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 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. 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 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). The result shows that geologically the existing formation is dominated by Coal Bearing Formation (Warukin Formation) which allows the presence of remains coal resource potential after the lifetime of mine, and the suitability of rubber plantation for the optimization of land use in all mining sites and also in some disposal places in conservation areas and protected forests.

Keywords: GIS, optimization, remaining resource, post-mining planning, AHP

1. Introduction

Coal is a nonrenewable energy resource that has been the primary energy resources and the most important in the world. Coal resources play a strategic role in economic and social development in many industrialized countries (Wang and Zhang, 2008; Liu et al., 2012). 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 (Wang and Zhang, 2008; Liu et al., 2012; Zhang et al., 2013). Therefore, the coal mining industry should follow environmental protection principles for achieving sustainable development.

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 (Westman, 1999; Watson, 2002 and Rohrbacher et al., 2009). 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.

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 (Westman, 1999; Watson, 2002; Rohrbacher et al., 2009; and Cryanon, 2012). 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.

In recent decades, there have been considerable improvements and empowerment in the area of computing software (Schmitt, 2010). Mathematical modeling techniques have been developed to predict the locality of point events of interest (Schmitt, 2010). Each technique can be regarded as a function that combines the various "predictor maps" to produce a map of the prospect (Bonham-Carter, 1994). 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 (Saaty, 1980; Isnain and Juhari, 2013). 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. Since then this method evolved and improved over time.

2. 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 Province, 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 (Fig. 2.). The total area of work agreement of PT. Adaro Indonesia is 35.800,80 hectares (Directorat General of Mineral and Coal, 2014).

PT Adaro has been running the mining operation for 22 years, from the first approval of operation given by Government. 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 approximately 4 Billion Ton coal and total reserves of coal about 2,3 Billion Ton (Directorat General of Mineral and Coal, 2014).
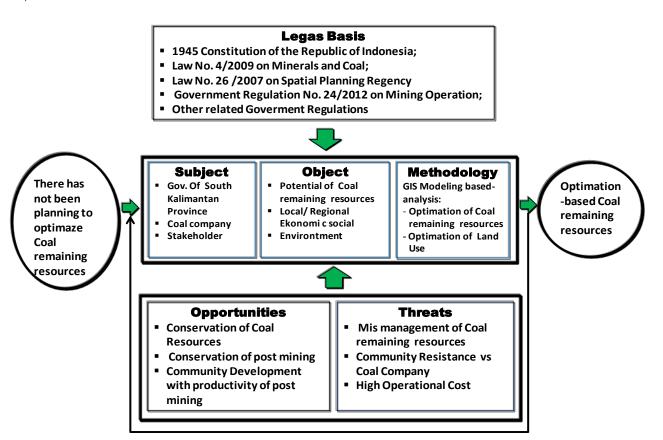

Fig. 1. Mindset of the Research

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

2.1 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 (Sutcu, 2012). 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 (Bonham -Carter, 1994 and Harris, 2006).

2.2 AHP Method

This study uses a knowledge-driven approach integrated with GIS (Geographic Information System), i.e. AHP or the Analytic Hierarchy Process (Saaty, 1980).
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 (Saaty, 1980; Isnain and Juhari, 2013);

A. Calculate Consistency Index (CI):

$$CI = \frac{\lambda max - n}{n - 1} \qquad (1)$$

Where

λmax 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 = 10)
CI =   is Consistency Index

B. Consistency Ratio (CR) calculation:

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

Where
RI   is random index
CR   is Consistency Ratio
Random index values (RI) are introduced by Thomas Saaty (1980). RI are shown in Table 1 for n = 4.
After the above steps then calculate the relative weight and priority for each element in the hierarchy.

Table 1. Random Index Value (RI), Saaty (1980)

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

Table 2. Matrix Pair-Wise Features Thematic Map Individual Coal Potential Zone

Kriteria	FB	KSB	PL	KSG	Kal	TS	Ash	TM	KL	KT
FB	1	2	3	4	5	6	7	7	8	10
KSB	0,500	1	2	2	4	5	6	6	7	8
PL	0,333	0,500	1	1	2	4	4	5	7	7
KSG	0,250	0,500	1	1	2	3	3	4	5	6
Kal	0,200	0,250	0,500	0,500	1	2	3	3	3	4
TS	0,167	0,200	0,250	0,333	0,500	1	2	3	3	4
Ash	0,143	0,167	0,250	0,333	0,333	0,500	1	2	2	3
TM	0,143	0,167	0,200	0,250	0,333	0,333	0,500	1	2	2
KL	0,125	0,143	0,143	0,200	0,333	0,333	0,500	0,500	1	1
KT	0,100	0,125	0,143	0,167	0,250	0,250	0,333	0,500	1	1
Total	2,96	5,05	8,49	9,78	15,75	22,42	27,33	32	39	46

2.3 GIS-Based Optimization

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 4.

3. 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 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 potential area coal remaining resource 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.

3.1 Analysis of the coal resource remaining for Optimization

Based on the analysis of this study the order/ranking of influential variables are as follows:

1. Rock formations (FB);
2. Condition of Geology Structure (KSG);
3. Condition of Coal Seam (KSB);
4. Land use (PL);
5. Quality Specification of Coal Calorie (Kal);
6. Quality Specification of Total Sulfur (TS);
7. Quality Specification of Total Moisture (TM);
8. Quality Specification of Ash Content (Ash);
9. Slope (KL);
10. 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.

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*B1 + KSB* B2 + PL* B3 + KSG*B4 + Kal*B5 + TS*B6 + TM*B7 + Ash * B8 + KL * B9 + KT * B10

PSB = FB*0,29 + KSB* 0,20 + PL* 0,14 + Kal* 0,11 + KSG * 0,08 + TS * 0,06 + Ash * 0,04 + TM * 0,03 + KL * 0,02 + KT * 0,02

PSB is Potential Coal Area (see Fig. 7)

λmax = (2,96*2,98) + (5,05*2,04) + (8,49*1,37) + (9,78*0,16)+ (15,75*0,075) + (22,42*0,057) + (27,33*0,04) + (32*0,031) + (39*0,023) + (46*0,02) / 10

λmax= 8,819+10,327+11,637+11,326+11,768+12,701 + 11,038 +9,943+8,779 8,952 / 10

λmax = 10,5289

$$CI = \frac{\lambda max - n}{n - 1} = \frac{10,5289 - 10}{9} = 0,059$$

$$CR = CI/RI = 0,059/1,49 = 0,039$$

CR values obtained from CI / RI (RI obtained from Table 2 / random index value with n = 10) as the calculations showed that the value of CR is below / less from 0.1 and is 0.039, indicating that the value of CR is consistent and acceptable.

The same stage is also carried out to count every sub criteria 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 Modeling approach trough carrying out overlaying potential map with infrastructure one as shown at Fig. 3. The analysis should first change spatial raster map into vector map to produce accurate optimization map.

3.2 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 around the mining as well as result of the environmental 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).

In conducting analysis of suitability optimization 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 optimization decision of land suitability. Analysis of GIS Modeling (Fuzzy logic) of suitability optimization / land utility uses the criteria above and guidance of reference related to determining land utility which is accurate after post mining. 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. 4). It is in lane with the and lead to increase economic rank in the Tabalong dan Balangan Regency.

Table 3. Normal matrix obtained from the Pair-Wise matrix

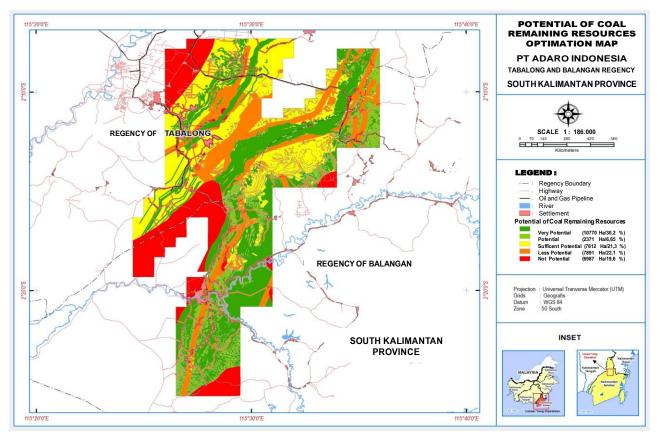| Kriteria	FB	KSB	PL	KSG	Kal	TS	Ash	TM	KL	KT	Total	Avg	Bobot
FB	0,338	0,396	0,354	0,409	0,317	0,268	0,256	0,219	0,205	0,217	2,98	0,30	0,30
KSB	0,169	0,198	0,236	0,204	0,254	0,223	0,220	0,188	0,179	0,174	2,04	0,20	0,20
PL	0,113	0,099	0,118	0,102	0,127	0,178	0,146	0,156	0,179	0,152	1,37	0,14	0,14
KSG	0,084	0,099	0,118	0,102	0,127	0,134	0,110	0,125	0,128	0,130	1,16	0,12	0,12
Kal	0,068	0,049	0,059	0,051	0,063	0,089	0,110	0,094	0,077	0,087	0,75	0,07	0,07
TS	0,056	0,040	0,029	0,034	0,032	0,045	0,073	0,094	0,077	0,087	0,57	0,06	0,06
Ash	0,048	0,033	0,029	0,034	0,021	0,022	0,037	0,063	0,051	0,065	0,40	0,04	0,04
TM	0,048	0,033	0,024	0,026	0,021	0,015	0,018	0,031	0,051	0,043	0,31	0,03	0,03
KL	0,042	0,028	0,017	0,020	0,021	0,015	0,018	0,016	0,026	0,022	0,23	0,02	0,02
KT	0,034	0,025	0,017	0,017	0,016	0,011	0,012	0,016	0,026	0,022	0,19	0,02	0,02
Total	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1	1	1	10,00	1,00	1,00

Fig. 3. Potential of Optimation of Coal Remaining Resources at location Map of PT Adaro
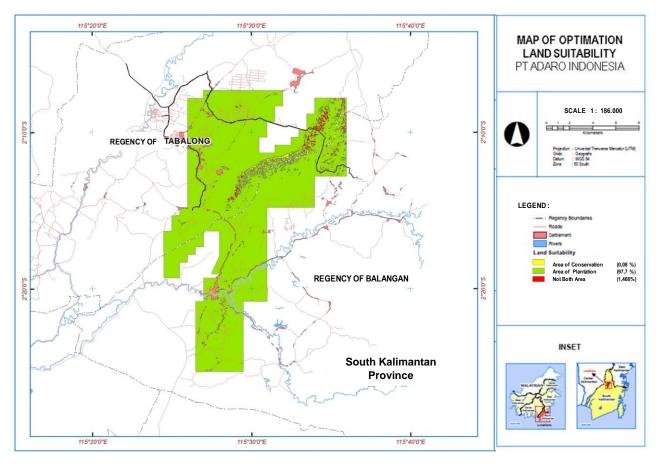

Fig. 4. Optimized Suitability Land Map at location of PT Adaro

Discussion

Table 4. The potential area Zone of remaining coal resources

Potential	Priority	Optimation	Large (Ha)	%
Very Potential	I	SM	10773	30
Potential	II	SM	2371	7
Sufficient Potential	III	SM	7612	21
Less Potential	IV	SD	7891	22
Not Potential	V	SD	6987	19.6
			35634	100

The table above shows that from the initial area of PT Adaro around 35.634 Ha., The area that still has the potential to have coal resources is about 20,755.9 Ha or 58.2%. While the area has the potential of remaining coal resources calculated based on the total area of PT Adaro actively reduced by the area of infrastructure is about 14,878 ha or 48.2%. If subdivided areas of potential area contain potential coal resources remaining 10.772,9 Ha or 30.23%, while the remaining area is categorized as very potential and potential.

From the above conditions can be shown that the area of PT Adaro Indonesia is still very potential to be optimized and cultivated for sustainable mining (SM) is an area of 10,772.9 ha or 30.23%. Another thing is to show that this mining company has an area of 9,983 Ha or 28.8% which is still feasible to continue its mining activities even though the age of the mine will end in 8 years. This condition is also supported by the company's statistics that the remaining coal resource content of PT Adaro's mine is still around 4 billion tons and reserves of about 2.3 billion tons and production rate of about 80 million tons.

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 for rubber plantation area (Pic. 4). 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.

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 plan give contribution significant enough out the mining sector. Social-economically, 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 (Fig. 4.). The Company also has an area of approximately 14,878 Ha or 48.2% which is feasible and significant to be diverted to other sectors outside mining activities ie to achieve complete sustainable development above can be seen in the following fig.

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 20,755.9 Ha or 58.2%., (see Fig. 3), so achieving sustainable mining after the lifetime of the mine is still possible. Potential areas are generally located in the rock 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. 4).

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