GIS-based optimization method for utilizing coal remaining resources and post-mining land use planning: A case study of PT Adaro coal mine in South Kalimantan

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***Abstract*—**Coal is a non-renewable energy resource that has been the main source of energy and the most important in the world. Resource coal plays a strategic role in economic and social development in many industrialized countries [3, 4, 6]. Coal mining activities may cause a series of environmental and socio-economic issues in communities around the mining area. Mining can become an obstacle to environmental sustainability and a major hidden danger to the security of the local ecology [3, 4, 6]. Therefore, the coal mining industry should follow some specific principles and factors in achieving sustainable development. These factors include geological conditions, land use, mining technology, environmental sustainability policies and government regulations, socio-economic factors, as well as sustainability optimization for post-mining land use. Resources of the remains of the coal which is defined as the last remaining condition of the resources and reserves of coal when the coal companies have already completed the life of the mine [1, 2, 5] or the expiration of the licensing contract (in accordance with government permission). This research uses approch of knowledge-driven GIS based methods mainly Analytical Hierarchy Process (AHP) and Fuzzy logic for utilizing coal remaining resources and post-mining land use planning. The mining area selected for this study belongs to a PKP2B (Work Agreement for Coal Mining) company named Adaro Indonesia (PT Adaro).

***Keywords*—** GIS, optimization, remaining resource, post-mining planning, AHP.

INTRODUCTION

The remaining of coal can be defined as coal remain resource (mainly measured and indicated) which are the remaining reserves from a coal mining activity [15, 26, 27]. These remaining reserves are mainly measured after the mining companies have already completed contracts and their license granted by the Government has already been expired. The remaining coal resources will be reevaluated with more complex parameters that can influence the sustainability of mining and sustainable development with reference to the recommended parameters of previous studies [15, 19, 23, 26, 27].

This study analyzes the feasibility of continuing mining operations in terms of the possible environmental effects of the operation and by considering more dynamic and complex factors [15, 17, 19, 23, 26, 27, 28]. These factors include geological conditions, mining technology, land use, environmental sustainability policies and government regulations, the social economy (the community around the mine), and the post-mining land use sustainability. Furthermore, we will generate a dynamic modeling that will also analyze the projected survival of remained coal resource for management and optimization purposes. The following is figure showing mindset of the research.

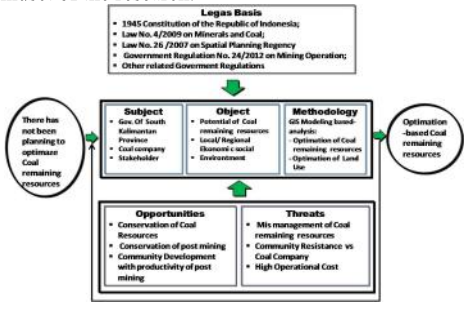

Fig.1. Mindset of the Research

In recent decades, there have been considerable improvements and empowerment in the area of computing software [18]. Mathematical modeling techniques have been developed to predict the locality of point events of interest [18]. Each technique can be regarded as a function that combines the various "predictor maps" to produce a map of the prospect [1, 2]. The method can be seen as generally fitting into one of two categories: knowledge-driven and data-driven. It is also possible to combine some features from both techniques.

AHP (Analytical Hierarchy Process) method has been widely used to assist in decision-making process. AHP helps the decision makers in finding the most appropriate decision with the purpose of an specific research and understanding an issues [9, 16]. It provides a comprehensive framework and rationale for structuring the problem to represent and measure things that are related to the overall objectives, and provide an alternative solution to this problem. AHP was introduced by Thomas Saaty in 1980 using mathematical methods and psychology concepts [9, 16]. Since then this method evolved and improved over time.

SAMPLE AND RESEARCH METHODS

There are several coal mining companies /PKP2B (Contract of Work) still active is in South Kalimantan province (about 14 companies), among which PKP2B PT Adaro Indonesia was selected for this research. The company site is located in Balangan and Tabalong regency, South Kalimantan, which is approximately 220 km from Banjarmasin city to the north and can be reached by road takes about 6 (six) hours. While the location of crushing (crushing plant) and the port of loading is in the village Kelanis, in South Barito regency, Central Kalimantan (Figure 2). The total area of work agreement of PT. Adaro Indonesia is 35.800,80 hectares [30].

Fig. 2. Location of PT Adaro mining site in Indonesia

PT Adaro has been running the mining operation for 22 years, from the first approval of operation given by

Goverment. Recently, PT Adaro has been the biggest coal mining company in Indonesia producing coal about 50 MT per years, but later it going to increase to 80 MT coal per year. It has total resources aproximately 4 Billion Ton coal and total reserves of coal about 2,3 Billion Ton [30].

GIS Modeling Method

Modeling activities to identify prospective mineral and coal are trying to describe the area that may be a major source of sediment formation zone [22]. This can be achieved through the process of defining the proof criteria, making evidentiary criteria maps (predictor maps) and weighting by combining these maps to produce final prospective map. Interpretation maps of these prospects can be used to generate the target area to do exploration activities [2].

This study uses a knowledge-driven approach integrated with GIS (Geographic Information System), i.e. AHP or the Analytic Hierarchy Process [16].

1. Developing comparison matrix for each rank hierarchy,
2. Calculate the relative weight and priority for each element in the hierarchy, and
3. Calculate the ratio of consistency to assess the consistency of assessment,

The application of the analysis is mainly determining the consistency (consistency analysis) performed after ranking order of each criterion. In terms of ensuring the accuracy of the assessment (weighting sequence of each of the criteria used in determining the Eigen Value) a consistent modeling equation is required and therefore consistency analysis was done using two main steps [9, 16];

1. Calculate Consistency Index (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

Where

λ max is the maximum value of the average that includes all the parameters / largest Eigen values of matrix number n,

n is the number of characters / parameters used (i.e. n=4)

CI is Consistency Index

2. Consistency Ratio (CR) calculation:

$$CR = CI/RI \quad (2)$$

Where

RI is random index

CR is Consistency Ratio

Random index values (RI) are shown in Table 1 for n = 4[16]

Table 1. Random Index Value (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	0,46	1,49

GIS Modeling Approach method also allows an area known to be free from non-mining activities (eg land use settlements, highways, oil and gas pipelines, large rivers and other land). The analysis results can be known the extent of the potential area which is completely free and clean of surface activity, so that later would be known areas of optimization for continuous mining operations.

The same thing can be determined by overlaying maps approaches related to the optimization of land use. Surely must first set the initial criteria for the optimization of land suitability (Fuzzy logic). This study uses a guide Law no. 26 of 2007 on Spatial Planning District. Optimization of the suitability of land / land use in this research is directed to the use of plantation/ agricultural and conservation areas, whereas the determination of the criteria optimization of land use can be seen in Table 2.

DATA AND ANALYSIS

GIS modeling approach also can be used to identify an area known to be free from non-mining activities (e.g. land use settlements, highways, oil and gas pipelines, large rivers and other land). The analysis results can be used to find the extent of the potential area which is completely free and clean of surface activity, so that later would be considered as areas of optimization for continuous mining operations.

Secondary data were taken from PKP2B (coal company) and related agencies (from the level of the central government and regional / Prov. Regency / City), located in the province of South Kalimantan. Retrieval of data from relevant government agencies was attained not only at the study area but also in government institution

Table 2. Criteria for the selection of the optimal value of four alternative land use

Criteria	Plantation/ Agriculture Land	Conservation Land	Recreation Land	Industry Land
Slope				
0 - 2 %	0 - 2 %		0 - 2 %	0 - 2 %
2 - 12 %	2 - 12 %		2 - 12 %	
12 - 25 %		12 - 25 %		
25 - 40 %		25 - 40 %		
> 40 %		> 40 %		
Rainfall				
0 - 100 mm			0 - 100 mm	0 - 100 mm
100 - 200 mm	100 - 200 mm	100 - 200 mm		
200 - 300 mm	200 - 300 mm	200 - 300 mm		
300 - 600 mm	300 - 600 mm	300 - 600 mm		
> 600 mm	> 600 mm	> 600 mm		
Distance to road				
1 - 3 km	1 - 3 km		1 - 3 km	1 - 3 km
3 - 5 km	3 - 5 km	3 - 5 km	3 - 5 km	3 - 5 km
> 5 km	> 5 km	> 5 km	> 5 km	> 5 km
Distance to resident				
1 - 3 km	1 - 3 km		1 - 3 km	
3 - 5 km	3 - 5 km		3 - 5 km	
> 5 km	> 5 km	> 5 km	> 5 km	> 5 km
Distance to river				
1 - 3 km	1 - 3 km	1 - 3 km	1 - 3 km	1 - 3 km
3 - 5 km	3 - 5 km	3 - 5 km	3 - 5 km	3 - 5 km
> 5 km	> 5 km	> 5 km	> 5 km	> 5 km

that support research data. Secondary data obtained from the company and the institutions were the most recent data (for the past 5 years) and were in the form of either maps or tables related to the research objectives The collected data from various resources were uniform and there was no serious difficulties in data provision. This research will was conducted in several stages of analysis:

a. Analysis of the coal resource remaining for Optimization:
   1. Analysis of the potential area of distribution of the coal remaining related to the PKP2B concession;
   2. The allocation of the coal resource remaining in the potential areas for optimization;

b. Analysis of the suitability of land for land use optimization.

For GIS modeling, Arc GIS 10.2 software was used to process AHP analysis. Attribute determination analysis, such as polygon classification and weighting assessment was carried out to produce thematic maps of rainfall, lithology (rock formations), the distance from the geological structures (faults), slope and mining progress.

c. Analysis of the coal resource remaining for Optimization

Based on the analysis of this study the order/ranking of influential variables are as follows (Figure 3 - 6):

1. Rock formations (FB);
2. Distance from geological structures/ faults (JS);
3. Slope (KL);
4. Progress mine (KT).

The next step is to develop the comparison matrix for each rank hierarchy. After the above steps then the relative weight and priority for each element in the hierarchy must be calculated.

Table 3. Matrix Pair-Wise Features Thematic Map Individual

Criteria	FB	JS	KL	KT
FB	1	2	3	4
JS	0,5	1	1	2
KL	0,33	1	1	1
KT	0,25	0,5	1	1
Total	2,08	4,50	6,0	8

After the above steps then calculate the relative weight and priority for each element in the hierarchy.

Table 4. Normal Matrix Obtained From The Pair-Wise Matrix

Criteria	FB	JS	KL	KT	Total	Eigen Value
FB	0,48	0,44	0,50	0,50	1,92	0,48
JS	0,24	0,22	0,167	0,25	0,88	0,22
KL	0,16	0,22	0,167	0,13	0,67	0,17
KT	0,12	0,11	0,167	0,13	0,52	0,13
Total	1	1	1	1	4	1

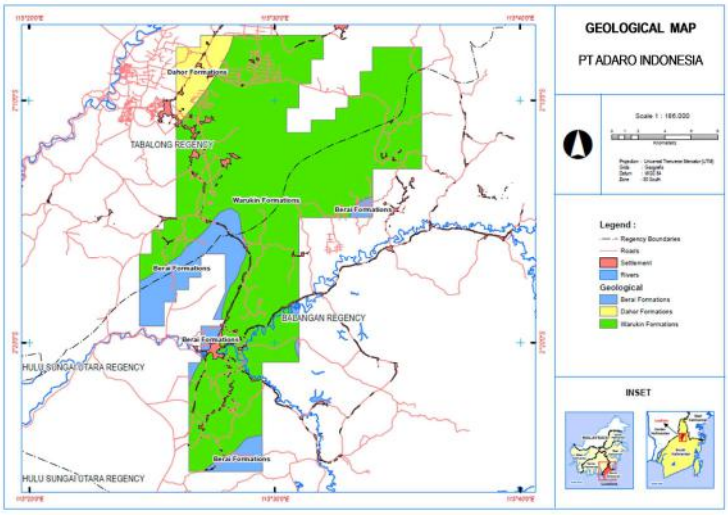

Fig. 3. Geological Map showing Rock Formation at location of PT Adaro

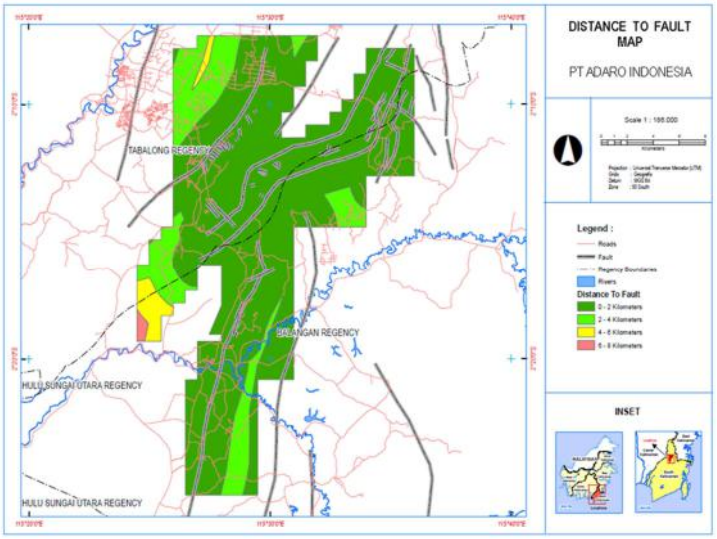

Fig. 4. Geological Structural Map showing Distance to Fault at location of PT Adaro

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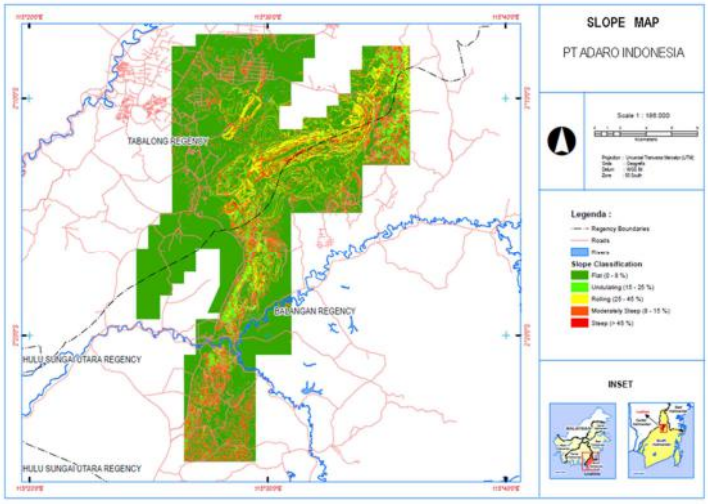

Fig. 5. Slope Map at location of PT Adaro

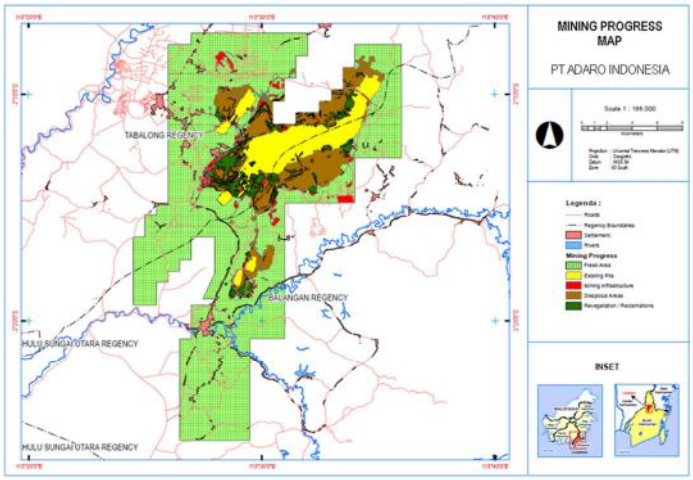

Fig. 6. Mine Progress Map at location of PT Adaro

After the normal matrix obtained weighting value for each criterion should be defined (Eigen Value) to be used for calculating the coal potential by the following equation,

PSB = (FB*0,48) + (JS*0,22) + (KL*0,17) + (KT*0,13)

PSB =1,023+ 0,989 + 1,318 + 1,758 = 5,067

PSB is Potensial Coal Area (see Fig. 7)

$\lambda max = 4{,}047 \quad CR = 0{,}018$

$$CI = CR / RI = 0{,}018/0{,}9 = 0{,}016$$

CR values obtained from CI / RI (RI obtained from Table 3 / random index value with n = 4) as the calculations showed that the value of CR is below / less from 0.1 and is 0.018, indicating that the value of CR is consistent and acceptable.

The same stage is also carried out to count every sub creteria of its variable above. Further, after spread potential of coal resources is identified, Analysis of the coal resource remaining for Optimization is conducted by GIS Modelling approach trough carriying out overlaying potential map with infrastructure one as shown at figure 7. The analysis should first change spatial raster map into vektor map to produce acurate optimazition map.

d. Analysis of the suitability of land for land use optimization

The analysis of the suitability of land for land use optimization should base on condition of economic social of the community arround the mining as well as result of the environtmental management/ reclamation performance of the coal company .

The result of analysis of the coal resource remaining for Optimization is then overlaid with some supporting map, such as rainfall map and slope one considering criteria in accordance with the Law No. 26/2007 about land pattern of the Regency area (as guidance for analyzing fuzzy logic) [12].

In conducting analysis of suitability optimation or land utility, This research uses criteria map. Some of the main criteria are mainly rainfall map around concession location of PT Adaro and slope map give significant contribution of optimation decision of land suitability. Analysis of GIS Modeling (Fuzzy logic) of suitability optimation / land utility uses the criteria above and guidance of reference related to determining land utility which is accurate after post mining.

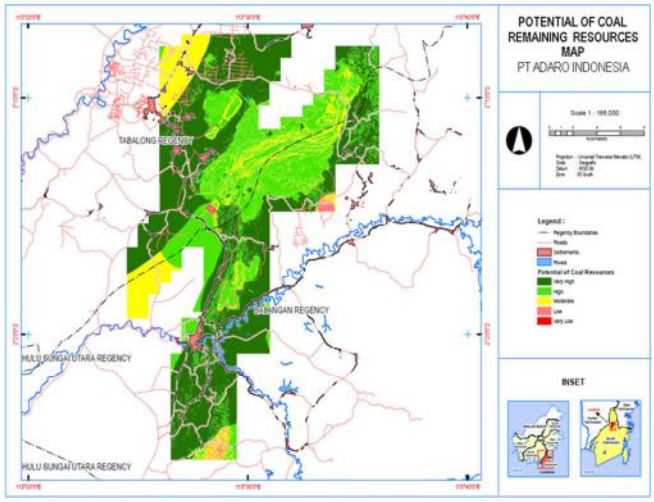

Fig. 7. Potential Remaining Coal Resources Map at location of PT Adaro

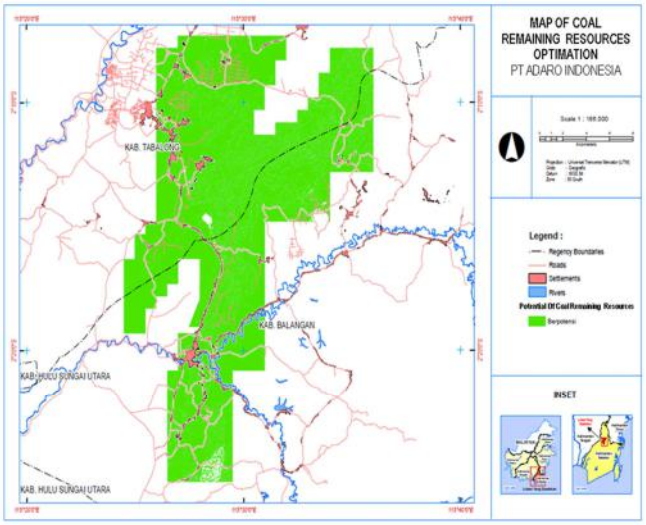

Fig. 8. Map of Coal Remaining Resources Optimation at location of PT Adaro

Base on The criteria include:

1. Slope, in the research area is generally 0 – 25 % for plantation and over 25 % for conservation land;
2. Rainfall, generally over 100 mm;
3. Distance from street, close enough around about 1 km;
4. Distance from settlement, close enough about 1 km;
5. Distance from river, close enough about 1 km;

From the consideration above, the analysis result would produce map of the suitability of land for land use optimization. The result is hope to return land to previous function that is rubber plantation area (Fig. 9). It is in lane with the and lead to increase economic rank in the Tabalong dan Balangan Regency.

DISCUSSION

Analysis of suitability optimation /land utility base on above criteria is that the research is propose when post mining activity pt Adaro is finished. Which is expected to be returned to the original function mainly about 87 % for rubber plantation area (Fig. 9). This is in accordance with the social need and encourage economic level in Tabalong and Balangan regency where there has been rubber plantation processing plant. The result of this analysis shows that social-economic performance of the society is dominant enough. Where as the utility of conservation land area is about 2-3 % of the whole of the concession area compared which the plantation area.

The result analysis also indicated that environment performance does not always affect directly because the performance of the processing surrounding of PT Adaro is still in the early stage. Where as this result has analyzed that plantation potential base on local statistic data plangive contribution significant enough out the mining sector. Social-ecnomically, it than be shown that plantation effort sector give contribution to sustainable development. Therefore, the data of plantation sector criteria should be considered for arranging future reclamation planning of PT Adaro.

The results from several analyzes illustrate that the potential remaining of the coal resource in PT Adaro is still quite large. When seen from the view of the mine life still remaining for age 8 years after the production operation of 22 years of mining lifetime and considering the production capacity approve by document of the Feasibility Study and EIA (Environmental Impact Assessment) amounting 80 million tons of coal, there is still a chance for sustainable mining. However, it, of course, depends on the market demand and favorable price and economical conditions.

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Based on the analysis results from GIS optimize modeling for the suitability study of the land (and also based on the criteria of guidance from the Law No. 26/2007) this study proposes that post-mining activities of PT Adaro is expected to restore the original function, namely rubber plantation area (Figure 9) . This is in accordance with the demands and the economical favorability level in Tabalong regency and Balangan for rubber processing factory [12].

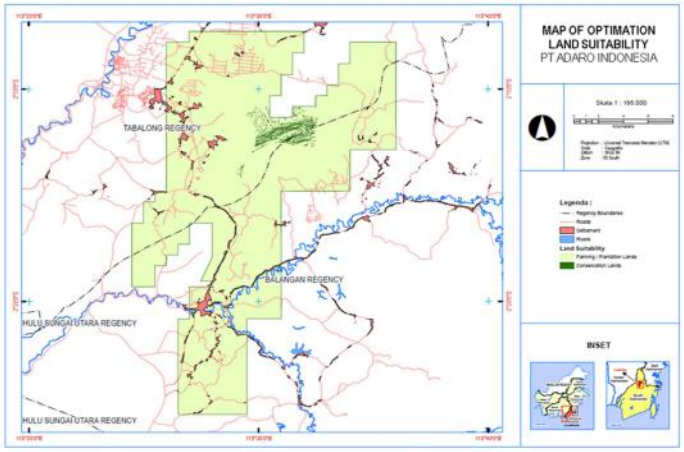

Fig. 9. Optimized Suitability Land Map at location of PT Adar

CONCLUSION

Conclusions obtained from the analysis of this study showed that PT Adaro have the potential resource area that has sufficient remaining coal of about 91.61% (32251.56 ha, Fig. 8) so achieving sustainable mining after the lifetime of the mine is still possible. Potential areas are generally located in the formations of Warukin and Dahor. Infrastructure land is only a little less potential area.

Based on the criteria from reference land, and the existing land use in the area and around the mines, the land optimization recommended planning a rubber plantation area and a restricted area for conservation in the north of the concession area of PKP2B PT Adaro (Fig. 9).

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