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APPLICATION OF ANALYTICAL HIERARCHY PROCESS (AHP) IN EVALUATING MEASURES FOR MITIGATION OF EMISSION IMPACT ON COMMUNITIES NEAR LIGNITE-FIRED POWER PLANT AT MAE MOH, THAILAND

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Abstract

A coal-fired steam power plant, located near an open pit coal mine in Mae Moh, Lampang, a province in the north of Thailand, has been in operation since 1978, with a generating capacity of 2,400 megawatts, and lignite consumption of 40,000 tons/day. A maximum hourly concentration of SO_2 of 3,418 μg/m^3 was measured and an emission of 150 tons/hour of SO_2 from the power plant was estimated. In order to mitigate the impacts of the emission on human health, crops and livestock, several measures have been implemented, such as (1) installation of flue gas desulphurization units (FGD), (2) remote monitoring stations, (3) corporate social responsibility (CSR) programs, and (4) community development fund. Nevertheless, there have still been complaints about the emission from the power plant and resistance to the operation of the plant. The objective of the study is to find out the preferred measures of the people who are directly exposed to the adverse effects of the pollution.

A survey was conducted in the area to interview the local villagers for their preferences among the four (4) measures with an inclusion of cessation of the plant as the fifth options. Fifty five (55) respondents who live in the vicinity of the power plant were asked to provide pair-wise comparison of their preferences of the five (5) alternatives based on four (4) different criteria as (A) job opportunity, (B) agricultural concern, (C) health improvement, and (D) public acceptability. Analytical hierarchy process (AHP) was applied to evaluate the results from the survey. The survey results show that health and income are the most important criteria. The community development fund is the most preferred alternative, while cessation of the power plant is the last option.

Key words: analytic hierarchy process, emission mitigation, Mae Moh coal-fired power plant

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1. Background and problem statement

Mae Moh power plant is a coal-fired steam power plant located in Lampang, a province in the north of Thailand. The power plant belongs to the Electricity Generating Authority of Thailand (EGAT) and consists of thirteen power generating units, which are fueled with lignite from the 135 square kilometers open pit mine nearby. The first unit was commissioned in 1978, and the rest were developed consecutively. The first three units with a capacity of 75 MW each were installed during 1978 to 1981, while units 4-7 of 150 MW each were started up during 1984 to 1985. The power generating units 8-13 with a 300 MW capacity each were commissioned during 1989 to 1995.

Since the last unit was connected to the grid in 1995, the power plant has been assigned as the base load generators as the cost of electricity generated from a lignite-fired power plant is lower than that from oil and natural gas. The first three units were then decommissioned in 2000. The plant continues

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delivering electricity by the remaining ten units with a total generating capacity of 2,400 megawatts, and lignite consumption of 40,000 tons/day.

1.1. Lignite quality and emission from the power plant

The design specifications of lignite required as fuel for the power plant are as shown in Table 1, while the low heating value (LHV) of the lignite supplied by the mine varies from 1,300 to 3,600 kcal/kg, and the average sulphur content is 2.88%.

Table 1. Design specifications of lignite to be used in the power plant (EGAT, 2013)

Parameters	***Unit 4-7***	***Unit 8-13***
LHV (kcal/kg)	2,011-3,299	2,000-3,100
Moisture (%)	25.0-38.9	25.0-36.0
Ash (%)	6.9-35.0	11.0-36.0
Sulphur (%)	1.32-4.00	0.94-3.35

It was reported that SO_2 emitted from the power plant which caused impacts to human health, crops and livestock, was measured in October of 1992 with a maximum hourly concentration of SO_2 of 3,418 $\mu g/m^3$. This was considerably higher than the standard level of 1,300 $\mu g/m^3$ (Wangwongwatana et al., 2003). SO_2 emission from the power plant was thus estimated in the study to be 150 tons/hour.

1.2. Impact mitigation

In order to mitigate the impacts of the emission on the surroundings, several measures have been implemented with regard to plant equipment modification and communication with people in the vicinity.

A. Flue gas desulphurization

From 1995 until 2000, flue gas desulphurization systems (FGD) were installed for units 4-13. No FGDs were installed for power generator units 1-3 as they were kept as cold stand-by units. The systems include wet limestone process for the scrubbing units which are capable of removing as much as 95% of SO_2. Limestone of an approximate amount of 0.89 million tons a year or 127 tons an hour required for the systems is acquired from a nearby area within the same district (EGAT, 2013). After the completion of the FGD installation, SO_2 emissions from the power plant were reduced from 150 tons/hour to less than 7 tons/hour, and the maximum hourly concentration of SO_2 was reduced from more than 3,000 $\mu g/m^3$ in 1992 to less than 500 $\mu g/m^3$ (Wangwongwatana et al., 2003). Presently, the strict control is required for the operation of the power plant, as the power plant is not allowed to operate without the FGDs in operation.

B. Remote monitoring stations

In addition to the continuous emission monitoring systems (CEMS) installed for all generating units to monitor SO_2 emitted from all stacks and alarm when the emissions exceed the control limits, an ambient air monitoring network was set up in the Mae Moh valley to ensure that the air quality was up to the standards. Regular monthly inspections are required to validate the ambient air quality in winter and once every two months for the rest of the year. Eleven air monitoring stations have been set up around the power plant. The 24-hour average concentrations of SO_2 in the ambient air from the monitoring stations are reported and available on-line at the Electricity Generating Authority of Thailand's website (EGAT, 2013).

C. Corporate Social Responsibility (CSR)

Activities are conducted by the power plant management through the corporate social responsibility (CSR) programs to improve the quality of life for the villagers. The programs are designed for community development and the participation of the people living around the power plant. This includes 42 villages in 5 sub-districts. The programs promote community development in education, culture, health, and careers, such as tree growing, monkhood entering ceremony, local music classes, small dam construction, training on agriculture and farming, etc.

D. Community development fund

Power plants are required to contribute to the community development fund, which is used to rehabilitate residents in the surrounding area who are affected by the plant's operation. During the plant's construction, the contribution is at a rate of 50,000 Baht/MW/year, while during the plant's operation the rates are different depending on the fuel type used for power generation, as shown in Table 2.

Table 2. Contribution Rates to the Community Development Fund imposed on power generation licensees during commission (ERC, 2013)

Fuel	***Satang*/kWh***	***Fuel***	***Satang*/kWh***
Coal, Lignite	2.0	Wind, Solar	1.0
Hydro power	2.0	Biomass, Biogas	1.0
Fuel oil, Diesel	1.5	Residues and Waste	1.0
Natural gas	1.0	Municipal solid waste	1.0
		Other renewable energy	1.0

** 100 Satangs = 1 Thai Baht = approx. 0.032 USD*

The Mae Moh power plant which is operated as a base load power generator, has contributed about 27 million Baht a month or 17% of the whole country to the community development fund (EPPO, 2010). The community development fund is used to develop or rehabilitate, and to increase the knowledge, the awareness and the participation of the localities who are affected by the power plant's operation.

Details of the purposes of the community development fund are as (ERC, 2013):

- to encourage the electricity industry licensees to extend their services to facilitate decentralization to provincial areas and to power consumers who are socially or economically deprived with compensation and subsidy;
- to compensate power consumers who have to pay higher tariffs due to unjust power generation;
- to develop or rehabilitate localities affected by power plant operation;
- to minimize the impacts on environment by promoting the use of renewable energy and technologies;
- to provide knowledge of power generation and its environmental effects, and to encourage awareness and participation in energy efficiency improvement of local communities;
- to pay for the administrative cost of the fund.

Although a great amount of effort has been expended through the above mentioned measures, there still exist complaints about the emission from the power plant and resistance to the operation of the plant. Therefore, it is worth finding out about the preferred measures for the people who are directly exposed to the adverse effects of the pollution. The findings will be useful for future planning for the mitigation of the emission impacts.

1.3. Literature review

A. Emission from Mae Moh coal-fired power plant

Brigden et al., (2002) reported that samples of fly ash from two coal fired power plants located in Thailand; Mae Moh coal fired power plant in Lampang and Thai Petrochemical Industry (TPI) coal fired power plant in Rayong were collected and analyzed in 2002. All samples were found contaminated with a range of toxic and potentially toxic elements including arsenic, chromium, lead and mercury. The total annual quantities of each element contained in the fly ashes produced by both power plants were estimated from the annual quantities of fly ash. It was recommended to avoid the releases of toxic and potentially toxic elements to the environment through the cessation of coal combustion and the implementation of sustainable technologies. Wangwongwatana et al., (2003) reported that SO_2 emission after the installation of FGD was reduced from 150 tons/hour to less than 7 tons/hour. It was the result of the strict control imposed on the operation of the power plant, which was not allowed to operate without FGD in operation. The observed maximum hourly concentration of SO_2 was reduced from more than 3,000 μg/m^3 in 1992 to less than 500 μg/m^3. Punyawadee et al., (2006) carried out a cost-benefit analysis of the flue-gas desulfurization (FGD) systems installed at the Mae Moh coal-fired power plants.

The detailed direct investment in the FGDs installed at the Mae Moh power plant in the northern region of Thailand to reduce the adverse environmental impacts resulting from SO_2 emissions was analyzed, and the indirect costs of carbon dioxide emissions attributed to the FGD process were estimated. A ‘before and after’ study of the impacts caused by air pollution on human health, local agriculture and forest productivity in the area surrounding the power plant were assessed. The cleanup technology by using FGDs was found ineffective in terms of cost and benefit, and cheaper options should be considered.

B. Analytical Hierarchy Process and its application

AHP which is intended to be used as a decision-making tool, was first developed by Professor Thomas L. Saaty. It has been viewed as a multi-criteria decision-making (MCDM) tool, which can consider both tangible and intangible criteria. There are many decision making studies that utilize the analytic hierarchy process (AHP) as a tool for the determination of the best alternative.

Zeng et al., (2007) presented a modified analytical hierarchy process to structure and prioritize diverse risk factors in construction. Risk analysis of steel erection of a superstructure in a shopping center was used to demonstrate the effectiveness and efficiency of the proposed methodology. Four scenarios for an expansion of the electricity system in Greece were examined by Diakoulaki and Karanggelis (2007) by using two decision support techniques, multi-criteria decision analysis and cost-benefit analysis. It was confirmed with both evaluation approaches that the best scenario for the Greek power generation sector was the one that assumed the highest penetration of renewable energy sources. Yedla and Shrestha (2007) presented a comparative analysis of different group aggregation methods adopted in AHP, and demonstrated that weighted arithmetic mean method with equal weights (WeAMM) resulted in better aggregation of individual member priorities compared to weighted arithmetic mean method with varying weights (WAMM). Kahraman and Kaya (2010) proposed the fuzzy multi-criteria decision-making methodology to determine the best energy policy for Turkey. Daniel et. al., (2010) attempted to prioritize the renewable energy sources available in India like solar, wind and biomass, using Analytical Hierarchy Process (AHP) with a consideration of important parameters like cost, efficiency, environmental impact, installed capacity, estimated potential, reliability and social acceptability. The result of the survey showed the order of merit as wind energy (0.501), biomass energy (0.288), and solar energy (0.2056) with respect to Indian policies and conditions to meet the future energy demand. Chatzimouratidis and Pilavachi (2012) assessed both positive and negative factors affecting the quality of life. These factors were generated by 10 major types of power plants under 12 criteria.

There were 13 fixed and infinite customized probability assessed weight set scenarios with AHP. The power plants in consideration ware coal/lignite, oil, natural gas turbine, natural gas combined cycle, nuclear, hydro, wind, photovoltaic, biomass and geothermal. Geothermal, wind and photovoltaic power plants were found to be excellent choices in most of the cases. Biomass and hydro power should also be preferred to nuclear and fossil fuel. Zimmer et al., (2012) presented the support of a bid decision with AHP, based on the three basic project evaluation criteria realization for projects in the power plant industry: chance (go), award chance (get) and profitability. The impacts of the intervention policies such as -30% target, set-aside, carbon central bank, and long-term target, on the emissions trading system carbon price and emissions were analyzed by Clo et al., (2013). An application of a multi-criteria evaluation method was utilized to compare the policy options against several criteria. The criteria are environmental performance, political acceptability, and feasibility of implementation. It was found that the final ranking depended on the criteria or goals to be achieved.

2. Methodology

2.1. Analytical hierarchy process (AHP) and Applications

AHP structures a decision problem into a hierarchy with a goal, criteria and alternatives, as shown in Fig. 1 (Saaty, 1980). The AHP key characteristic is the pairwise comparison for scoring each alternative under the criteria. The scores are given by pairwise comparison between the different alternatives by using a relative scale measurement which ranges from 1 to 9. 1 means equally preferred and a greater number means a higher preference as detailed in Table 3. Each criterion and alternative is considered independently from another. The pairwise comparison values a_{ij} is written as a matrix A (Eq. 1), where $a_{ji} = 1/a_{ij}$ or the matrix A is reciprocal, a_{ij} can be further represented by a ratio of weights w_1, w_2,….., w_n as given by Eq. (2).

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & \dots & a_{nn} \end{bmatrix} \quad (1)$$

$$a_{ij} = \frac{w_i}{w_j} \quad (2)$$

where i, j = 1, 2, 3, …, n.

Then the matrix A can be written as (Eq. 3):

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & \dots & w_n/w_n \end{bmatrix} \quad (3)$$

It is observed that (Eqs. 4, 5):

$$a_{ij}, a_{ji} = 1 \quad (4)$$

where i,j = 1, 2, 3, …, n, and

$$a_{ij}.\frac{w_j}{w_i} \quad (5)$$

where i, j = 1, 2, 3, …, n,

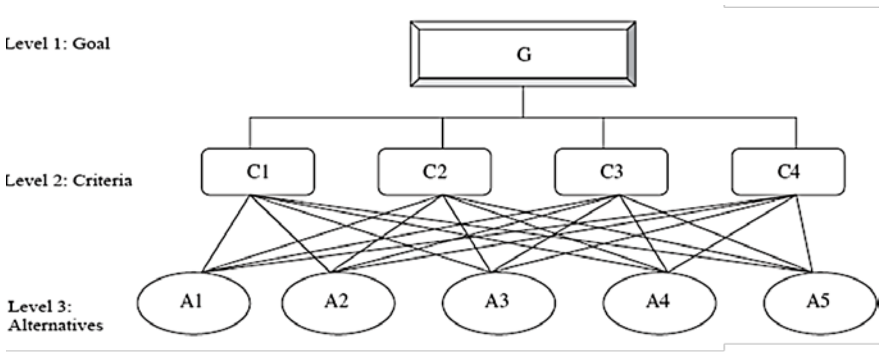

Fig. 1. Hierarchy structure of AHP

Table 3. Pair-wise comparison scale for AHP preferences (Saaty, 1980)

Numerical rating	***Verbal judgments of preferences***
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Consequently, the relationship among A, w, and n can be derived as given by Eqs. (6, 7).

$$\sum_{j=1}^{n} a_{ij} \frac{w_j}{w_i} = n \quad (6)$$

where i, j = 1, 2, 3,…, n

and

$$\sum_{j=1}^{n} a_{ij} w_j = n w_i \quad (7)$$

which is equivalent to Eq. (8):

$$Aw = n w_j \quad (8)$$

or (Eq. 9):

$$\begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & \dots & w_n/w_n \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ \dots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ \dots \\ w_n \end{bmatrix} \quad (9)$$

It can be shown that w_i is the average of $a_{ij}.w_j$ by re-writing Eq. 7 into Eq. 10. The weight w_i is less affected by small changes in a_{ij} when n is close to its largest value, which is denoted as λ_{max} or largest eigenvalue.

$$w_i = \frac{1}{n} \sum_{j=1}^{n} a_{ij} w_j \quad (10)$$

where i, j = 1, 2, 3,…, n

As a result, the matrix A is consistent with small variations of a_{ij} and n is close to the largest eigenvalue, λ_{max}. Thus it is desirable to find the priority vector w which satisfies Eq. (11):

$$Aw = \lambda_{max} \quad (11)$$

The consistency index can be calculated by Eq. (12):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (12)$$

Further, the consistency ratio (CR) is defined as given by Eq. (13):

$$CR = \frac{CI}{RI} \quad (13)$$

where the random index, RI, for various matrix sizes are given in Table 4. A consistency ratio of 0.1 or less is considered acceptable.

Table 4. Average random index for different matrix size (Saaty, 1980)

n	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41
n	***9***	***10***	***11***	***12***	***13***	***14***	***15***	
RI	1.45	1.49	1.51	1.48	1.56	1.57	1.59	

where n is Matrix size, RI: Random index.

There are four criteria included in the study:
1. Health improvement
2. Agricultural concern
3. Income and job opportunity
4. Public acceptance.

The following mitigation measures are considered as alternatives for the relief of the concerns.
1. Community development fund
2. Corporate social responsibility (CSR) programs
3. Remote monitoring
4. Flue gas desulfurization
5. Stopping the plant operation.

2.2. Survey sampling

A survey was conducted to interview the residents who reside in the area and have been affected by the pollution emitted from the lignite power plant in Mae Moh. The samples were randomly selected from the two sub-districts, Som Pad and Ban Dong, which are most impacted by the pollution (Fig. 2).

Two of the most affected villages by the power plant operation were selected. One of them is Sob Pad Village which is located about 5 kilometers south of the power plant. The other is Ban Dong Village, which is about 5 kilometers north of the coal mine. A total of 55 households were interviewed.

2.3. Answer boards

The interviewees were asked to compare the severity of impacts and preferences in different measures. Regular question-and-answer could cause confusion and did not allow the interviewees to verify their answers.

Answer boards were prepared for convenience for the interviewees. A set of answer boards consisted of a comparison of impacts and a comparison of measures. The answer boards including all possible pairs for comparison and scales 9-1-9 with sliding indicators are provided for interviewees to state their choices and verify their selections after completion.

The criteria and alternatives can be structured as shown in Fig. 3.

2.4. Calculation and software

The data obtained from survey was processed by using the AHP Excel template version 19.02.13 provided by Klaus (2013). The template was designed for a maximum number of criteria of 10 and a maximum number of participants of 10, with the geometric average method for multiple participants. The template was expanded to include up to a maximum number of 60 participants, in spite of the actual number of participants of 55.

3. Results and discussion

Among the four criteria (health, income and job opportunity, agricultural concern, and public acceptance), income and health were of the most concerns of the interviewees. They were weighted at 0.373 and 0.345 respectively, while public acceptance and agriculture were 0.152 and 0.130.

The resulting priorities given for the measures with respect to each criterion are illustrated in the following sub-sections.

3.1. Criterion 1: Health

For the concern for health, the interviewees agreed that flue gas desulfurization and the improvement of the environment through CSR programs were the two major mitigation measures, being weighted 0.302 and 0.287 respectively. The comparison is represented by priority ratios as shown in Fig. 4.

Remote monitoring stations and community development fund were ranked in the second group with weights of 0.180 and 0.156 respectively, as shown in Table 6. Closing down the power plant seemed to be the last choice for the interviewees. It weighted at 0.074. The consistency ratio is as low as 0.018, which is acceptable. The comparison results of the four criteria are shown in Table 5, with a consistency ratio of 0.050 which is less than 0.1.

Fig. 2. Locations of villages in Mae Moh

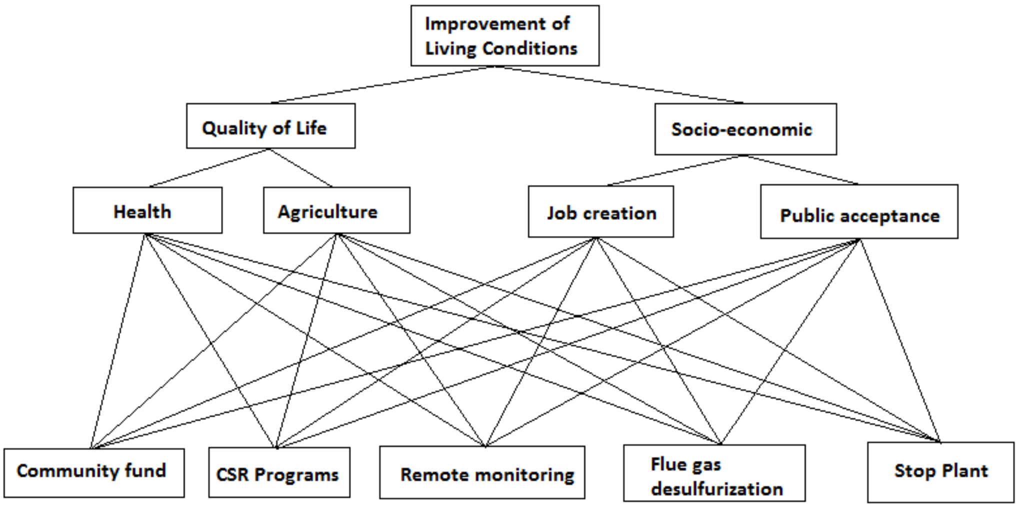

Fig. 3. Hierarchy structure of criteria and alternatives

3.2. Criterion 2: Agriculture

Focusing on the agriculture, in the view of the interviewees, the community fund, flue gas desulfurization units, and CSR programs were the measures that could be the effective remedies. They were weighted of 0.278, 0.254, and 0.212 respectively, while remote monitoring stations and the ceasing of plant operation were 0.180 and 0.076, as shown in Table 7.

The consistency ratio of 0.009 shows a very good consistency of the comparison.

3.3. Criterion 3: Income and job opportunity

Table 8 shows that the community development fund was accepted as the best measure to ease off the concerns of income and job opportunity with a weight of 0.451. Flue gas desulfurization units, CSR programs, and remote monitoring stations are grouped with weights of 0.181, 0.180, and 0.127 respectively. Stopping the plant's operation is the last option with a weight of 0.061. The comparison is acceptable as the consistency ratio is 0.037 which is less than the limit of 0.1.

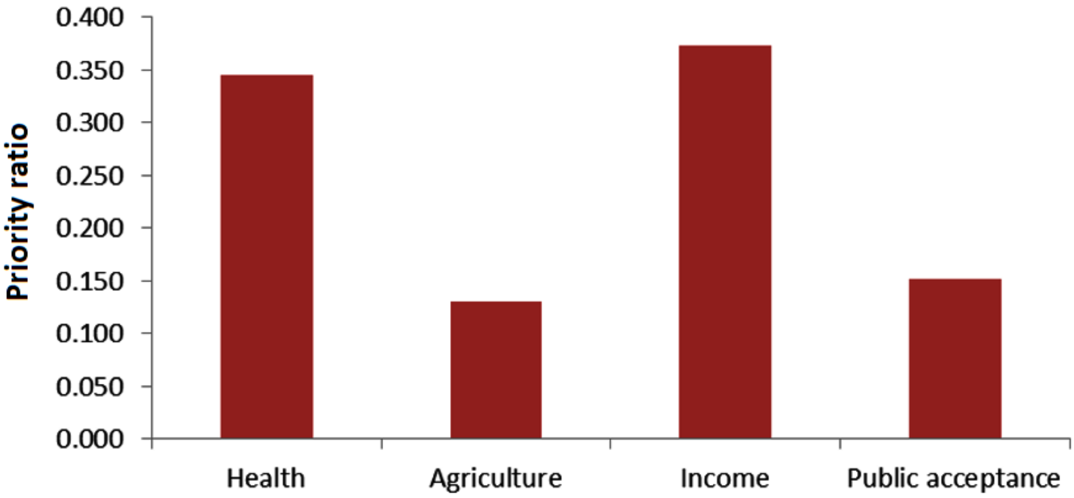

Fig. 4. Priority ratios of different criteria

Table 5. Consolidated pairwise comparisons of different impacts

Impacts	*Health*	*Agriculture*	*Income*	*Public acceptance*	*Priority vector*
Health	1	4 2/9	3/5	2	0.345
Agriculture	9/38	1	5/11	1	0.130
Income	1 2/3	2 1/5	1	2	0.373
Public acceptance	1/2	1	1/2	1	0.152

λ_{max} = 4.134; CI = 0.04; RI = 0.900; CR = 0.050

Table 6. Priorities of the measures for the concern for health

Measures	*Community Fund*	*CSR Programs*	*Remote Monitors*	*FGD*	*Stop Operation*	*Priority Vector*
Community Fund	1	5/9	3/4	2/5	3	0.156
CSR Programs	1 7/9	1	1 5/7	1 1/8	3 1/3	0.287
Remote Monitors	1 1/3	4/7	1	1/2	3	0.180
FGD	2 1/2	8/9	2	1	3	0.302
Stop Operation	1/3	3/10	1/3	1/3	1	0.074

λ_{max} = 5.079; CI = 0.020; RI = 1.120; CR = 0.018

Table 7. Priorities of the measures for the concern for agriculture

Measures	*Community Fund*	*CSR Programs*	*Remote Monitors*	*FGD*	*Stop Operation*	*Priority Vector*
Community Fund	1	1 5/8	1 1/2	8/9	3 7/9	0.278
CSR Programs	8/13	1	1 2/5	1	2 1/2	0.212
Remote Monitors	2/3	5/7	1	2/3	2 3/4	0.180
FGD	1 1/8	1	1 1/2	1	3	0.254
Stop Operation	9/34	2/5	4/11	1/3	1	0.076

λ_{max} = 5.041; CI = 0.010; RI = 1.120; CR = 0.009

3.4. Criterion 4: Public acceptability

The interviewees credited CSR programs and flue gas desulfurization units with help in gaining back public acceptability of the area, with the weights of 0.298 and 0.289, respectively, as shown in Table 9. Also, community development funds and remote monitoring stations were in the second group with 0.185 and 0.168 weights.

Shutting down the plant was weighted as 0.060 as the last among all of the choices. The consistency ratio of 0.008 indicates an acceptability of the result. The priority ratios of the criteria and mitigation measures can be illustrated in the hierarchy structure as shown in Fig. 5.

The priorities for the mitigating measures are consolidated by the inclusion of the weights of the criteria, as shown in Table 10. The community development fund is the first with a weight of 0.286 when the criteria weightings are included. Flue gas desulfurization units and CSR programs are closely weighted at 0.249 and 0.239, respectively, and followed by remote monitoring stations with a weight of 0.158. The option of turning off the operation of the plant is the last with 0.067 weight. The option of shutting off the power plant is in the last of the priority list of the consolidated prioritized mitigating measures as shown in Fig. 6.

4. Conclusions

The survey results can be concluded as follows:

A. Community development fund is agreed by the interviewees to be the most powerful measure that could help in easing the concerns, especially for the concerns of income and job opportunity, and agriculture. It is worth noting that although most of the interviewees are aware of the existence of the community fund, it is not clear to some of them about the amount and how it is spent.

Table 8. Priorities of the measures for the concern for income and job opportunity

Measures	*Community Fund*	*CSR Programs*	*Remote Monitors*	*FGD*	*Stop Operation*	*Priority Vector*
Community Fund	1	3 3/5	4	2 2/3	4	0.451
CSR Programs	5/18	1	1 8/9	1	3 3/7	0.180
Remote Monitors	1/4	9/17	1	5/7	3 1/6	0.127
FGD	3/8	1	1 2/5	1	3 1/2	0.181
Stop Operation	1/4	7/24	6/19	2/7	1	0.061

λ_{max} =5.166; CI = 0.041; RI = 1.120; CR = 0.037

Table 9. Priorities of the measures for the concern for public acceptability

Measures	*Community Fund*	*CSR Programs*	*Remote Monitors*	*FGD*	*Stop Operation*	*Priority Vector*
Community Fund	1	4/7	1	2/3	3 3/4	0.185
CSR Programs	1 3/4	1	2	1	4 3/8	0.298
Remote Monitors	1	1/2	1	1/2	3 1/3	0.168
FGD	1 1/2	1	2	1	4	0.289
Stop Operation	4/15	8/35	3/10	1/4	1	0.060

λ_{max} = 5.037; CI = 0.009; RI = 1.120; CR = 0.008

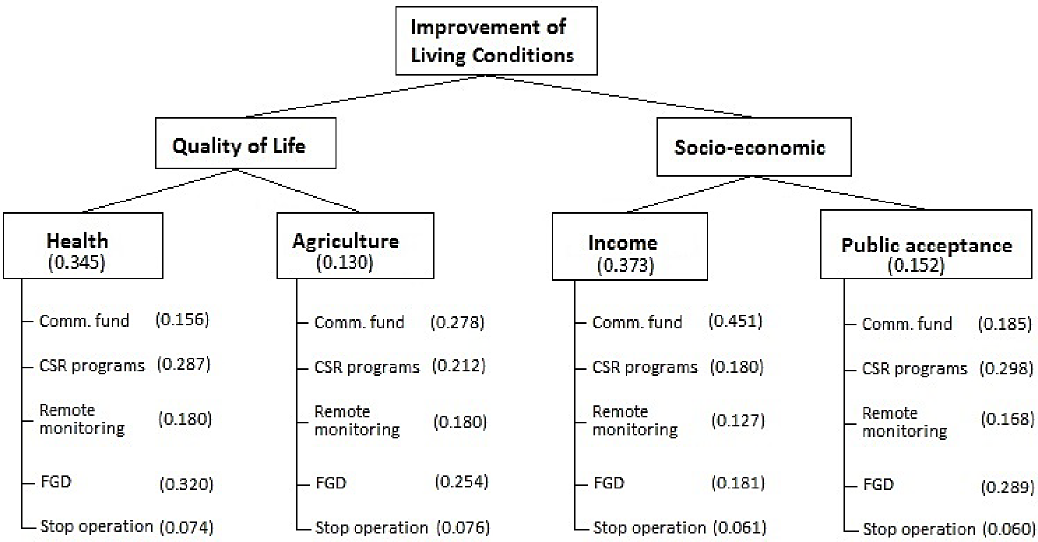

Fig. 5. Priorities of criteria and mitigation measures (Values in parentheses are priority ratios)

Table 10. Consolidated percentages given for the measures

Mitigation measures	***Criteria***				
	Health 0.345	***Agriculture 0.130***	***Income 0.373***	***Public 0.152***	***Total***
Community Fund	0.156	0.278	0.451	0.185	0.286
CSR Programs	0.287	0.212	0.180	0.298	0.239
Remote Monitoring	0.180	0.180	0.127	0.168	0.159
Flue Gas Desulphurization	0.302	0.254	0.181	0.289	0.249
Stop Operation	0.074	0.076	0.061	0.060	0.067
					1.000

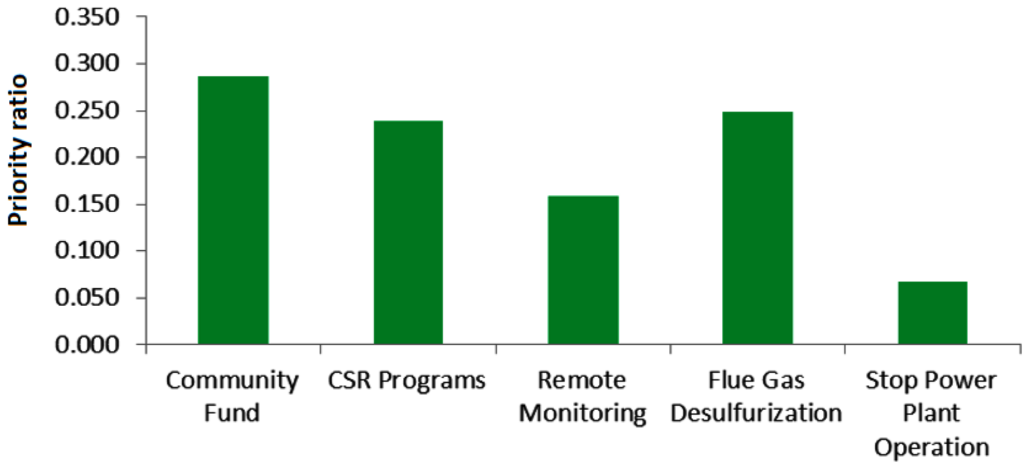

Fig. 6. Consolidated priority ratios of mitigating measures

B. Regardless of the resistance raised among the villagers against the plant operation, the survey results show that the emission from the power plant is not a strong concern any more. Cessation of the power plant is the last option among all measures. This could be credited to other measures that are continuously implemented to improve the environment and the living conditions of the villagers.

C. The interviewed villagers gave their answers without asking for clarification of the technical terms, which implies that they have full knowledge of the complicated systems such as flue gas desulfurization units and remote monitoring systems. This can be the result of good publicity and CSR programs of the plant operators.

D. It is noticeable that health and income are the most important criteria with significant weights for the villagers. Agriculture is weighted the least, which implies that either agriculture is not the main source of income or there is adequate compensation from other sources.

E. The calculated consistency ratios (CR) for the criteria and measures are less than the required ratio of 0.1, ranging from 0.008 to 0.050. This confirms consistency of the result from the survey.

F. The spreadsheet provided by Kluas (2013) is a powerful program for the calculation of the geometric mean of the answers from a large number of samples. The program simplifies the calculation and provides suggestions for adjustment.

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