An ANP (Analytic Network Process)-based Multi-Criteria Decision Approach for The Selection of Sugar-Cane Industry Development

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Abstract*—Acknowledging the issue of energy sustainability, the sugar industry has begun to look at plans to sell electricity to address energy sustainability issues. A scenario with the potential to sell excess electricity motivates this research to analyze the strategies of the sugar industry development. In such situations an ANP approach is applied for the selection of appropriate strategies. This study analyzes the potential for electricity sales in two alternative plant development strategies of three sugarcane industries which from the results, Strategy A (cogeneration scheme) allows to sell electricity for 223-293 days while strategy B (independent power plant scheme) allows to sell throughout the year. The result also shows that by using ANP, it is found that strategy A is better than strategy B.

***Keywords*—Energy Sustainability, Electricity Sales, ANP, Sugar Industry.**

I. Introduction

The issue of energy sustainability is a global problem that the world is facing. It has driven renewable energy considerations to combat energy shortage [1]. Moreover, environmental issues coming in the path of sustainable development which drives the green energy resources to play a very crucial role [2]. This issue encourages industries to begin strategizing necessary measures to overcome this. Numbers of studies are found on deciding the potential energy which can maximize the beneficial of renewable energy for sustainable development. In many countries like Brazil and Thailand, the sugar industry has also begun to eye the action for electricity sales to address energy sustainability issues. Electricity generation through bagasse cogeneration is efficacious energy scheme and very utmost [3]. By strategizing energy efficiency measures, it will be possible to the sugarcane industry produce surplus electricity besides the sugar product [4].

A scenario with the potential to sell excess electricity to the distribution network, or else, using bagasse as a feedstock for other processes, motivates this research to analyze the potential of the sugar industry to generate electricity. However, the existence of alternative schemes for the selection of energy sustainability and the diversity of criteria that become the standard of consideration make decisions must be done carefully. In situations like this the Multi-Criteria Decision Analysis (MCDA) approach is very useful for choosing the right alternative.

MCDA is an integrated form of sustainability evaluation which is an operational evaluation and decision support approach appropriate to address complex issues (high uncertainties, conflicting goals, different forms of data and information, multiple interests and perspectives, and complex and growing considerations Biophysical and socio-economic systems). There are several methods in MCDA such as SMART, Swing, AHP, ANP, WSP, WSM, TOPSIS, ELECTRE, PPROMETHEE, and many others. MCDA is used in many problem evaluation for multi disciplines, such as technology selection on energy exploration [5], manufacturing, land use [6], energy sources, sustainable development [7], agriculture [8], and many others.

Analytic Network Process (ANP) is one of the best methods in multi-criteria decision analysis. It has significant power in decision making when an extensive number of criteria are involved [9]. Because of these advantages, this method is designated as a method for solving decision-making problems of this study.

Analytic Network Process (ANP) is a simplification of Analytic Hierarchy Process (AHP) which taking into account the dependence between hierarchical elements. Many decision-making problems can not be structured hierarchically because they involve higher-level elemental interactions and dependencies in the hierarchy at lower-level elements. Therefore, ANP is represented by a network, not a hirarchy. The feedback structure does not have a top-down shape of the hierarchy but is more like a network, with cycles connecting element components, which can not be called a level.

ANP is a method that produces a framework to solve the problems of decision makers without making assumptions related to independency between higher level elements with weakness and independency of elements in one level. ANP uses a network without specific explanation of the existing levels as in a hierarchy [10]. Interaction activity is the core concept of ANP.

ANP involves a hierarchical relationship but does not require a standard structure such as AHP, so it can handle complex relationships between decision levels and attributes. ANP consists of two parts, the first is the hierarchical control or network criteria and subcriteria that control the interaction and the second is a network that

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describes the interplay between elements [10]. In ANP also used pairwise comparison method as in AHP with a relative scale.

II. Model Concept

The scope of this study is to investigate the best plant development strategies for three sugarcane industries within Tebuireng cluster. This study first analyzes the availability electricity generation of each strategy through thermodynamics calculation. After the availability of electricity generation is identified, ANP model is applied to solve the problem of decision making the best development strategy.

The initial step in solving decision making problem with ANP algorithm is identifying the decision criteria of the main problem. There are two groups of criteria to be determined: the criteria of the technical and non-technical aspects. The criteria of the technical aspects that must be met by each scenario alternatives are the aspects that favor the bagasse as a source of biomass such as the criteria of biomass source mobilization, the securities of biomass availability and the energy value that can be used in the biomass. In the other hand, the criteria of the non-technical sectors to be considered are the criteria of the social and economic aspects. Social aspects may vary from the benefits or social managerial implications that coming up from the development of the plant and the economic aspects can be the various costs that arise; operating costs and maintenance; and the cost installed. All good criteria from all aspects will then be developed in accordance with the results of the field survey.

An Analytic Network Process (ANP) model was established to make decisions. The criteria used to serve as the basic aspects of the assessment are classified into three aspects namely technological, economic and social. Technological aspects consist of energy generation (c1), availability of energy generation (c2) and bagasse mobility (c3); economic aspects comprises investment cost (c4) and operational & maintenance cost (c5); and social aspects is composed of social benefit (c6) and management & administration (c7).

Those seven indicators are generated based on the technological, economic, and social criteria. These indicators are selected as a basis for evaluating the choice of plant development strategies provided. These indicators are detailed in table 1, the arrows on the indicator indicate the direction of the priority vector of each indicator where the upward arrow indicates the higher the value on the indicator the better the alternative. This indicator is described briefly as follows:

- Energy generation. This indicator should be considered to measure the importance of future PG development strategies in line with energy sustainability objectives of selling electricity.
- Availability of energy generation. This indicator represents the amount of time of the plant ability to generate electricity over a period of time, where one of the regulation of electricity sales to the grid sees the availability of electricity generation time
- Bagasse mobility. This indicator becomes necessary to consider as it will affect the cost of electricity production due to its inherent cost of transport.
- Investment costs. These important economic indicators include all purchases and installations of energy cost technologies such as mechanical equipment, engineering services and construction costs.
- O&M costs. In order to measure operating and maintenance costs of both variable costs and fixed costs of products and services over any period of time, this indicator should be considered.
- Social benefits. This demonstrates the benefits of technological development to the community, thus, this indicator signifies a major influence on the direction of development.
- Management and Administration. This indicator is covered by the company's administrative headquarters in assessing the proposed alternative strategy.

Criteria	Indicator
Technological	↑Energy generation (c_1)
	↑Avalability of energy generation (c_2)
	↓Bagasse mobility (c_3)
Economic	↓Investment costs (c_4)
	↓O&M costs (c_5)
Social	↑Social benefits (c_6)
	↑Management and administration (c_7)

In order to overcome the decision-making problems, the main problem has to be pointed out and structured. Structuring decision-making is started by organized the process for engaging multiple stakeholders interest that appraise both facts and standards [11].

Once the decision criteria are established, alternatives are then explored to resolve the problem in this study. In order to spawn the potential alternatives, these alternatives are then discussed carefully in number of iteration according to the main problem of this research. The results of the iteration are then proposed to develop the plant in order to achieve the goal of energy sustainability at the Tebuireng cluster sugar plant which is conical into two alternative strategies as follows:

- Strategy A. Develop each plant into a more efficient cogeneration plant so that the plant can be self-sustaining energy and has an energy surplus that can be converted into electricity.
- Strategy B. Develop one of the plants to become an independent power plant within the Tebuireng cluster, where the other plant remains an energy independent sugar mill and has an energy surplus that can be converted into electricity during the milling season.

In this ANP model, this study wants to analyze the priority weight of both strategies by adding the dependency influence from the management & administration criterion (c7) towards all technological aspects (see figure 1). The influence that is used as one aspect of strategic appraisal is considered because of the dynamics of interest that exist in the management domain, considering that it concerns three sugar factories that have their own management system. There will obviously be a big adjust if the management system due to one or another reason become mixed up with each other, like the issue about f energy generation into electrical energy in each plant, for instance. This problem undoubtedly makes the direction of decision-making more unclear when compared with the judgment that is merely assessing alternative strategies based on stand-alone decision criteria without any interrelationships influences. For this reason, this research will assess alternative strategies available using seven indicators of decision criteria that have an influence relationship between the indicators that best illustrated in figure 1.

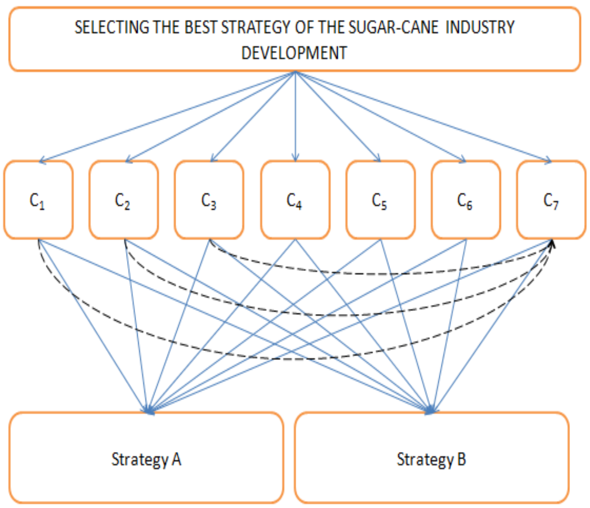

Figure 1. ANP model concept for selecting the best strategy

III. Results and Discussion

Based on secondary data obtained from the field, the capacity of sugar cane processing in 2015 for the Tebuireng cluster reaches 1,211 kilotons with sugar processing capacity at the plant of 438 kilotons, 471 kilotons and 301 kilotons respectively. There are two potential alternative plant development strategies to offer: the first strategy is to develop each plant to implement a cogeneration-based technology known as combine heat and power (CHP) and the second strategy is to make one power plant separate from the sugar factory by appointing a sugar plant to become power plant where the sugar production from this plant will be transferred to two other factories according to their respective sugar production capacity. By applying the first law of thermodynamics through Rankine cycle model, it derives energy surplus sourced from bagasse with energy values that can be converted to electrical energy for sale to the grid during the milling season. While the remaining excess bagasse used in the milling season can be sold to the grid for a certain period.

Table 1.
Pairwise comparison

	Tech.	economic	social	Weight	Normalized weight
Tech.	1	3	5	1,91	0,64
economic	0,33	1	3	0,77	0,26
social	0,2	0,33	1	0,32	0,11
Total	1,53	4,33	9	3	1
	c1	c2	c3	Weight	Normalized weight
c1	1	3	5	1,91	0,64
c2	0,33	1	3	0,77	0,26
c3	0,2	0,33	1	0,32	0,11
Total	1,53	4,33	9	3	1
	c4	c5		Weight	Normalized weight
c4	1	2		1,33	0,67
c5	0,5	1		0,67	0,33
Total	1,5	3		2	1
	c6	c7		Weight	Normalized weight
c6	1	2		1,33	0,67
c7	0,5	1		0,67	0,33
Total	1,5	3		2	1

The result shows that both of strategy A and B can meet the energy need for production, however, strategy B have longer electricity sales availability (full year sales) compared to strategy A which can sell for about 223-292 days.

ANP approach has been implemented to find the best strategy for developing sugar industry in order to address sustainability energy issues. Table 1 lists the weight of each indicator that obtained from pairwise comparison. This weight is then used as input for the ANP model that has been built. After determining the weight vector of criteria using pairwise comparison, the ANP will perform the weighting task in accordance with the influence relationships set in previous section which will result in a weighted supermatrix (table 2). After the weighted supermatrix is obtained, the ANP then multiplies the weighted supermatrix by itself until several times, or in other words, the weighted supermatrix is lifted by the number k (where k is arbitrarily large number) until the weights meet and become stable. When the weight of each column has the same value, the limit of supermatrix has stabilized and the matrix multiplication process is stopped and becomes a limited supermatrix (table 3). The value of each line in the supermatrix limit is then normalized and becomes the priority weight value of each alternative.

TABLE 2.
WEIGHTED SUPERMATRIX

	Goal	Strategy A	Strategy B	Tech.	Economic	Social	c1	c2	c3	c4	c5	c6	c7
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy A	0	0	0	0	0	0	0.3	0.08	0.38	0.3	1	0.33	0.8
Strategy B	0	0	0	0	0	0	0.3	0.42	0.13	0.8	1	0.67	0.3
Tech.	0.64	0	0	0	0	0	0	0	0	0	0	0	0
Economic	0.26	0	0	0	0	0	0	0	0	0	0	0	0
Social	0.10	0	0	0	0	0	0	0	0	0	0	0	0
c1	0	0.25	0.04	0.64	0	0	0	0	0	0	0	0	0
c2	0	0.04	0.08	0.26	0	0	0	0	0	0	0	0	0
c3	0	0.04	0.22	0.10	0	0	0	0	0	0	0	0	0
c4	0	0.06	0.28	0	0.67	0	0	0	0	0	0	0	0
c5	0	0.28	0.06	0	0.33	0	0	0	0	0	0	0	0
c6	0	0.28	0.04	0	0	0.67	0	0	0	0	0	0	0
c7	0	0.06	0.29	0	0	0.33	0.5	0.5	0.5	0	0	0	0

TABLE 3.
LIMITED SUPERMATRIX

	Goal	Strategy A	Strategy B	Tech.	Eco.	Social	c1	c2	c3	c4	c5	c6	c7
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy A	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Strategy B	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Tech.	0	0	0	0	0	0	0	0	0	0	0	0	0
Economic	0	0	0	0	0	0	0	0	0	0	0	0	0
Social	0	0	0	0	0	0	0	0	0	0	0	0	0
c1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
c2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
c3	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
c4	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
c5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
c6	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
c7	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

The results shows that by applying ANP method, the priority weight of strategy A is higher than strategy B which means that strategy A is better to execute than strategy B. Figure 2 shows priority weight both of strategy A and B for each criterion. It can be seen that priority weight related to goal of the selection, strategy A is 0.52 while strategy B is 0.48.

By using ANP algorithm to this selection problem, the priority weights for particular criterion changed dramatically from the original value that inputted in pairwise comparison. This is due to the influence of dependency between criteria as illustrated in figure 1. The results also shows that for particular criterion, c1, c5 and c6, strategy A dominates priority weights excellence against strategy B, in contrast, strategy B is superior in criterion c2, c3, c4 and c7 compared with the strategy A.

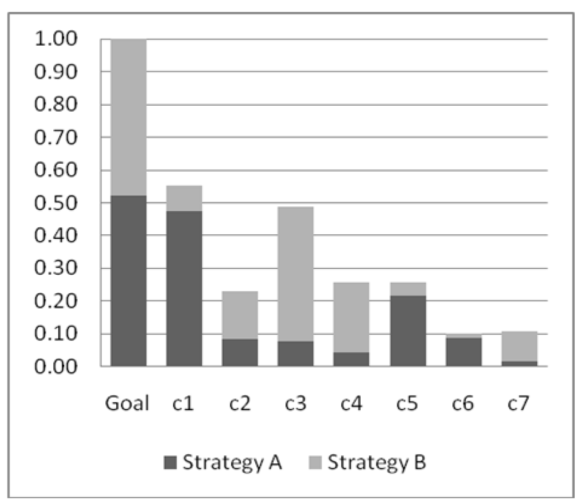

Figure 2. Priority weight of each of the alternatives.

IV. CONCLUSION

By using bagasse, the plant can meet the energy needs for production and can sell excess power to the grid through both cogeneration scheme and independent power plant with sales availability at roughly 223-292 days for cogeneration schemes and full year sales (365 days) for a independent power plant scheme. The result shows that by implementing ANP in the selection of the best factory development strategy, the priority weight of strategy A higher than strategy B, where each priority weight is 0.52 and 0.48 consecutively. Likewise, in indicator c1, c5 and c6 strategy A is better than strategy B.

The current work has still few limitations and can be improved in the future:

- The decision criteria are taken into account while it is not considered the business and environmental criteria.
- Our approach based experiment result performance can be evaluated with available methods

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