs run on coal and 565 MW in facilities based on renewable energy sources (mostly large hydro power plants). On annual basis, most of the energy within EPBiH is produced by burning coal, and depending on the hydrology, share of RES generally ranges up to 23 %. It is also worth noting that seven coal mines are a part of the EPBiH Concern, and they employ a large number of local inhabitants. It is crucial to make a mine disturbed land environmentally stable in order to transfer an unpolluted environment and natural resources to the next generations. Therefore, post-mining reclamation works are those aiming to regain landscape's fertility, its ecologic, economic and aesthetic values [29]. Several mining locations have completed exploitation as well as land cultivation, and there are large number of free areas which should be further used in a sustainable and economically viable way.

With that in mind, EPBiH has identified and mapped all such areas. In total, 21 locations with a total area of 714 ha, were identified as suitable for further energy use. Not all of these locations are in the same condition since some were used as ash or slug dumps and others as open cut mining areas. Also, some areas were only recently abandoned while others have been abandoned for a long time and are totally recultivated. Other factors, such as the existing infrastructure or the power grid capacity at the locations, were also taken into consideration. Considering all that, EPBiH has identified some locations, as shown in the Table 2, that are suitable for the growing of biomass (green) and other that are suitable for the construction of large-scale photovoltaic power plants (yellow) [30]. Some locations (grey) are identified as suitable for either SRC plantations or PVPP projects and require further analysis [31]. In such a case, further analysis is performed following the developed method described in Fig. 1.

As part of the efforts towards achieving a carbon–neutral energy production, EPBiH has already performed the techno-economic analysis for PVPP Gračanica [32] and PVPP Kreka – Šićki Brod [33], while also exploring the possibility of growing biomass to replace coal in coal-based power plants. In this regard, two willow plantations have been established and two plantations of Miscanthus are in their preparatory phases with the aim of establishment during autumn season 2022.

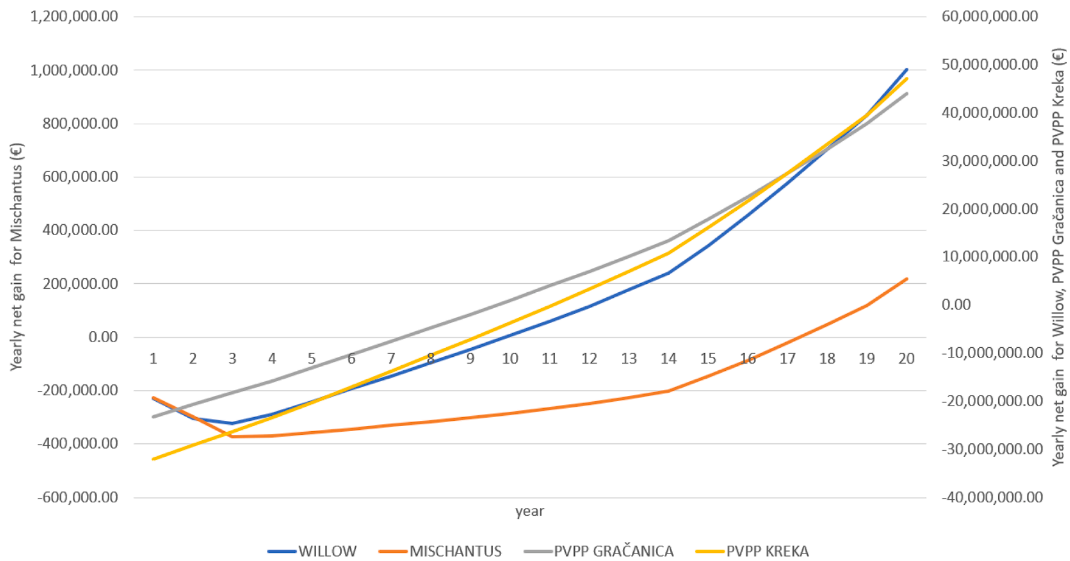

Fig. 3. AEA cash flow chart.

Previous research and experiments performed indicate that biomass and coal co-firing are possible with biomass share of up to 15 % without the need for retrofit. Such an approach would be the first phase and a temporary solution, since it would not eliminate CO_2 emissions in total. Complete retrofit at units is also viable option. Under an assumption that enough biomass resources could be provided, full biomass repowering would be the second phase of the transition path, being a significant contribution to the overall EPBiH's sustainable development plan.

This paper looked at the possibilities of planting both Miscanthus and SRC on abandoned areas of two coalmines (RU Gračanica and RU Kreka). The size of the test plantation plot in this analysis is 50 ha, Fig. 2. The main goal is to analyse the possibilities of sustainable development of the plantations and the use of produced biomass for co-firing in coal power plants. In order to decide which plant is better suited as a coal alternative, various technical, economic and environmental indicators are analysed, applying the developed method as described in chapter 2.

Since both coal mines, RU Gračanica and RU Kreka, are a part of the EPBiH Concern it is necessary to analyse the social indicators as well. In order to truly decide whether any of the plants is suitable for a sustainable development project, all the parameters will be compared with those of a photovoltaic power plant (PVPP) on roughly the same area (50 ha), Fig. 2.

Analysis description

For the main technical parameter, the average annual electricity generation in each case will be analysed. The average annual electricity generation of the large-scale PVPPs was obtained using the software tool PV*SOL Premium. For the biomass, the analysis consisted of comparing the heating value of two types of biomasses versus the heating value of coal used in one large scale TPP operated by EPBiH. Average annual electricity generation was then calculated by using average coal consumption per MWh in the same large scale TPP. It is worth noting to say that in average, 10 % of biomass (0.1 biomass co-firing) in coal-based power stations decreases the net efficiency by 1 % while 20 % of biomass (0.2 biomass co-firing) decreases the net efficiency by 2 % [34]. Biomass co-firing option considered in this paper is quite small - only at 0.1 % or 0.001 biomass co-firing, with consequently minor affecting the net efficiency. To calculate the profit, a fixed price of 57.37 €/MWh was used, since it is the average reference value in EPBiH. To perform an economic assessment, defined economic parameters as CAPEX and OPEX have been taken into consideration. As explained in chapter 2, for a proper work of PVPPs and making them comparable in the operating regime with biomass co-firing options, the economic analysis included necessary balancing costs, whereby this service is not required for operating facilities burning biomass.

Impact on the environment was analysed by the reduction of CO_2 emissions. EPBiH in its strategies approximated the CO_2 emission factor (kg/MWh) and its trajectory in the coming years [35,36]. Using the emission factor, as well as the projected carbon prices on the EU ETS, additional income was calculated as the amount that would not have to be paid in case of both biomass and large-scale PVPP project implementation. As emphasized before, coal mines employ a large number of people and it is necessary to valorize the social impact of any transition scenario, being either the construction of large-scale PVPPs or the growing of biomass. Number of coal miners directly related to the coal mine industry sector that would still be employed, after the retraining, was taken into the account.

The decision making process was evaluated applying the within this paper developed method, firstly calculating costs in the three chosen categories, namely economic, environmental and social. Finally, sustainability of the two considered RES options has been rated via AEA and MCA.

Case study results

As it can be seen on the Fig. 3, cash flow for the two PVPPs at two different locations and the two types of fast-growing biomass plantations, are almost identical, except for the first two years. Namely in that period there is no energy yield from biomass cultivation; there is no profit and the expenses prevail.

Applying the method and equations as defined in chapter 2, SR_{AEA} and SR_{MCA} have been assessed, calculating the identified EcIn, EnIn and ScIn indicator groups for each of the two locations, namely for RU Gračanica and RU Kreka, as well as for the different RES types considered for future energy production. In that sense, PVPPs have been designed at the two 50 ha areas taking into account local characteristics. The energy production, panel positions and row spacing are location specific, and thus, the costs are also project dependent. At the same area, plantations of miscanthus (*Miscanthus* × *giganteus*) and willow (*Inger clone*) have been considered with all requirements for their establishment, cultivation and harvesting.

As emphasized throughout this paper, special attention has been made to adequately valorise the contribution to the preservation of jobs through retraining of people who have been employed in coal mines before. It has been calculated that for a biomass planation of 50 ha, 10

Table 3
Calculation results of SR_{AEA}.

RES type/location	SR_{AEA} (€/MWh)
PVPP Kreka	35.16
PVPP Gračanica	39.35
Mischantus	9.85
Willow	29.91

local employees could be engaged, whereby for a PVPP at the same area only 2. In this regard, the social indicator took into account the amount of money needed to retrain workers; in the case of a PVPP for 2 of them, and in the case of biomass cultivation and co-firing for 10 of them. On the other hand, the costs of severance pay, or payment of salaries to workers who do not contribute significantly but cannot be laid off for social reasons, was taken into account for 8 workers in the case of PVPP, since in the case of biomass cultivation all 10 can justify their positions. $WAGE_{mon}$ was approximated to 800 € while the RET cost was estimated to be 1000 € per one worker.

The results of the performed SR_{AEA} calculations are presented in the Table 3 below.

It can be seen from the table above that the PVPPs have higher values of profit per 1 MWh of generated electricity compared to biomass options considered. Willow is not that far behind, due to its large yearly yield.

When looking at the results presented in Fig. 4, sustainability ratio dominantly depends on the value of EnIn and EcIn while the ScIn has a negative contribution in total. During this analysis, the average yields were considered in the case of biomass harvests. Should the yield be greater than the average, both the EcIn and the EnIn will increase and the SR_{AEA} would be much closer to that of the PVPPs.

However, the performed AEA does not adequately valorize the social aspect of the RES options here applied. In order to consider the implication of favouring one aspect over the other and derive viable conclusions, the elaboration has been widened with performing the MCA. For this purpose, indicator groups have been expressed in units given in Table 1 while obtained values are given in Table 4.

MCA analysis included the use of weighting factors and assessments were performed, as demonstrated in Table 5. Four different cases of distribution of weighting factors values between the considered indicators were used, to reflect different scenarios of favouritism of any of the indicator over the other by decision makers. For an exemplification, in Case I, see Table 5, there is no favouritism of any of Indicator; distribution of weighting factors values is equal between the indicators considered. In other cases, one indicator is favoured over other two.

Calculated SR_{MCA} for all RES types and all cases considered are given in Fig. 5.

MCA more adequately valorises the social indicator and thus makes the overall assessment more viable. As it can be seen from Fig. 5, when all indicator groups are given equal priority (case I), the SR_{MCA} for all considered RES types are much closer to each other compared to the analysis under AEA (see results of SR_{AEA}). Even more, in that case, in selection process slight favours might go to Willow option. In case II, however, when advantage is given back to economic indicator over the other two, PVPP options are favourable. In case III, all RES types have similar SR_{MCA} values and their positive environmental impact (CO_2 emission reduction) is significant. But, when favour is given to the social indicator (ScIn), case IV, the projects based on biomass plantations are clear winners.

Eventually, comparing the results of AEA and MCA, grounded on the averaged levelized values derived for the RES options under consideration (PVPP vs Biomass), one can undoubtedly conclude that PVPP is favourable option in cases where the advantage is being entirely devoted to the economic criteria (see red points and grey columns in Fig. 6). Moreover, in case where all criteria are equally valorised (see orange columns in Fig. 6), PVPP option is still favourable before Biomass option, whereby the difference decreased. This is also valid when advantage is

Table 4
Indicator groups for the MCA.

	Indicator groups			Normalized indicator groups		
	EcIn [€/MWh]	EnIn [tCO_2/MWh]	ScIn [-]	EcIn [p.u.]	EnIn [p.u.]	ScIn [p.u.]
PVPP Kreka	17.49	0.929	2	0.80	1.000	0.20
PVPP Gračanica	21.89	0.929	2	1.00	1.000	0.20
Mischantus	−12.29	0.922	10	−0.56	0.992	1.00
Willow	8.70	0.923	10	0.40	0.993	1.00

Table 5
Weighting factors distribution for four cases.

	I	II	III	IV
wf_{en}	0.33	0.25	0.5	0.25
wf_{ec}	0.33	0.5	0.25	0.25
wf_{sc}	0.33	0.25	0.25	0.5

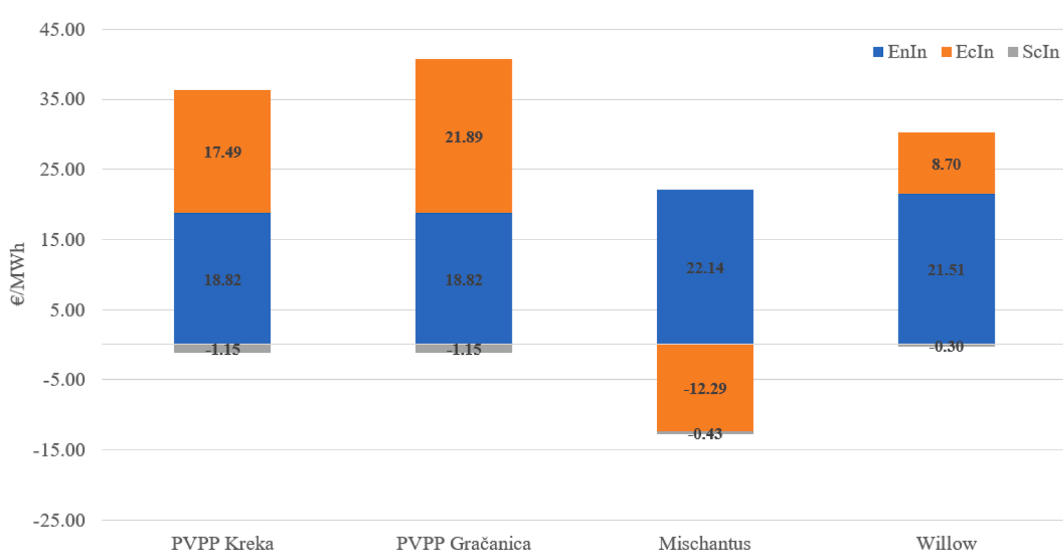

Fig. 4. Calculation results by indicator groups.

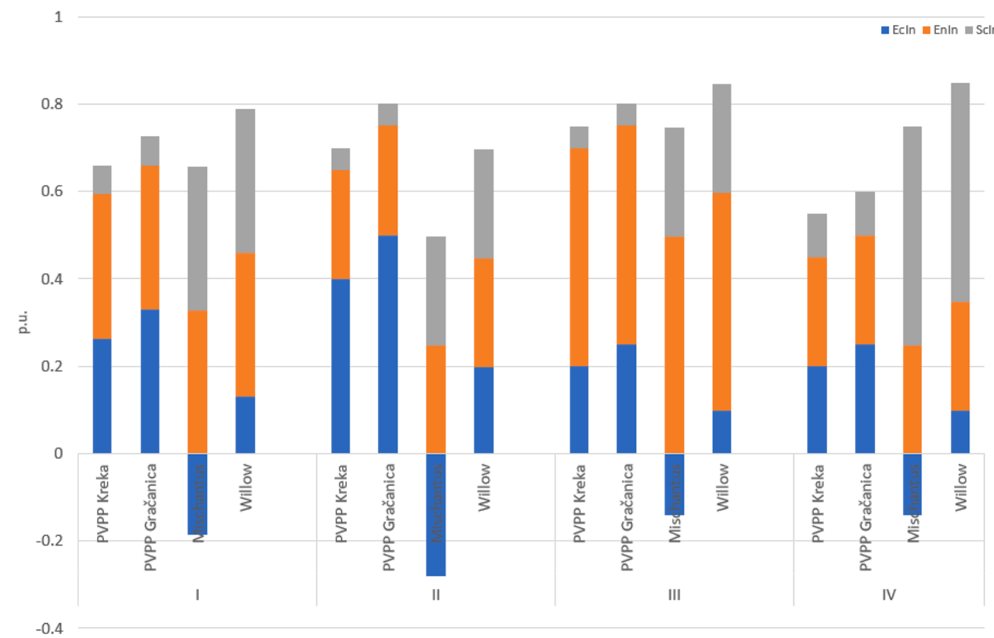

Fig. 5. MCA results for different weighting factors distribution.

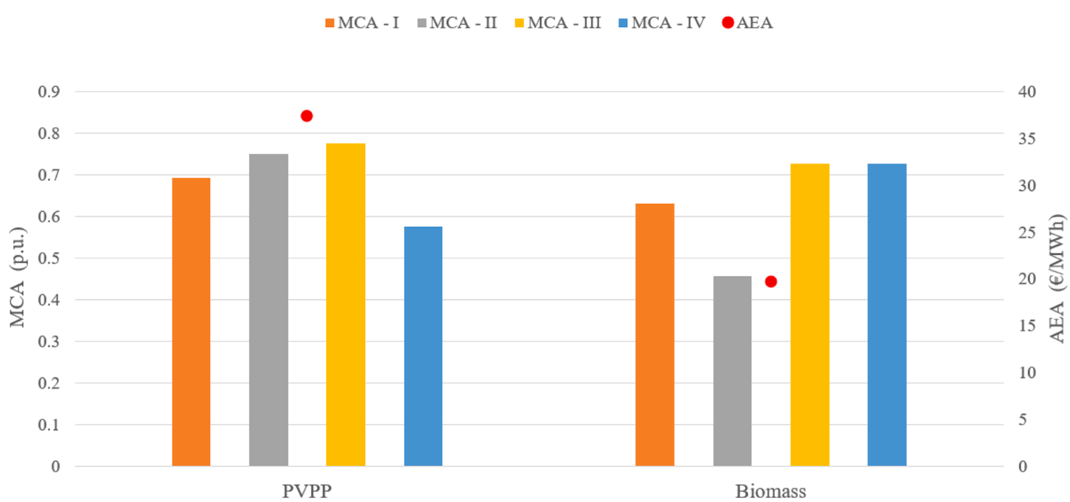

Fig. 6. Benchmarking of AEA and MCA.

given to environmental criteria (see yellow columns in Fig. 6). However, once the social indicator is dominant, Biomass option is overtaking and getting more favourable at the specific extent.

Conclusions

Abandoned coal mine areas can be reclaimed in a variety of ways and, along for green energy purpose, used for many other different useful human and economic activities, such as tourism, recreation, industry etc. Otherwise, it is reasonably assumed that establishment of green energy options on abandoned coalmine area and thus keeping the core business of power utility which owns or operates the coal mines and thermal power plants in the coal region, is at the top of the priority, in order to secure energy supply while exiting from coal.

In this paper, as a novelty, different RES based alternatives to the coal (in this case biomass and solar) were considered simultaneously, on the same abandoned coal mine plot. A model was developed to evaluate energy yield and sustainability of the options under consideration by using variety of economic, environmental and social parameters. A broad spectrum of sustainability indicators was considered to strengthen the evaluation of specific sustainability criteria, i.e. specific indicator groups (economic, environmental and social). Chosen RES technologies that were mutually compared within the paper; SRC and energy crops vs photovoltaic, are quite different in a number of characteristics (variable vs base load operation, labor requirements etc.). In order to fairly and equally evaluate their outcome, the analysis was expanded using untypical single indicators such as yearly balancing power costs, cost of employee retraining and severance packages / employee wages. In addition, the proposed model includes an assessment using both aggregated economic analysis (AEA) and multi criteria analysis (MCA). Such a comprehensive approach contributes to the scientifically grounded selection of appropriate RES option for the specific abandoned coal mine plot, in this specific case SRC and energy crops versus PVPP. It has been shown that such an approach leads to making a more informed decision.

Performed AEA lightly favours the construction of PVPPs over the use of willow as fuel instead of coal in the case study considered. In the analysis, mischantus is lagging far behind due to its lower yield compared to willow. MCA on the other hand, valorises the social indicator adequately and the results of sustainability ratio are much closer for all considered RES types, enabling decision-makers to draw appropriate conclusions.

This approach fulfils the gap in sense of lack of decision making works; articles and methods, for RES selection options to be implemented on former coalmine area.

CRediT authorship contribution statement

A. Merzic: Methodology, Software, Validation, Investigation, Writing – review & editing. **N. Turkovic:** Data curation, Writing – review & editing, Visualization, Investigation. **N. Ikanovic:** Resources, Investigation. **E. Lapandic:** Resources, Investigation. **A. Kazagic:** Investigation, Conceptualization, Writing – original draft. **M. Music:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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