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Developing Sustainability Index for Malaysian Palm Oil Industry with Fuzzy Analytic Network Process

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As one of the world's major exporters of crude palm oil, Malaysian palm oil industry plays a crucial role in the country's economic development. The utilization of palm oil biomass residues into high value-added products also has grown tremendously in recent years and has significantly contributed to the country's GDP. Despite obvious benefits to the country's economy and welfare of its population, the oil palm industry also contributes to environmental degradation, both at the input and output sides of its activities. Therefore, it is imperative that the implementation of sustainable supply chain and green logistics practices should be considered within the industry. With increasing pressure from various stakeholders to act and report on sustainability best practices, a number of sustainability assessment tools have emerged and some of which are adopted by industry players to demonstrate their commitment to sustainable development. Sustainability indicators and composite index are increasingly recognized as a powerful tool for policy making and corporate communication in providing information on sustainability performance in areas such as environment, economy and society. The uncertain parameters are particularly noticeable in the palm oil industry since the demand and supply are very volatile, and there are many uncertain variables associated with the industry's supply chain. The fuzzy analytical network process (FANP), a multi-criteria decision-making analysis tools that has been applied to problems in various industries is adopted in this work. A complex of relationships between economic, environmental and social performance indicators related to the oil palm industry is constructed as a network model. Pairwise judgements are then elicited from experts to derive priority weightages for every component in the sustainability model. Varying with traditional ANP, using fuzzy numbers for pairwise comparisons ratios allows the confidence level of the judgements to be quantified explicitly. Converged priority vector that captures the correlation and importance of named indicators is then converted to form the sustainability index. The sustainability index will provide a framework for best practices assessment for the oil palm industry and is likely to raise the performance and delivery of sustainability. Such a comprehensive index will also stimulate positive change within the industry, through both internal performance and external perception and image branding.

1. Introduction

The 2030 agenda for Sustainable Development Goal (SDGs) introduced by European Union has created a strong resonance on a wide range of industry throughout the world. SDGs contain a total of 17 main goals to improve the overall well-being of life for future generation, inclusive but not limited to human well-being, education, clean energy, environmental issue etc. As palm oil is the main oils and fats producer that accounted for 31 % (i.e. 6.465 x 10^7 t) of the world's consumption (MPOC, 2017), the need to assimilate sustainable development into its operation is receiving higher attention nowadays. Malaysia, as the second world's largest exporter of palm oil after Indonesia and contributes about 1.605 x 10^7 t (i.e. 36.75 %) of world palm oil exports on a yearly basis (MPOC, 2017). Palm oil thus is the one of the major contributors to the country's GDP. There has been increasing dispute on the "sustainability" of the palm oil production in Malaysia, both for oil palm plantations as well as the palm oil mills. With European Union (EU) Parliament in favour of the ban to import palm oil for the production of biofuels and bioliquids due to the long term environmental impact created by the industry, it has created a higher urgency for industry stakeholders to initiate sustainable practices in its operation (Reuters, 2018). There are multiple certification standards introduced to aid the stakeholders to comply with the sustainable practices related to the industry. Roundtable on Sustainable Palm Oil (RSPO) and Malaysian Sustainable Palm Oil (MSPO) are the two most recognized standards in Malaysia. RSPO is the first international organization to develop and implement global standards for sustainable palm oil. It is firstly introduced in the year 2004 and formally recognized as an accreditation in 2013 (RSPO, 2018). Malaysia also introduced its own certification, MSPO to ensure that the local palm oil stakeholders will uphold sustainable practices that are in line with international standards. At the initial stage, the adoption of MSPO was completely voluntary. It is later mandated by law that all the palm oil stakeholders have to receive the MSPO certification by 2019 at the latest. MSPO contains 7 principles for oil palm plantation and 6 principles for oil palm mill. Malaysian government has also allocated incentives up to MYR 1.3 $x10^8$ to subsidize smallholders, oil palm plantations and organized smallholders to obtain the MSPO certification.

Even though there are different sets of sustainability standards in place to guide industry stakeholders to comply with the environmental and social requirements, there is still lack of comprehensive guidelines that aids stakeholders to maximize economic benefit while fulfilling the obligation of environmental and social well-being. Thus, in this work, Fuzzy Analytic Network Process (FANP) is employed to develop a sustainability index to aid stakeholders to optimize the palm oil supply chain. The sustainability index can act as a framework for the assessment of palm oil industry to improve overall economic, environmental and social performance. It also enhances the overall decision-making process of the new entrant to the industry to select the best location, process and/or equipment for their project.

2. Background

2.1 Fuzzy Analytic Network Process

Analytic Network Process (ANP) was proposed by Saaty (1986) in late 1980s to incorporate feedback and dependence relationship in the top-down hierarchy relationship as described in the Analytic Hierarchy Process (AHP). It is a generalization of AHP that not only takes in account of the dependency of lower level elements on higher level elements, but also includes the "bottom-up" dependence of the higher-level elements on lower level elements and the inner dependency of elements within each cluster. The flexibility that ANP offered in structuring the problem and converting subjective judgements into objective measure has enabled a wide range of application, both in the research and business arena (Sipahi and Timor, 2010). Furthermore, ANP that refrain the unidirectional problem is also more applicable for real life issue that associates with complex relationship and correlation between multiple variables and level. Despite of the mathematically simplicity and flexibility offered by the method, the crisp value input for the pairwise comparison based on Saaty's traditional 9-point fundamental scale has been controversial. It is argued that human judgement can be vague and ambiguous at the same time (Promentilla et al., 2008). In relation with that, fuzzy set theory has often been combined with AHP or ANP for a comprehensive representation of the judgements. Fuzzy set theory was first introduced by Zadeh (1965) to overcome constraints of limited information and data. It was later applied to aid decision making, particularly those associated with personal or subjective opinions that involve high degree of uncertainty and imprecision. Fuzzy set theory is incorporated with ANP and AHP by replacing the crisp input for pairwise comparison with fuzzy membership function. Fuzzy membership function does not only enable the level of dominance relationship to be implied more precisely with the inclusion of upper and lower bound, the range of lower bound and upper bound also indicates the confidence level of experts in giving such judgements (Tan et al.,2014).

3. Methodology

The development of the sustainability index consists of 4 main stages as the following: (i) Identification of sustainability indicators; (ii) Calculation of individual sub-index (iii) Derivation of priority weightage via FANP; (iv) Integration of priority weights of sustainability indicators and multiple sub-indices to form the sustainability index. As the highlight of this work is to incorporate subjective judgements (i.e. experience, expertise) for both qualitative and quantitative sustainability indicators to form a comprehensive set of sustainability index, more emphasis is put on the demonstration of FANP in deriving priority weights for sustainability indicators.

Step 1: Identification of sustainability indicators - Economic, environmental and social indicators are selected based on the nature of the industry and predilection of stakeholders.

Step 2: After the possible pathway and process is determined, simulation is performed to determine the minimum and maximum point for quantitative parameters (i.e. cost, carbon emission, job creation etc.). For qualitative parameters (i.e. health and safety), appropriate index is adopted to run the assessment. Normalization is then performed to convert the value into a same scale for comparison to form individual sub-indices.
Step 3: FANP is employed to derive the priority weights of the selected indicators. The procedure of Fuzzy ANP is illustrated in the following:
(a) Problem structuring: The problem is structured into a hierarchical network model, where the goal is located on the top level, follow by the stages of the industry (i.e. supply of raw materials, processing hub, production site, transportation), and sustainability indicators. The components can be represented by levels, clusters, and elements as illustrated in Figure 1a. Arrow is used to represent the relationship between levels, clusters, and elements. For example, the downward arrow from level 1 to level 2 represents the priority weights of n elements in level 2 with respect to goal. Similarly, the downwards error from level 2 and level 3 represents the priority weightages of n clusters, with n elements in each cluster with respect to the elements in level 2. The upward arrow indicates the priority weightages of elements in level 2 with respect to clusters and elements in level 3. Self-loop arrow for each level shows the inner dependence of elements in its clusters or level. Last but not least, the feedback control loop arrow from level 2 and level 3 back to level 1 represent the connection of elements in different level back to the controlling element of the model, the goal.

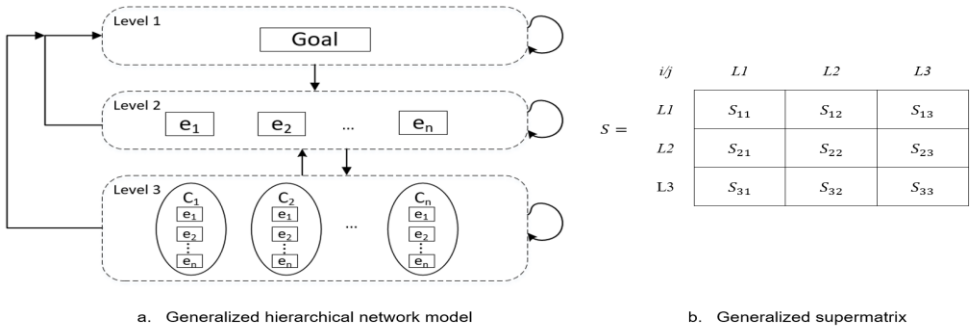

Figure 1: A sample of generalized hierarchical network model and generalized supermatrix

(b) Elicit judgements with pairwise comparisons' survey – The nature of ANP method for relative measurement based on the knowledgeable and experts do not always require statistically significant sample size. Depending on the subject matter, a minimum number of 2 domains that well-represent the group of decision makers or industry stakeholders is admissible. Experts are required to compare the dominance relationship (i.e. importance, preferences, likelihood and influence) of the elements in pair. Linguistics scales that represent triangular fuzzy value calibrated by Promentilla et al. (2016) is adopted in this work. The set of linguistic scale and its respective triangular fuzzy number are showed in Table 1. Triangular fuzzy number (TFN) consist of 3 values, ⟨l,m,u⟩ where l represent the lower bound, m represents the modal value, and u represent the upper bound of the said judgement. This fuzzy scale follows the Fibonacci sequence where the degree of fuzziness increased with the intensity of the dominance relationship. Geometric mean method is used to aggregate multiple individual fuzzy judgement into a single vector (Orbecido et al., 2016).

Table 1: Fuzzy scale for pairwise comparative judgement

Linguistic scale	Fuzzy Number	Lower bound (l_{ij})	Modal value(m_{ij})	Upper bound (u_{ij})
Equally	1	1.0	1.0	1.0
Slightly more	2	1.2	2.0	3.2
Moderately more	3	1.5	3.0	5.6
Strongly more	5	3.0	5.0	7.9
Very strongly more	8	6.0	8.0	9.5

(c) Derive priority vector for local pairwise comparisons matrices – Verbal judgements of experts from pairwise comparison questions are interpreted with TFN to form reciprocal pairwise comparison matrix. Unlike traditional ANP that contain (n)(n-1)/2 questions, the priorities of FANP can be computed even for incomplete pairwise comparison matrices with a minimum of (n-1) pairwise comparative judgments (Promentilla, 2014). The formation of the pairwise comparisons matrix (i.e. $\widehat{A}$) is described as following, where:

$$\widehat{A}=\begin{bmatrix} \langle 1,1,1\rangle & \hat{a}_{12} & \cdots & \hat{a}_{1n} \\ \hat{a}_{21} & \langle 1,1,1\rangle & \cdots & \hat{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{a}_{n1} & \hat{a}_{n1} & \cdots & \langle 1,1,1\rangle \end{bmatrix} \text{ where } \hat{a}_{ij}=\langle l_{ij},m_{ij},u_{ij}\rangle \text{ ; } \hat{a}_{ji}= \langle \frac{1}{u_{ij}},\frac{1}{m_{ij}},\frac{1}{l_{ij}}\rangle \quad (1)$$

Next, the priority weightages (i.e. w_k) for each local priority matrix, (i.e. $\widehat{A}$) is then calculated with the non-linear fuzzy programming (NLP) formulation (Promentilla et al., 2015) as shown in Eq(2):

$$\text{Maximize } \lambda \quad (2a)$$

s.t.:

$$(m_{ij}-l_{ij})\lambda w_j-w_i+ l_{ij}w_j\leq 0,\forall i=1,\ldots,n-1;j=i+1,\ldots,n \quad (2b)$$

$$(u_{ij}-m_{ij})\lambda w_j-w_i+ u_{ij}w_j\leq 0,\forall i=1,\ldots,n-1;j=i+1,\ldots,n \quad (2c)$$

$$(m_{ij}-l_{ij})\lambda w_i-w_j+ l_{ji}w_i\leq 0,\forall j=j,\ldots,n-1;i=j+1,\ldots,n \quad (2d)$$

$$(u_{ji}-m_{ji})\lambda w_i-w_j+ u_{ji}w_i\leq 0,\forall j=1,\ldots,n-1;j=j+1,\ldots,n \quad (2e)$$

$$\textstyle\sum_{i=1}^{n} w_i =1 \quad (2f)$$

$$w_i>1,\forall i=1,\ldots,n \quad (2g)$$

The priority vectors are calculated by maximizing the overall degree of satisfaction, λ. In this formulation, λ acts as a measure of consistency while the ratio of these computed weights also satisfies the initial fuzzy judgments (a_{ij}). λ value is recommended to be in between 0.0 and 1.0, wherein 0.0 indicates the judgments are satisfied at their boundaries and 1.0 indicates perfect consistency (Tan et al., 2014). In the event where λ is negative value, it is suggested for the respective expert(s) to revisit his/her pairwise comparison judgements.
(d) Formation of supermatrix – Arrange the ratio-scale priority vectors of each local priority matrix based on the hierarchical network model to form unweighted supermatrix, S, as illustrated by Figure 1b. S_{ij} is interpreted as the direct relationship of the elements in level j with respect to level i. Meanwhile, S_{ji} is interpreted as the feedback dependence of the elements in level i with respect to level j. If there is no direct relationship between the two clusters (i.e. level 1 with level 3), then the block matrix (i.e. S_{31}) will be represented by null block matrix (i.e. [0,…,0]). S_{ii} for all i=j represents the inner dependence relationship of the elements on its own clusters. There are two type of inner dependence relationship. Independence relationship applied for the level where the elements in the cluster only depend on itself while interdependence relationship take places when the elements in the cluster do not only depend on itself, but also depends on other element(s) within the same cluster. For independence relationship, the entry is represented by identity matrix (I). Feedback control loop is represented by e^T, an unit row vector (i.e. [1,…,1]). The supermatrix is then normalized to achieve column stochastics (i.e. weighted supermatrix) and raised to power until the values converged.
Step 4: Individual indices (i.e. economic, environmental and social index) are integrated with the final priority weightages generated from FANP to form sustainability index. The formula is as the following:

$$SI=I^{EC}w^{EC}+I^{EN}w^{EN}+I^{SC}W^{SC} \quad (3)$$

where I^{EC},I^{EN},I^{SC} is the index score for the economic, environmental and social indicators while w^{EC},w^{EN},w^{SC} is the priority weightage assigned for the economic, environmental and social indicators with Fuzzy ANP.

4. Case study

To illustrate, a case study of deriving priority weightages for sustainability index for palm oil biomass industry is demonstrated. As different stages of oil palm biomass industry are associated with different economic, environmental and social factors, the model is structured based on stages of palm oil biomass industry to understand the priority of sustainability indicators on individual stages and as an overall industry. The model consists of 3 levels as illustrated in Figure 2. The top level is the goal, followed by level 2, stages of palm oil biomass industry (i.e., oil palm plantation (OPP), palm oil mill (POM) and transportation (TPT)) and level 3, sustainability indicators (i.e., economic cluster - cost (CS), profit margin (PM) and compliance and penalty cost

(CP); environmental cluster - energy footprint (EF), carbon footprint (CF), and water footprint (WF); social cluster - health and safety (HS), job opportunity (JO), and public awareness and acceptance (PA)).

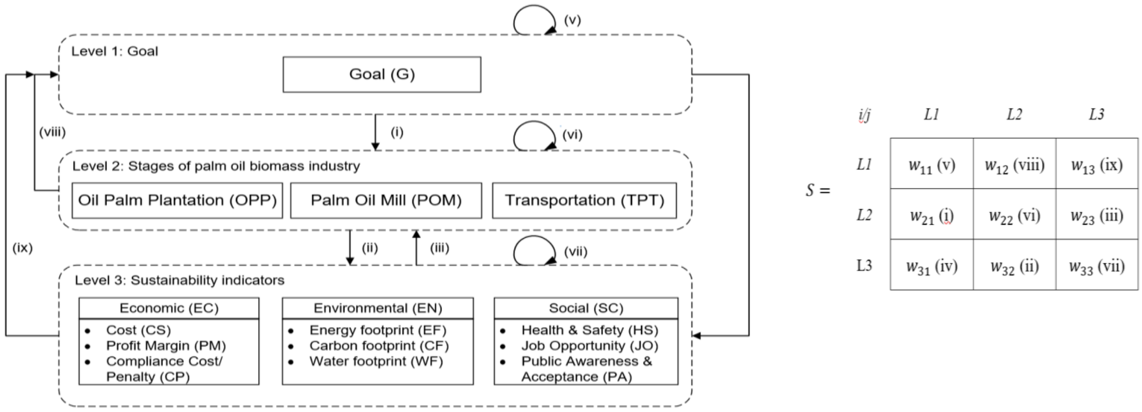

Figure 2: Diagraph of the hierarchical network model representing oil palm industry with sustainability indicators and its supermatrix

	Goal	OPP	POM	TPT	CS	PM	CP	EF	CF	WF	HS	JO	PA	Limiting value
Goal	1	1	1	1	1	1	1	1	1	1	1	1	1	1.0000
OPP	0.3527	1.0000	0.4565	0.5000	0.3338	0.2920	0.2483	0.2225	0.1896	0.4133	0.2762	0.3153	0.3152	0.3173
POM	0.4291	0.5745	1.0000	0.5000	0.3712	0.4084	0.4143	0.5034	0.3942	0.3901	0.4513	0.3930	0.4096	0.4033
TPT	0.2182	0.4255	0.5435	1.0000	0.2950	0.2996	0.3375	0.2741	0.4163	0.1966	0.2724	0.2917	0.2752	0.2794
CS	0.1007	0.2030	0.1980	0.1378	1	0	0	0	0	0	0	0	0	0.1417
PM	0.2013	0.3558	0.2474	0.2070	0	1	0	0	0	0	0	0	0	0.2359
CP	0.1148	0.1110	0.0622	0.1000	0	0	1	0	0	0	0	0	0	0.1015
EF	0.1988	0.0000	0.1123	0.0000	0	0	0	1	0	0	0	0	0	0.1221
CF	0.0943	0.0735	0.1220	0.1655	0	0	0	0	1	0	0	0	0	0.1065
WF	0.0396	0.0000	0.0536	0.0000	0	0	0	0	0	1	0	0	0	0.0306
HS	0.1181	0.1430	0.1169	0.2123	0	0	0	0	0	0	1	0	0	0.1350
JO	0.0543	0.0656	0.0554	0.0964	0	0	0	0	0	0	0	1	0	0.0622
PA	0.0781	0.0481	0.0321	0.0810	0	0	0	0	0	0	0	0	1	0.0644

Figure 3: Initial supermatrix populated by priority vectors and final limiting values

All the relationships between level, clusters and elements are represented by italic numerical in bracket to enhance the understanding on the arrangement of priority vectors in initial supermatrix. For instances, w_{21} is the priority vector that represents the direct dependence of elements in level 2 with respect to the goal, represented by downward arrow (i). Similarly, downward arrow (ii) shows the dependency of the elements in level 3 with respect to different elements in level 2, with priority vector w_{32}. w_{23} is the priority vector that represented by upward arrow (iii), the feedback dependence of the elements in level 2 with respect to elements in level 3. Downward arrow (iv) represent the direct dependence of the elements in level 3 with respect to the goal, not taking consideration of the elements in level 2. The priority vector of this relationship is represented by w_{31}. Self-looping arrows (v), (vi), (vii) represent the inner dependence relationship between the element(s) in its level. Feedback control loop (viii) and (ix) are the arrows connecting every level back to the the goal of the study. The priority vectors for feedback control loop, w_{21} and w_{31} are row vector (i.e., e^T, [1,1,…,1]). A group of industry stakeholders and researchers (N = 10) are invited to response to the questionnaires through email. The participants consist of oil palm plantation owner, miller, logistics personnel and researchers in the area of biomass-related research (i.e., processing routes for conversion of oil palm biomass, biomass supply chain, socio-economic and sustainability). The priority vectors of each fuzzy local priority matrix are then calculated based on the NLP formulation as described in Eq(2) by using LINGO 16.0. The priority vectors are then populated to form initial supermatrix as illustrated in Figure 3. The initial supermatrix is normalized to achieve column stochastic prior power by itself to form limiting value.

The final priority weightage of the sustainability indicators is reported in the “limiting value” column in Figure 3. Based on the result, economic cluster (47.92 %) is relatively important in determining the implementation of sustainability practices in Malaysia oil palm biomass industry, followed by social factors (26.16 %) and environmental factors (25.92 %). Profit margin that carries 23.59 % is the main driver for industry stakeholders to initiate and maintain sustainable practices in oil palm biomass operation, followed by upfront cost (14.17 %), health and safety practices (13.50 %), energy footprint (12.21 %) and carbon footprint (10.65 %). It is observed that better economic performance is still necessary to encourage sustainable development. In terms of stages, palm oil mill (40.33 %) is slightly more important as compared to oil palm plantation (31.73 %) and transportation (27.94 %) to enhance the overall sustainability of the oil palm biomass industry.

5. Conclusion

With the global tension for sustainable development, implementation of sustainability practices in daily operation is a must. This work presented a model to develop a sustainability index with FANP. The proposed method enables the incorporation of human preferences on sustainability indicators to derive sustainability index. By taking consideration of the human factors for sustainability development, the model provides a more feasible solution for the industry stakeholders to assess, monitor, and implement relative sustainability practices in its operation. Furthermore, it also helps to enhance decision making process on selecting technology and process that not only maximize economic performance, but also preserve and conserve the environment and improve social well-being. It should be noted that the priority weights derived with FANP can be vary depending on the problem structures based the nature and main objective of the projects. Future work will focus on optimizing oil palm biomass supply chain to select the process, technology, location for the processing site and end-products for sustainable development.

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