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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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Evaluation of Corporate Sustainability

Abstract As a consequence of an increasing demand in sustainable development for business organizations, the evaluation of corporate sustainability has become a topic intensively focused by academic researchers and business practitioners. Several techniques in the context of multiple criteria decision analysis (MCDA) have been suggested to facilitate the evaluation and the analysis of sustainability performance. However, due to the complexity of evaluation, such as a compilation of quantitative and qualitative measures, interrelationships among various sustainability criteria, the assessor's hesitation in scoring, or incomplete information, simple techniques may not be able to generate reliable results which can reflect the overall sustainability performance of a company. This paper proposes a series of mathematical formulations based upon the evidential reasoning (ER) approach which can be used to aggregate results from qualitative judgments with quantitative measurements under various types of complex and uncertain situations. The evaluation of corporate sustainability through the ER model is demonstrated using actual data generated from three sugar manufacturing companies in Thailand. The proposed model facilitates managers in analysing the performance and identifying improvement plans and goals. It also simplifies decision making related to sustainable development initiatives. The model can be generalized to a wider area of performance assessment, as well as to any cases of multiple criteria analysis.

Keywords: corporate, organization, sustainability, evidential reasoning, evaluation, assessment

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1 Introduction

It is widely accepted that performance measurement is a prerequisite for further improvement and decision making in business management (Neely, Gregory, & Platts, 2005; Searcy, 2011). The scope of business performance assessment has been broadened from a narrow range of criteria, such as quality or financial performance, to cover more comprehensive views of organizational performance (Goyal, Rahman, & Kazmi, 2013; Neely, Mills, Platts, Richards, Gregory, Bourne, & Kennerley, 2000). Nowadays, in response to the emergence and significance of environmental and social concerns in the business context, the evaluation of corporate sustainability becomes a major issue being addressed in the research community.

Recent literature review shows that the number of companies which regularly assess and report their performances towards sustainable development has been increasing every year (Hubbard, 2009; Isaksson & Steimle, 2009; KPMG, 2011; Lozano & Huisingh, 2011; Schneider & Meins, 2012). Goyal et al. (2013) presented the bibliographic scheme of literature in the academic research of corporate sustainability evaluation during 1992 to 2011. They found that the number of published articles in this area dramatically increased in recent years and many studies in the past few years focused more on the combined measurement of the triple bottom line (environment, economic, and social), compared to the earlier period when most studies only discussed the individual assessment of environmental or social performance. However, rigorous methods to combine quantitative and qualitative assessment are required. Most studies are based on secondary data which may be less well documented, incomplete, or not up-to-date. As suggested by Goyal et al. (2013), empirical research, which is limited in this field, is recommended since the research methodology and data collection can be tailored to the specific requirements of such a study. There is also a lack of sustainability assessment research in the food industry.

Corporate sustainability evaluation is complex because it deals with a large number of interrelated criteria, and many of them are qualitative in nature. Moreover, uncertainties in scoring and weighting criteria always exist. For instance, an assessor or a decision maker (DM) might be unsure about giving a precise judgment especially when qualitative criteria are involved. Although a set of rating scales can be used to convert subjective judgments into numerical values, there are a number of concerns about this type of method. Firstly, each DM may interpret the meaning of each scale differently. Secondly, a DM might not be confident in stating that a criterion being considered matches an individual scale, and one or more scales might better suit the current practice being assessed. Furthermore, incomplete information may result in a DM's hesitation in assigning a score. From these concerns, a challenge arises as to how uncertain information can be aggregated rigorously.

Corporate sustainability evaluation is in essence a multiple criteria assessment problem that can be solved using multiple criteria decision analysis (MCDA) techniques (Sen & Yang, 1998; Xu & Yang, 2001). The evidential reasoning (ER) approach is a unique MCDA method that can be used to handle both qualitative judgments and quantitative measures in complex and uncertain situations. It is based on the Dempster-Shafer (D-S) theory of evidence and differs from most conventional MCDA methods by employing a belief distribution to describe an assessment. The advantage of doing so is that uncertainties are preserved in the process of aggregation (Wang, Yang, Xu, & Chin, 2006; Yang, 2001; Yang & Singh, 1994; Yang & Xu, 2002). In addition, since the ER approach does not require additive independence among criteria, it is applicable to the case of sustainability assessment in which some interrelationships among various criteria exist (De Montis, Getzner, Spash, & Stagl, 2005, pp.99–133; Munda, 2005).

The objective of this paper is to demonstrate how effective and useful the ER approach is in facilitating the assessment and analysis of corporate sustainability. The list of criteria and indicators was determined based upon the literature review and the case studies of four sugar companies in Thailand. Three of the four companies then participated in the process of performance assessment and analysis. This paper is divided into six sections. After the introduction, section 2 presents a review of studies to propose an instrument for the assessment of corporate sustainability, as well as a review of performance analysis methods commonly seen in the literature. In section 3, the ER approach is briefly described. The list of criteria and indicators is displayed in section 4. This is followed by the demonstration of the ER application in the actual assessment in section 5. The conclusion is given in section 6.

2 Literature review

During the past decade, a range of criteria and indicators for the evaluation of corporate sustainability have been proposed by many researchers and organizations (Azapagic & Perdan, 2000; Britain's Institution of Chemical Engineers, 2004; Figge, Hahn, Schaltegger, & Wagner, 2002; Global Reporting Initiative, 2006; Labuschagne, Brent, & Van Erck, 2005; Panayiotou, Aravossis, & Moschou, 2009; Veleva & Ellenbecker, 2001; Yongvanich & Guthrie, 2006). A number of studies have also attempted to construct a composite index of the overall sustainability performance which can be used to compare and track the progress of a company toward sustainable development (Hubbard, 2009; Krajnc & Glavic, 2005a, 2005b; Li, Zhang, Yuan, Liu, & Fan, 2012; Phillis & Davis, 2009; Tseng, Divinagracia L., & Divinagracia R., 2009; Ugwu, Kumaraswamy, Wong, & Ng, 2006; Ziout, Azab, Altarazi, & ElMaraghy, 2013). In these studies, methods akin to the additive value function approach, in particular the simple additive weighting (SAW) method, are mainly employed to aggregate indicators. Although such methods are simple, they assume additive preferential independence and complete compensation among criteria, which may be too strong to be realistic in sustainability assessment (De Montis et al., 2005, pp.99–133; Munda, 2005). Furthermore, the complications which could arise in actual assessment, such as the qualitative nature of many indicators and the uncertainty or incompleteness of data or DM's judgments, are generally overlooked.

Weighted geometric mean (WGM) is another aggregation technique widely used by academic researchers (Ebert & Welsch, 2004; Zhou, Ang, & Poh, 2006). Unlike the SAW method, WGM allows non-compensation among criteria in the sense that the overall value will be zero as long as one criterion has zero value (Zhou et al., 2006), no matter how small the weight of that criterion is. However, this assumption may not be acceptable in sustainability assessment.

Analytic hierarchy process (AHP) is a method generally used not only for determining criteria weights but also for selecting the best alternative. The feature of AHP is that it does not require a DM to provide a precise performance value for each alternative since the comparison between two alternatives is based on the ratio scale. Thus, it is able to deal with qualitative criteria which are difficult to measure and compare by directly assigning numerical scores (Belton & Gear, 1983; Dyer & Forman, 1992). However, AHP requires pairwise comparisons between alternatives for each indicator, which blocks its application in this study. This is because the aim of this paper is not to explore the most sustainable company but to propose a logical and practical assessment method which enables a company to conduct self-assessment in corporate sustainability.

Data envelopment analysis (DEA) is applied to sustainability assessment in several sectors, such as the industrial sector (Callens & Tyteca, 1999) and agriculture (De Koeijer, Wossink, Struik, & Renkema, 2002; Gomes, João Carlos Correia Baptista Soares de Mello, Geraldo da Silva e Souza, Lidia Angulo Meza, & João Alfredo de Carvalho Mangabeira, 2009). It employs a linear programming model to measure the relative efficiency of decision making units (DMUs). Multiple criteria are classified into inputs and outputs in DEA. DEA can be used to address how to improve an inefficient DMU based on the best practice achieved by other DMUs in the peer group. However, there are a number of issues that raise concerns. Firstly, the significance of the results depends on whether DMUs in a peer group cover the real best performers or not. Secondly, one widely adopted rule of thumb suggests that the number of DMUs should be at least twice as large as the total number of input and output criteria; otherwise the discriminating power of DEA would be affected (Ramanathan, 2006; Zhou, Ang, & Poh, 2008). These are the critical obstacles for sustainability assessment which depend on a large number of criteria. Moreover, the assumption of DEA that outputs will be increased when adding more inputs into the process may not always be true (Shimshak, Lenard, & Klimberg, 2009). In the corporate sustainability context, inputs may not be substituted completely by outputs, particularly within a short period (Dyllick & Hockerts, 2002). Finally, similar to AHP, DEA may not be a practical method for a company's self-assessment without other alternatives for comparison.

The next section provides the details of the ER approach which is suggested in this paper as the most appropriate method to support the evaluation of corporate sustainability under the concerned conditions.

3 The ER approach

As mentioned, the ER approach is developed based upon Dempster's rule of evidence combination in the D-S theory, or the evidence theory. This section therefore starts with an overview of the D-S theory following by a review of the ER algorithm. Mathematical formulations used for the assessment of corporate sustainability are presented at the end.

The D-S theory was introduced by Arthur P. Dempster in 1967 (Dempster, 1967) and was later formalized by Glenn Shafer in 1976 (Shafer, 1976). It is considered as a generalization of traditional probability theory. While probabilities are associated with singleton propositions only in probability theory, the D-S theory allows probabilities to be assigned to any subsets of propositions so as to represent such uncertainty as ignorance (Shafer, 1990; Sentz & Ferson, 2002; Xu, Yang, & Wang, 2006). The D-S theory considers a belief function instead of a probability function, where degrees of belief can be assigned to all possible propositions and their subsets. Beliefs assigned to subsets of propositions signify the degree of incompleteness of the evidence. Incompleteness exists when the evidence is unable to reflect the whole view of the situation precisely (Lowrance, Garvey, & Strat, 2008, pp.419–434).

Based on Shafer (1976), let H be a finite set of mutually exclusive and collectively exhaustive propositions, called a frame of discernment, at least one of the propositions in the frame is definitely true. θ is the power set of H, consisting of all 2^N subsets of H, including the empty set (Ø) and H itself, as shown below (Yang & Xu, 2011, pp.7–15; Yang & Xu, 2013).

$$2^N=\{i|A_i\subseteq H\} \tag{1}$$

$$\theta=\{\emptyset,\{H_1\},\ldots,\{H_N\},\{H_1, H_2\},\ldots,\{H_1, H_N\},\ldots,\{H_1, \ldots,H_{N-1}\},H\} \tag{2}$$

A basic probability assignment (BPA) or mass function, denoted by $m(A)$, is given as a representative of the portion of belief committed exactly to a subset A of. In other words, $m(A)$ represents how strongly A is supported by evidence. The mass function needs to satisfy the following conditions (Florea, Jousselme, Bossé, & Grenier, 2009; Gordon & Shortliffe, 2008, pp.311–344; Wang et al., 2006b):

$$0\leqslant m(A)\leqslant 1, \quad \forall A\subseteq H \tag{3}$$

$$\sum_{A\in\theta} m(A)=1 \tag{4}$$

$$m(\varnothing)=0 \tag{5}$$

A is called a focal element if and only if $m(A)>0$ and the above conditions regulate that the assigned probabilities of all focal elements sum to one, and there is no belief in Ø; a probability assigned to H, or $m(H)$, represents the degree of "global ignorance"; on the other hand, a probability assigned to any subset of H which is not a singleton or H itself is regarded as the degree of "local ignorance" (Yang & Xu, 2011, pp.7–15; Yang & Xu, 2013).

BPA or the mass function is associated with a belief measure (Bel) which can be defined as a function: $\theta\rightarrow[0,1]$. A belief measure Bel(A) represents a total support for a proposition A, as defined by equation (6) (Shafer, 1987, pp.51–84; Wang et al., 2006b; Yang & Xu, 2011, pp.7–15; Yang & Xu, 2013).

$$\mathrm{Bel}(A)=\sum_{B\subseteq A} m(B) \tag{6}$$

Equation (6) indicates that Bel(A) is equal to $m(A)$ only when A is a singleton (Gordon & Shortliffe, 2008, pp.311–344). When Bel(A) is a positive value, that means the evidence leads a DM to believe in A at least to some extent. In contrast, when it is equal to zero, it does not mean lack of belief in A but, instead, it reflects the lack of evidence supporting the DM's belief in A (Shafer, 1987, pp.51–84).

Dempster's rule is employed in the evidence theory to aggregate information from different sources. To use Dempster's rule, the following three conditions must be satisfied (Dempster, 1967; Dezert, 2002; Florea et al., 2009; Liu & Yager, 2008, pp.1–34; Shafer, 1990; Yang, Dale, & Siow, 2001): ① All pieces of evidence or sources of information are independent of each other; ② all propositions within a finite frame of discernment (H) must be mutually exclusive and collectively exhaustive; ③ propositions defined for all pieces of evidence must be the members of the same frame of discernment (H).

Dempster's rule employs the so-called orthogonal sum to combine multiple belief functions. Let m_1 and m_2 be the belief functions from two pieces of evidence. The new mass function of a new focal element, $m(A)$, can be determined as follows (Barnett, 2008, pp.179–216; Liu & Yager, 2008, pp.1–34; Shafer, 1976; Yang & Xu, 2011, pp.7–15; Yang &Xu, 2013).

$$m(A)=\frac{1}{1-K}\cdot\sum_{X\cap Y=A} m_1(X)m_2(Y),\ \ \forall A,\ X,\ Y\in\theta,\ A\neq\varnothing \tag{7}$$

$$K=\sum_{X\cap Y=\varnothing} m_1(X)m_2(Y) \tag{8}$$

$$m(\varnothing)=0 \tag{9}$$

Dempster's rule is associative, which means that the combination process is independent of the order of operations (Sentz & Ferson, 2002). The main critical issue of Dempster's rule is the counterintuitive results occurring when immensely conflicting pieces of evidence exist. This means Dempster's rule cannot be used to handle a combination problem where two pieces of evidence are completely contradictory since the orthogonal sum has no definition in this case (Dezert & Smarandache, 2004, pp.3–36; Sentz & Ferson, 2002; Zadeh, 1984). The ER approach described below can overcome such limitations and enhance Dempster's rule.

The ER approach was originally introduced by Yang and Singh (1994) as a new decision making procedure to combine multiple criteria. The ER algorithm was firstly developed as a recursive algorithm. Later, in Yang (2001), the ER approach was equipped with the rule- and utility-based techniques to transform various sets of evaluation standards into a unified format. As a result, both quantitative and qualitative assessments can be combined within the same framework. Next, Yang and Xu (2002) proposed a new scheme for BPAs by dividing the remaining probability mass unassigned to any individual grades into two parts according to the relative weight of the indicators and the incompleteness of the assessment. Wang, Yang, and Xu (2006a) then applied the ER approach to compare various options in environmental impact assessment and provided an equivalent analytical algorithm in order to present an explicit aggregation function.

Several types of interval data have been added to the ER approach to deal with several types of uncertainty. For example, Xu et al. (2006) introduced the interval ER (IER) algorithm by extending the ability of ER approach to deal with local ignorance in assessing an alternative. The major contribution of this article which differs from the original ER algorithm is that the incompleteness or ignorance (unassigned belief degree) of an assessment is not assigned to the whole range of grades but to any range of adjacent grades based on known or partially known information. In the same year, Wang et al. (2006b) extended the ER algorithm to handle interval data and interval belief degree. Following this, interval weights of criteria were incorporated into the ER algorithm by Guo, Yang, Chin, and Wang (2007). In Zhou, Liu, and Yang (2010), the assignment of weights in the ER approach was extended to a triangular fuzzy number. Also, the utility of the assessment grades has been extended here from certain values to intervals in order to capture the diversity of preferences from several DMs. Recently, Yang and Xu (2011, pp.7–15; 2013) presented a new ER rule which allows the assignment of probability to any subsets of the frame of discernment, rather than only to singletons and subsets of adjacent grades as specified in Xu et al. (2006). The formulation of the new rule can be considered as a generalized version of the ER algorithm. That means all cases which can be solved by the typical ER and IER rules can also be handled by the new ER rule.

For the assessment of corporate sustainability, the challenges are the inclusion of various criteria and their indicators which are assessed using different units. Moreover, the data collected from the actual assessment case studies are uncertain and incomplete. This is because the data for many indicators tend to fluctuate over a year, or may not be available in some companies. Some information is also likely to be confidential so company managers might not feel comfortable in disclosing it. Furthermore, there may be uncertainty and lack of consensus about the weights of criteria elicited from practitioners or experts.

Based on the literature, the ER algorithm used for the assessment of corporate sustainability is briefly described below.

Let $H_n(n=1, \dots, N)$ denotes an assessment grade in which an indicator e_i is assigned. Note that e_i can become a dimension, a criterion, a sub-criterion, or an item when the aggregation moves to each level of the hierarchy. The word "indicator" is used as a representative here for simplification of explanation. When referred to the D-S theory, the assessment grade H_n is considered as an element or a proposition, and an indicator e_i is considered as a piece of evidence or a source of information. Therefore, all grades are required to be mutually exclusive and collectively exhaustive (Yang, 2001). Then, the frame of discernment can be defined by equation (10) where H_{n+1} is preferred to H_n. Thus, H_1 and H_N represent the worst and the best grades, respectively.

$$H=\{H_1,\ H_2,\ \dots,\ H_n,\ \dots,\ H_N\} \tag{10}$$

In order to simplify the explanation of the ER approach, it is supposed here that the framework has only two hierarchical levels: the top attribute y and its indicators e_i. Then a set of L indicators can be defined as follows.

$$E=\{e_i,\ i=1,\ \dots,\ L\} \tag{11}$$

According to this, a belief distribution for a company a_l, called alternative $a_l(l=1, \dots, M)$, for an indicator e_i can be expressed by:

$$\begin{aligned} S(e_i(\mathrm{a}_l))=\{&(H_n,\ \beta_{n,i}(\mathrm{a}_l)),\ n=1,\ \dots,\ N;\\ &(H,\beta_{H,i}(\mathrm{a}_l))\},\ i=1,\ \dots,\ L,\ l=1,\ \dots,\ M \end{aligned} \tag{12}$$

$\beta_{n,i}(a_l)$ denotes a belief degree in which an indicator e_i of a company a_l is assessed to a grade H_n, where $\beta_{n,i}(a_l)\geqslant 0$ and $\sum_{n=1}^{N}\beta_{n,i}(a_l)\leqslant 1$; $\beta_{H,i}(a_l)$ represents the degree of global ignorance in which $\beta_{H,i}(a_l)\geqslant 0$ and $\sum_{n=1}^{N}\beta_{n,i}(a_l)+\beta_{H,i}(a_l)=1$; from this, $\beta_{n,i}(a_l)$ is regarded as the lower bound of the probability that a_l is assessed to H_n when considering the indicator e_i, while the upper bound is represented by $\beta_{n,i}(a_l)+\beta_{H,i}(a_l)$ (Yang, 2001; Yang & Xu, 2011, pp.7–15; Yang & Xu, 2013).

When uncertainty in scoring or assessing exists, the belief distribution of each alternative (a_l) for each indicator e_i can be defined using intervals. Then, equation (12) becomes equation (13) as shown below.

$$S(e_i(a_l))=\{(H_n, \beta_{n,i}(a_l)\in[\beta^-_{n,i}(a_l), \beta^+_{n,i}(a_l)]),\ n=1, \ldots, N; \\ (H, \beta_{H,i}(a_l)\in[\beta^-_{H,i}(a_l), \beta^+_{H,i}(a_l)])\},\ i=1, \ldots, L,\ l=1, \ldots, M \tag{13}$$

It is also necessary to ensure that the following conditions are satisfied (Wang et al., 2006b).

$$\sum_{n=1}^{N}\beta^-_{n,i}(a_l)\leqslant 1 \tag{14}$$

$$\beta^-_{H,i}(a_l)=\max\left(0,\ 1-\sum_{n=1}^{N}\beta^+_{n,i}(a_l)\right)$$

and

$$\beta^+_{H,i}(a_l)=1-\sum_{n=1}^{N}\beta^-_{n,i}(a_l) \tag{15}$$

Based on the ER approach, the relative weights of L indicators, denoted by $w=\{w_1, \ldots, w_i, \ldots, w_L\}$, are used to indicate that each indicator e_i only plays a role relative to its weight. The weights are identified under the following conditions (Yang, 2001; Yang & Xu, 2002).

$$0\leqslant w_i\leqslant 1 \text{ and } \sum_{i=1}^{L}w_i=1 \tag{16}$$

In order to aggregate all assessments represented by equation (13), the analytical ER algorithm is here applied together with optimization function. A series of mathematical equations employed in this study mainly following Wang et al. (2006b) and Guo et al. (2007) are defined as follows.

Objective functions:

$$\text{Max/Min } \beta_n(a_l)=\frac{m_n}{1-\bar{m}_H},\ n=1, \ldots, N \tag{17}$$

$$\text{Max/Min } \beta_H(a_l)=\frac{\tilde{m}_H}{1-\bar{m}_H} \tag{18}$$

Subject to (s.t.)

$$m_n=k\left[\prod_{i=1}^{L}\left(m_{n,i}+\bar{m}_{H,i}+\tilde{m}_{H,i}\right)-\prod_{i=1}^{L}\left(\bar{m}_{H,i}+\tilde{m}_{H,i}\right)\right],\ n=1,\ldots,N \tag{19}$$

$$\tilde{m}_H=k\left[\prod_{i=1}^{L}\left(\bar{m}_{H,i}+\tilde{m}_{H,i}\right)-\prod_{i=1}^{L}\bar{m}_{H,i}\right] \tag{20}$$

$$\bar{m}_H=k\left[\prod_{i=1}^{L}\bar{m}_{H,i}\right] \tag{21}$$

$$k=\left[\sum_{n=1}^{N}\prod_{i=1}^{L}\left(m_{n,i}+\bar{m}_{H,i}+\tilde{m}_{H,i}\right)-(N-1)\prod_{i=1}^{L}\left(\bar{m}_{H,i}+\tilde{m}_{H,i}\right)\right]^{-1} \tag{22}$$

$$m_{n,i}=w_i\beta_{n,i}(a_l),\ n=1,\ldots,N;\ i=1,\ldots,L \tag{23}$$

$$\tilde{m}_{H,i}=w_i\beta_{H,i}(a_l),\ i=1,\ldots,L \tag{24}$$

$$\bar{m}_{H,i}=1-w_i,\ i=1,\ldots,L \tag{25}$$

$$\beta^-_{n,i}(a_l)\leqslant\beta_{n,i}(a_l)\leqslant\beta^+_{n,i}(a_l),\ n=1,\ldots,N;\ i=1,\ldots,L \tag{26}$$

$$\beta^-_{H,i}(a_l)\leqslant\beta_{H,i}(a_l)\leqslant\beta^+_{H,i}(a_l),\ i=1,\ldots,L \tag{27}$$

$$\sum_{n=1}^{N}\beta_{n,i}(a_l)+\beta_{H,i}(a_l)=1,\ i=1,\ldots,L \tag{28}$$

$$\sum_{n=1}^{N}m_{n,i}+\bar{m}_{H,i}+\tilde{m}_{H,i}=1,\ i=1,\ldots,L \tag{29}$$

$m_{n,i}$ is interpreted as the weighted belief which supports the assessment of a_l to the grade H_n based on the indicator e_i; $m_{H,i}$ is the remaining probability mass unassigned to any grade after all N grades have been considered. As mentioned, according to Yang and Xu (2002), $m_{H,i}$ is divided into two parts, in order to provide a more rational basis for the aggregation process. $\bar{m}_{H,i}$ is the remaining probability mass unassigned to any single grade due to the fact that an indicator e_i only partly contributes to the assessment in proportion to its weight. Generally speaking, it reflects the degree to which other indicators contribute to the overall assessment. Therefore, $\bar{m}_{H,i}$ will be zero if e_i dominates the assessment or if its relative weight (w_i) is equal to one. On the other hand, $\tilde{m}_{H,i}$ is an unassigned probability mass resulting from the incompleteness of the assessment $S(e_i)$. Thus, $\tilde{m}_{H,i}$ will be zero if the assessment is complete, or $\sum_{n=1}^{N}\beta_{n,i}=1$. Similar to Dempster's rule, K is a normalizing factor used to make sure that $\sum_{n=1}^{N}m_n+m_H=1$. β_H represents the degree of belief unassigned to any single grade after all L indicators have been assessed. In other words, it reflects the total degree of incompleteness in the assessment.

Finally, the aggregated result for company can be described as follows.

$$S\left[y\left(a_l\right)\right]=\left\{\left(H_n,\beta_n\left(a_l\right)\in\left[\beta_n^-\left(a_l\right),\beta_n^+\left(a_l\right)\right]\right),\ n=1,\ldots,N;\left(H,\beta_H\left(a_l\right)\in\left[\beta_H^-\left(a_l\right),\beta_H^+\left(a_l\right)\right]\right)\right\},\ l=1,\ldots,M \tag{30}$$

with $\sum_{n=1}^{N}\beta_n\left(a_l\right)+\beta_H\left(a_l\right)=1$

According to the algorithm presented above, the number of nonlinear programming models used to aggregate the belief degrees of each alternative is equal to 2(N+1) for one combination process. At the end of the processes, the overall sustainability performance of each company is expressed in the form of a belief distribution which provides a panoramic view of the assessment information. If a company conducts self-assessment with the aims of monitoring their own performance and supporting decision making related to their sustainability policies, the belief distribution obtained can be considered as meaningful and applicable. However, if the assessment is to be used for ranking or comparing several companies, factories, or options, the combined distribution cannot be used straight forwardly for these purposes. Instead, the comparison can be conducted according to the expected utilities (Guo et al., 2007; Wang et al., 2006b; Yang, 2001; Zhou et al., 2010). Utility reflects the degree of the DM's preferences for the value of the indicator being considered, and it is a consequence of his/her attitude toward risk (Winston, 2004). The utility of an evaluation grade H_n, represented by $u(H_n)$, is estimated from 0 to 1, where $u(H_{n+1}) > u(H_n)$. When the utility of each grade is quantified, the expected utility of a company can be defined by the following equation (Yang, 2001).

$$u\left\{S\left[y\left(a_l\right)\right]\right\}=\sum_{n=1}^{N}\beta_n\left(a_l\right)u\left(H_n\right) \tag{31}$$

When an incomplete assessment is involved, the maximum and minimum expected utilities of a company a_l, denoted by $U_{\max}(a_l)$ and $U_{\min}(a_l)$, can be calculated by assuming that the unassigned belief degree (β_H) is respectively transferred to the best (H_N) and the worst grades (H_1). The average utility, $U_{\text{avg}}(a_l)$, can then be computed as the midpoint between the maximum and minimum values (Yang, 2001).

From the interval of the combined belief degrees, equation (30), the interval of the expected utility for a company can be determined, based upon the optimization function shown as follows.

Objective functions:

$$U_{\max}\left(a_l\right)=\text{Max }u_{\max}\left(a_l\right)=\sum_{n=1}^{N-1}u\left(H_n\right)\beta_n\left(a_l\right)+u\left(H_N\right)\left[\beta_N\left(a_l\right)+\beta_H\left(a_l\right)\right] \tag{32}$$

$$U_{\min}\left(a_l\right)=\text{Min }u_{\min}\left(a_l\right)=u\left(H_1\right)\left[\beta_1\left(a_l\right)+\beta_H\left(a_l\right)\right]+\sum_{n=2}^{N}u\left(H_n\right)\beta_n\left(a_l\right) \tag{33}$$

s.t.

$$\beta_n^-\left(a_l\right)\leqslant\beta_n\left(a_l\right)\leqslant\beta_n^+\left(a_l\right),\ n=1,\ldots,N \tag{34}$$

$$\beta_H^-\left(a_l\right)\leqslant\beta_H\left(a_l\right)\leqslant\beta_H^+\left(a_l\right) \tag{35}$$

$$\sum_{n=1}^{N}\beta_n\left(a_l\right)+\beta_H\left(a_l\right)=1 \tag{36}$$

The required variables for this model are the aggregated degrees of belief and the utilities of each grade. Note that if all assessments are complete, then there is no unassigned belief degree or $\beta_H(a_l)$=0. Thus, there is no difference among the maximum, minimum, and average utilities. Although the average utility can be used to rank alternatives, it must be remembered that such a ranking may still be inconclusive. For example, if $U_{\text{avg}}(a_l) > U_{\text{avg}}(a_k)$ but $U_{\max}(a_k) > U_{\max}(a_l)$, then the conclusion needs to make clear that a_l is preferred to only on an average basis. As a consequence of an existing uncertainty, there is a chance that the utility of a_k is greater than a_l. A suggestion for improving the reliability and robustness of the ranking is to lessen the uncertainty or incompleteness of the assessment (Yang, 2001).

4 The assessment of corporate sustainability for the sugar industry

This section shows the list of criteria and indicators employed for the assessment of corporate sustainability. They were determined based upon an empirical study (multiple case studies and a survey) conducted in Thailand during the years 2012 and 2013, and then were constructed as a hierarchical structure. The first level of the hierarchy is the overall sustainability performance. It is then divided into four major dimensions including environment, economic, social, and quality. Their criteria and sub-criteria are placed at the third and the fourth levels, respectively, as shown in *Figure 1.*

Since most of the words used to form the sub-criteria are still ambiguous and/or do not indicate how they can be assessed, their indicators need to be identified as displayed in Table 1. Some of the indicators are quantitative in nature in which the measurement units can be simply defined, whereas many of them are still qualitative. For qualitative indicators,

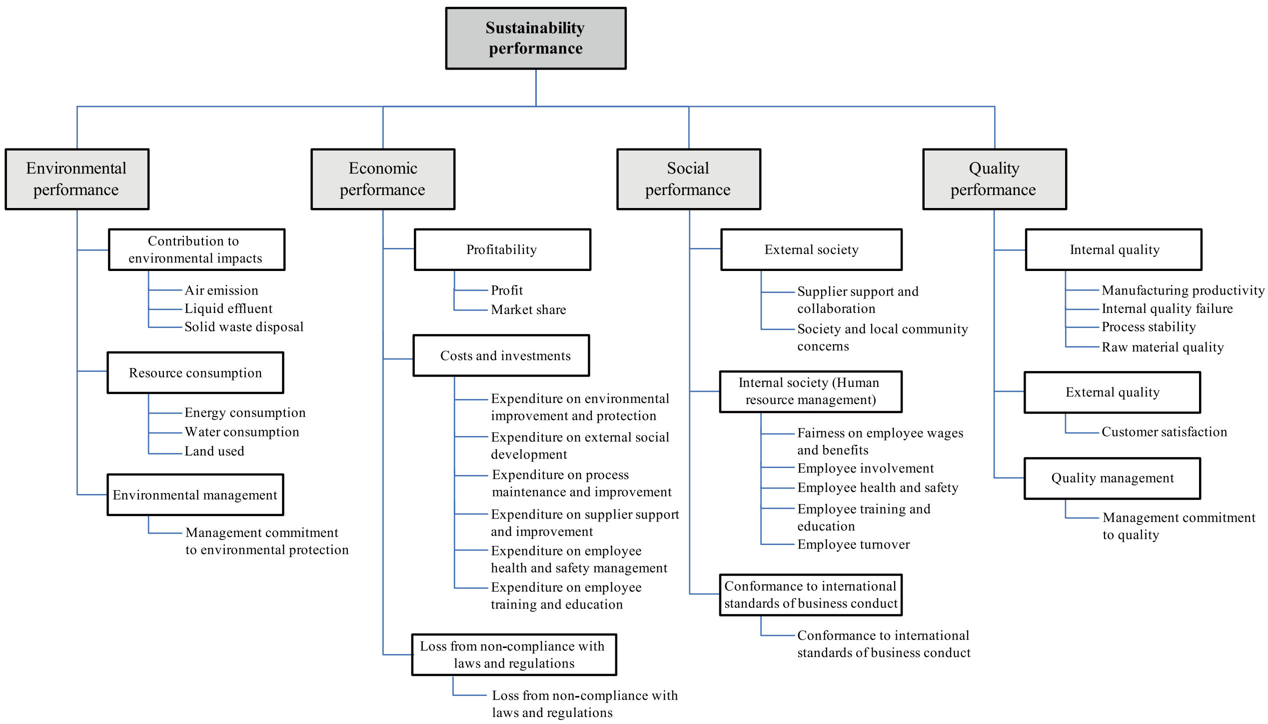

Figure 1. A hierarchical framework of corporate sustainability assessment for sugar manufacturing.

such as "social development and participation", a number of practice items are generated, based upon the empirical study and the literature, in order to together reflect the whole picture of each indicator. The assumption here is that these items are measures of different things which are part of the same aspect. Then, for each item, a solution to standardize the assessment and minimize inconsistency in the assessor's subjective judgment is to employ a set of evaluation grades or rating scales, and they need to be defined as clearly as possible by linking each grade with pieces of evidence or feasible practices. The number of grades for each item can be different according to how many distinct levels of feasible practices are needed. By this way, the assessor can simply select the grade which best reflects the actual practices of a company being considered.

Table 1 *List of Indicators Belonging to Each Sub-criterion*

Sub-criteria	Indicators	Measurement Units
Air emission	Rate of fossil fuels used by steam boilers relative to total amount of electricity produced per year	kg/(kW·h) or l/(kW·h)
	Concentration of total suspended particulate (TSP)	mg/m^3
Liquid effluent	Rate of water discharged into the environment relative to a tonne of cane processed per year	m^3/t
Solid waste disposal	Rate of hazardous waste disposed of relative to a tonne of cane processed per year	t/t
	Rate of non-hazardous waste disposed of relative to a tonne of cane processed per year	t/t

cont.

Sub-criteria	Indicators	Measurement Units
Energy consumption	Rate of steam consumption relative to a tonne of cane processed per year	t/t
	Rate of electricity consumption relative to a tonne of cane processed per year	kW·h/t
Water consumption	Rate of external water consumption relative to a tonne of cane processed per year	m^3/t
Land used	Rate of areas of sugar manufacturing sites relative to a tonne of cane processed per year	m^2/t
Management commitment to environmental protection	Management commitment to environmental protection	Qualitative evaluation (5 items)
Profit	Gross profit margin per year	%
Market share	Percentage of market share based on the quantity of sugar produced per year	%
Expenditure on environmental improvement and protection	Rate of expenditure on environmental improvement and protection per tonne of sugar produced per year	Monetary unit/t
Expenditure on external social development	Rate of expenditure on external social development per tonne of sugar produced per year	Monetary unit/t
Expenditure on process maintenance and improvement	Rate of expenditure on process maintenance and improvement per tonne of sugar produced per year	Monetary unit/t
Expenditure on supplier support and improvement	Rate of expenditure on cane farming support and improvement per tonne of sugar produced per year	Monetary unit/t
Expenditure on employee health and safety management	Rate of expenditure on employee health and safety management per tonne of sugar produced per year	Monetary unit/t
Expenditure on employee training and education	Rate of expenditure on employee training and education per tonne of sugar produced per year	Monetary unit/t
Loss from non-compliance with laws and regulations	Total amount of fines paid per year	Monetary unit
	Total number of non-monetary sanctions and warnings per year	Number
Supplier support and collaboration	Cane farmers support and collaboration	Qualitative evaluation (4 items)
Society and local community concerns	The number of complaints from the local community per year	Number
	Social responsibility	Qualitative evaluation (1 item)
	Social development and participation	Qualitative evaluation (3 items)
Fairness on employee wages and benefits	Internal fairness on employee wages and benefits	Qualitative evaluation (3 items)
	External fairness on employee wages and benefits	Qualitative evaluation (3 items)
Employee involvement	Employee involvement and empowerment	Qualitative evaluation (4 items)
	Employee communication	Qualitative evaluation (2 items)
Employee health and safety	Rate of work-related accidents relative to the total working hours in the working schedule per year	Number/h
	Percentage of working hours lost relative to the total working hours in the working schedule per year	%
	Employee health and safety provision	Qualitative evaluation (10 items)
Employee training and education	Employee training and education provision	Qualitative evaluation (7 items)
Employee turnover	Annual employee turnover rate	%
Conformance to international standards of business conduct	Conformance to international standards of business conduct	Qualitative evaluation (11 items)
Manufacturing productivity	The sugar yield at 96 Polarisation (POL) - 10 commercial cane sugar (CCS) equivalent (adjusted kilograms of sugar produced per tonne of cane processed)	kg/t
Internal quality failure	Percentage of reprocessing, derived from the weight of remelted sugar relative to total weight of the sugar produced per year	%
Process stability	Percentage of production shutdowns, derived from the total hours of unplanned shutdowns relative to the total operating hours per year	%

cont.

Sub-criteria	Indicators	Measurement Units
Raw material quality	Commercial cane sugar (CCS)	CCS
Customer satisfaction	The number of customer complaints and product returns per year	Number
Management commitment to quality	Management commitment to quality	Qualitative evaluation (5 items)

For example, the indicator "social development and participation" can be evaluated through 3 items, as described below: ① The company significantly contributes to a better quality of life for the local community through supporting education, health/medical, recreation, and public infrastructure and facilities; ② the company has been recognized as one of the major contributors to local employment; ③ the company employs indicators or methods to assess the image of the company in terms of social contributions and external perceptions.

The first item is then evaluated based on 5 grades shown as follows.

(1) There is no evidence of a budget and activities for supporting education, health/medical, recreation, and public infrastructure and facilities in the local community; and there is no evidence of plans to do this in the near future.

(2) The company is planning to do something that contributes to a better quality of life for the local community in the near future.

(3) Evidence shows that employees of the company have carried out some activities to support the education, health/medical, recreation, and public infrastructure and facilities of the local community by using their own resources or raising funds by themselves. No budget has been officially allocated by the company.

(4) Evidence shows that the company has officially made a contribution to a better quality of life for the local community. However, there is no evidence to show that the results and feedback have been followed up and reported.

(5) Evidence shows that the company has officially made a contribution to a better quality of life for the local community. Also, the operating results and feedback have been reported in management reviews.

The defined grades clearly indicate what evidence is required in order to achieve each level for each item. It can be a clear guideline for how a company can improve its performance in terms of each aspect. Unfortunately, due to the word limit for publication, practice items and their evaluation grades of all qualitative indicators are not shown in this paper.

5 The application of the ER model in corporate sustainability assessment

This section aims to demonstrate the applicability of the ER algorithm in analyzing sustainability performance by using actual data collected from three sugar manufacturers in Thailand. The data from the three companies is considered as adequately robust for demonstrating the applicability of the model since the model is developed to fulfill the need for a company's self-assessment, and the data aggregation under the ER approach of one company can be performed independently of the data of the others. This section also aims to show how the ER model can be utilized in performance analysis under different perspectives among top management and external experts within the Thai sugar industry.

Based on equations (17)-(29), two kinds of information are required as the inputs of the ER algorithm, including: ① belief distributions derived from the assessment data for each indicator/item; ② criteria weights. Before determining the belief distributions, the quantitative and qualitative information was gathered by different methods. Firstly, qualitative assessment was conducted through interviewing people in the top management positions of the three companies. For each item, the interviewees were asked to explain the extent of their practices regarding that aspect. The evaluation grades for each item were not presented to the interviewees since it is known that people tend to provide inflated grades or they may not want to disclose their poor performance in order to satisfy social desirability (Thompson & Phua, 2005). In other words, belief distribution was assigned to each item by the researcher, based on the evidence described by the interviewees, in order to avoid bias from self-assessment. In terms of quantitative assessment, the assessment sheets composed of 24 indicators were handed to the interviewees after the interviews. They were informed that this study allows them to provide interval values if they were not confident about giving a certain value or if the data fluctuated over the course of a year. Moreover, they could skip some of the questions if the data was not available or if they did not want to disclose that information. Within a month of the interview dates, the assessment sheets from the three companies were posted back to the researcher. Four indicators, including the percentage of market share based on the quantity of sugar produced per year, the sugar yield at 96 POL-10 CCS equivalence, the percentage of production shutdowns, and CCS, are not included on the assessment sheet since these kinds of information are available in the database of the Office of the Cane and Sugar Board (OCSB).

Before combining information using the ER algorithm, the D-S theory requires that elements or propositions (H_i) defined by all pieces of evidence must be members of the same frame of discernment (H). Generally speaking, all items/indicators must be assessed towards the same set of grades. Since the assessment data from quantitative indicators which were measured under different units has to be combined with the data from qualitative items which were also evaluated through different sets of grades, such a requirement was not satisfied. To solve this, the rule-based transformation technique, introduced by Yang (2001), was employed. The equivalent rules were constructed based on an interview with two experts. The term "experts" in this case means people who know a lot about the Thai sugar industry, and are able to provide the best practices, the worst situations, and general practices according to the industrial standards. People in the management positions of the OCSB are considered as most appropriate for this task. The responsibilities of this organization are to formulate policies for the development of the Thai sugar industry, to monitor the production and distribution of all sugar manufacturers within the country, as well as to promote research and development projects relating to canes, sugar, and by-products in order to enhance the competitiveness of the industry. It is believed that, when the information used to construct the rules of equivalence is provided by such experts rather than practitioners working in manufacturing companies, independence from the companies being assessed is guaranteed. The two experts, colleagues who are proficient in different aspects, preferred a group discussion rather than individual interviews. After the transformation following Yang (2001), Wang et al. (2006b), and Guo et al. (2007), numerical data from the quantitative measurements and belief distributions from the qualitative assessments were converted into belief distributions under five general grades, {None, Poor, Fair, Good, Excellent} or {N, P, F, G, E}. Unfortunately, the transformation processes cannot be displayed in this paper due to the word limit. The transformed belief distributions are shown in Table 2-Table 5 for the environmental, economic, social, and quality performances, respectively. Note that integer variables (I) appears at the belief distributions of some companies under some indicators/items for the cases that interval value is covered by two grades and it contains one or more consecutive grades. See Guo et al. (2007) for additional explanation.

Table 2 *Distribution Assessment Matrix for the Environmental Performance of the Three Companies*

Environmental Indicators	Company A	Company B	Company C
Rate of fossil fuel (fuel oil) used by steam boilers relative to total amount of electricity produced per year	{(E, 1.0)}	{(G, 0.017), (E, 0.983)}	{(E, 1.0)}
Concentration of TSP	{(P, [0, 0.5I_1]), (F, [0, I_1+I_2]), (G, [0, I_2+I_3]), (E, [0, 0.5I_3])}	{(N, 0.95), (P, 0.05)}	{(N, [0.2, 0.5]), (P, [0.5, 0.8])}
Rate of water discharged into the environment relative to a tonne of cane processed per year	{(E, 1.0)}	{(E, 1.0)}	{(G, 0.012), (E, 0.988)}
Rate of hazardous waste disposed of relative to a tonne of cane processed per year	{(N, 1.0)}	{(F, 0.55), (G, 0.45)}	{(F, 0.382), (G, 0.618)}
Rate of non-hazardous waste disposed of relative to a tonne of cane processed per year	{(N, 0.46), (P, 0.54)}	{(G, 0.6), (E, 0.4)}	{(E, 1.0)}
Rate of steam consumption relative to a tonne of cane processed per year	{(G, 0.65), (E, 0.35)}	{(F, 0.75), (G, 0.25)}	{(F, 0.25), (G, 0.75)}
Rate of electricity consumption relative to a tonne of cane processed per year	{(G, 0.854), (E, 0.146)}	{(G, 0.671), (E, 0.329)}	{(F, 0.126), (G, 0.874)}
Rate of external water consumption relative to a tonne of cane processed per year	{(G, 0.583), (E, 0.417)}	{(G, 0.433), (E, 0.567)}	{(G, 0.053), (E, 0.947)}
Rate of land used relative to the weight of cane processed within a year	{(N, 1.0)}	{(F, 0.6), (G, 0.4)}	{(G, 0.097), (E, 0.903)}
Management commitment to environmental protection	{(F, 0.148), (E, 0.852)}	{(N, 0.177), (G, 0.287), (E, 0.536)}	{(N, 0.642), (G, 0.141), (E, 0.217)}

Table 3 *Distribution Assessment Matrix for the Economic Performance of the Three Companies*

Economic Indicators	Company A	Company B	Company C
Gross profit margin per year	{(F, 0.475), (G, 0.525)}	{(N, [0.375, 0.750]), (P, [0.250, 0.625])}	{(F, [0, 0.5I_1]), (G, [0, I_1+I_2]), (E, [0, 0.75I_2])}
Percentage of market share based on the quantity of sugar produced per year	{(G, 0.079), (E, 0.921)}	{(F, 0.511), (G, 0.489)}	{(P, 0.86), (F, 0.14)}
Rate of expenditure on environmental improvement and protection per tonne of sugar produced per year	{(G, 0.228), (E, 0.772)}	{(P, [0, 0.823I_1]), (F, [0, I_1+I_2]), (G, [0, 0.353I_2])}	{(F, 0.152), (G, 0.848)}

cont.

Economic Indicators	Company A	Company B	Company C
Rate of expenditure on external social development per tonne of sugar produced per year	{(H, 1.0)}	{(F, [0, 1]), (G, [0, 1])}	{(G, 0.579), (E, 0.421)}
Rate of expenditure on process maintenance and improvement per tonne of sugar produced per year	{(P, 1.0)}	{(G, [0.667, 1]), (E, [0, 0.333])}	{(G, 0.456), (E, 0.544)}
Rate of expenditure on cane farming support and improvement per tonne of sugar produced per year	{(N, 1.0)}	{(F, [0, 1]), (G, [0, 1])}	{(P, [0, 1]), (F, [0, 1])}
Rate of expenditure on employee health and safety management per tonne of sugar produced per year	{(G, 0.126), (E, 0.874)}	{(F, [0, 0.714I_1]), (G, [0, I_1+I_2]), (E, [0, 0.428I_2])}	{(F, 0.233), (G, 0.767)}
Rate of expenditure on employee training and education per tonne of sugar produced per year	{(P, 0.429), (F, 0.571)}	{(F, [0.429, 0.857]), (G, [0.143, 0.571])}	{(G, 0.277), (E, 0.723)}
Total amount of fines paid per year	{(E, 1.0)}	{(E, 1.0)}	{(E, 1.0)}
Total number of non-monetary sanctions and warnings per year	{(E, 1.0)}	{(E, 1.0)}	{(E, 1.0)}

Table 4 *Distribution Assessment Matrix for the Social Performance of the Three Companies*

Social Indicators	Company A	Company B	Company C
Cane farmers support and collaboration	{(N, 0.016), (E, 0.984)}	{(N, 0.023), (F, 0.233), (G, 0.233), (E, 0.511)}	{(N, 0.044), (G, 0.507), (E, 0.449)}
The number of complaints from the local community per year	{(E, 1.0)}	{(E, 1.0)}	{(N, [0, I_1]), (P, [0, I_1+I_2]), (F, [0, 0.5I_2])}
Social responsibility	{(E, 1.0)}	{(E, 1.0)}	{(E, 1.0)}
Social development and participation	{(E, 1.0)}	{(F, 0.333), (G, 0.333), (E, 0.334)}	{(F, 0.333), (G, 0.333), (E, 0.334)}
Internal fairness on employee wages and benefits	{(E, 1.0)}	{(F, 0.334), (G, 0.148), (E, 0.518)}	{(N, 0.286), (E, 0.714)}
External fairness on employee wages and benefits	{(G, 0.286), (E, 0.714)}	{(F, 0.286), (G, 0.714)}	{(F, 0.308), (G, 0.538), (E, 0.154)}
Employee involvement and empowerment	{(F, 0.086), (E, 0.914)}	{(F, 0.231), (G, 0.231), (E, 0.538)}	{(F, 0.231), (G, 0.231), (E, 0.538)}
Employee communication	{(E, 1.0)}	{(E, 1.0)}	{(G, 0.5), (E, 0.5)}
Rate of work-related accidents relative to the total working hours in the working schedule per year	{(P, 0.714), (F, 0.286)}	{(G, 0.337), (E, 0.663)}	{(P, 0.307), (F, 0.693)}
Percentage of working hours lost relative to the total working hours in the working schedule per year	{(H, 1.0)}	{(F, [0.75, 1]), (G, [0, 0.25])}	{(P, 0.407), (F, 0.593)}
Employee health and safety provision	{(G, 0.067), (E, 0.933)}	{(P, 0.08), (F, 0.08), (G, 0.11), (E, 0.73)}	{(F, 0.069), (G, 0.034), (E, 0.897)}
Employee training and education provision	{(N, 0.111), (P, 0.077), (G, 0.033), (E, 0.779)}	{(N, 0.289), (P, 0.211), (F, 0.211), (E, 0.289)}	{(N, 0.443), (P, 0.199), (E, 0.358)}
Annual employee turnover rate	{(G, [0, 0.154]), (E, [0.846, 1])}	{(F, 0.538), (G, 0.462)}	{(G, 0.28), (E, 0.72)}
Conformance to standards of business conduct	{(F, 0.059), (E, 0.941)}	{(N, 0.064), (P, 0.064), (E, 0.872)}	{(N, 0.134), (E, 0.866)}

Table 5 *Distribution Assessment Matrix for the Quality Performance of the Three Companies*

Quality Indicators	Company A	Company B	Company C
The sugar yield at 96 POL-10 CCS equivalent	{(P, [0, 0.432I_1]), (F, [0, I_1+I_2]), (G, [0, I_2+I_3]), (E, [0, 0.982I_3])}	{(P, [0.030, 0.598]), (F, [0.403, 0.970])}	{(F, 0.058), (G, 0.942)}
Percentage of reprocessing, derived from the weight of remelted sugar relative to total weight of the sugar produced per year	{(H, 1.0)}	{(E, 1.0)}	{(G, 0.061), (E, 0.939)}
Percentage of production shutdowns, derived from the total hours of unplanned shutdowns relative to the total operating hours per year	{(P, [0, 0.32I_1]), (F, [0, I_1+I_2]), (G, [0, I_2+I_3]), (E, [0, I_3])}	{(N, [0, 0.905I_1]), (P, [0, I_1+I_2]), (F, [0, I_2+I_3]), (G, [0,0.101I_3])}	{(F, 0.655), (G, 0.345)}
CCS	{(P, [0, 0.37I_1]), (F, [0, I_1+I_2]), (G, [0, I_2+I_3]), (E, [0, 0.37I_3])}	{(P, [0,0.32I_1]), (F, [0, I_1+I_2]), (G, [0, 0.91I_2])}	{(P, 0.33), (F, 0.67)}
The number of customer complaints and product returns per year	{(G, 0.556), (E, 0.444)}	{(G, 0.444), (E, 0.556)}	{(E, 1.0)}
Management commitment to quality	{(N, 0.164), (F, 0.041), (G, 0.094), (E, 0.701)}	{(N, 0.179), (P, 0.054), (F, 0.063), (G, 0.184), (E, 0.520)}	{(P, 0.049), (F, 0.101), (G, 0.157), (E, 0.693}

From Table 2–5, the belief distributions were converted into forms which are applicable for analysis using the ER algorithm. The ER nonlinear optimization model, equations (17)–(29), was then used to combine the performances under multiple indicators/items. For each company, the model was run from the lowest level (indicators/items) to sub-criteria and criteria levels, respectively. Then, the overall sustainability performance was determined by aggregating performances under the four major dimensions (environment, economic, social, and quality). In terms of the criteria weights, the data was gathered from the interviews of nine people, six in top management (DM1–DM6) from six sugar manufacturing companies and three industrial experts (DM7–DM9). As claimed by the literature, while a local perspective from top management plays a key role in making decisions relating to corporate sustainability of their own company, an expert's knowledge could reflect in a more universal sense the perspectives of several groups of stakeholders. However, universal perspective might be argued to lack of specifically local knowledge. In other words, some internal concerns might be disregarded or not recognized by outside experts (Fischer, 2000; Skogen, 2003; Strager & Rosenberger, 2006). One of the aims of this section, therefore, is to investigate the extent to which differences in attitudes toward the importance of criteria among these people affect the ranking order of the three sample companies, or whether it is possible to reach a consensus among people in top management positions and external experts when judging which company is more sustainable. The weights were elicited based on the direct rating method, and the results are shown in Appendix 1. Note that the elicitation of weights was not carried out at the indicator and item levels since the list of these is more likely to change according to data availability and current circumstances. Moreover, an excessive workload would be required for each DM if all indicators/items were included. As such, all indicators for the same sub-criterion, as well as all practice items for the same qualitative indicator, are assumed to take equal weight in the combination processes.

After running the same model using individual sets of weights from the nine DMs, the aggregated interval degrees of belief for the overall sustainability performance can be determined, and the results are shown in Appendix 2. Next, the corresponding expected utilities can be obtained according to equations (32)–(36), and the results are displayed in Table 6. For this study, the utilities of the grades "None", "Poor", "Fair", "Good", and "Excellent" are assumed as linear which are equal to 0, 0.25, 0.5, 0.75, and 1, respectively. This study employs LINGO software version 12.0 to solve the optimization problems. The ranking order of the three companies can be determined according to the average of the expected utility. Note that, based on Yang (2001), the utilities described above are only used for ranking alternatives or characterizing the assessment, but not for the purpose of attribute aggregation.

Table 6 *Expected Utilities of the Overall Sustainability Performance and the Ranking Order of the Three Companies under the Weights Assigned by the Nine DMs (DM1–DM9)*

DMs	Company A			Company B			Company C			Ranking Order		
	U_{min}	U_{max}	U_{avg}	U_{min}	U_{max}	U_{avg}	U_{min}	U_{max}	U_{avg}	1st	2nd	3rd
DM1	0.744	0.827	0.786	0.558	0.669	0.614	0.646	0.744	0.695	A	C	B
DM2	0.804	0.861	0.832	0.643	0.711	0.677	0.699	0.761	0.730	A	C	B
DM3	0.811	0.874	0.843	0.648	0.706	0.677	0.633	0.692	0.662	A	B	C
DM4	0.818	0.893	0.855	0.669	0.724	0.697	0.675	0.728	0.702	A	C	B
DM5	0.776	0.857	0.817	0.572	0.679	0.625	0.647	0.733	0.690	A	C	B
DM6	0.816	0.875	0.845	0.650	0.725	0.687	0.650	0.735	0.692	A	C	B
DM7	0.759	0.838	0.798	0.650	0.721	0.686	0.678	0.744	0.711	A	C	B
DM8	0.769	0.853	0.811	0.582	0.693	0.637	0.647	0.741	0.694	A	C	B
DM9	0.776	0.856	0.816	0.609	0.700	0.654	0.672	0.739	0.705	A	C	B

From Table 6, the nine ranking orders give a consensus in the sense that company A is currently the most sustainable company. This is not only because it receives the highest average expected utility, but its interval expected utility also indicates its absolute dominance over the others. According to the absolute dominance concept under interval values, explained by Salo and *Hämäläinen* (1992, cited in Guo et al., 2007), an alternative *X* dominates *Y* when the minimum expected utility of *X* is greater than the maximum utility of *Y*.

The result is intuitively reasonable since there are many reasons supporting that company A should be the most sustainable company. For example, in terms of the environmental dimension, there are plenty of programmes and projects relating to environmental concerns which are not only implemented in manufacturing operations but also in other support processes such as campaigns to reduce the use of paper, electricity, personal cars, etc. In addition, many attempts have been made to reduce the emission of greenhouse gases from the production system so that its products have been certified for the Carbon Label. For company A, various key performance indicators (KPIs) relating to environmental aspects are also used to assess team and individual performance. Although their environmental performance is not officially targeted beyond the minimum requirements of the current environmental regulations, this company has generally implemented control limits which are tighter than specification limits. This implies the readiness of this company for changes in environmental requirements in the future. Furthermore, a department of environmental management has been established as an individual department in company A while this is not a common practice in other Thai sugar companies. This is also clear evidence showing that this company focuses intensely on environmental administration. The performance of company A for the criterion "contribution to environmental impacts" is also considered to be high. This is influenced by the fact that this company is the only one which has brought in the new legal minimum requirement for TSP while the other two companies have not achieved this yet. This has resulted from the implementation of electrostatic precipitators (ESPs) and the muti-cyclone air pollution treatment. However, the weaknesses of this company in terms of the environmental dimension are for the indicators "rate of hazardous waste disposed of" and "rate of land used" where they receive 100% degree of belief for the grade "None". This means company A should focus more on their space utilization and efficiency as well as on the reduction of hazardous waste in its processes. The common good practices of the three companies are mainly for the criterion "contribution to environmental impact". They have utilized bagasse and other kinds of biomass for combustion in boilers instead of using fossil fuels, although company B still uses a small amount of oil to supplement the start-up process. Moreover, the three companies have achieved, or nearly achieved, the policy of zero water discharge. The treated water from their stabilization ponds is reused in the production system and is also distributed to nearby agricultural areas.

Regarding the economic dimension, company A is also ranked first in general. The major strength of company A is its profitability, from both the sub-criteria "profit" and "market share", while their weakness is clear for the criterion "costs and investments". By looking through the individual belief structures (Table 3), company A has spent significantly more than the others to enhance their corporate sustainability, especially in cane farming support, process maintenance and improvement, and employee training. Moreover, the top management does not provide data about expenditure on external social development, which can affect the aggregated utilities both positively and negatively. Although the performance on the costs and investments of company A looks poorer than the others to a great extent, this contributes only a little to the overall economic performance due to the low weight of this criterion particularly when compared to the weight of the criterion "profitability" (see Appendix 1).

Company A also leads the group for the social dimension. Although all companies are able to show the evidence of how they continuously assess the risks and impacts that their operations have had on the local community, and they also continuously launch activities to satisfy social expectation and improve the quality of life of the local community, the major difference between company A and the others is that its results for such activities have been officially followed up and reported in management reviews. Moreover, company A employs a formal survey and has also established a community relation team to assess community perceptions. This is the clear evidence of how this company is intensely concerned about external society. For the internal society criterion, company A performs better than B and C in almost all aspects. For instance, in terms of fairness on employee wages and benefits, there is the evidence of KPIs and goals which are used to assess individuals' performance and contribution to the organization in order to annually adjust their wages. In addition, the top management could describe transparent communication processes which allow employees to understand how their wages are adjusted each year. The wage range of each job grade has also been logically determined within this company. Furthermore, there is evidence to show that company A offers the highest wages and benefits to its employees in operational positions when compared to other companies in the same local area, whereas the other two companies do not. Regarding the aspect of employee health and safety, company B has a lower rate of work-related accidents and percentage of working hours lost than A and C. However, companies A and C generally outperform B in terms of management strategies. When considering the aspect of employee training and education, company A leads the group by providing additional training programmes which have not been established in B and C, such as an individual development programme, job rotation, and sponsorship for qualified employees to study for a higher degree. The superiority of company A in terms of human resource management over the others, as mentioned previously, is consistent with their rate of employee turnover which is considerably lower than that of the others. Furthermore, company A outperforms the other two companies in terms of the criterion "conformance to standards of business conduct", especially the item which suggests that companies B and C need to consider the establishment of an official code of conduct and then communicate this to their workers, suppliers and business partners.

Lastly, for the quality dimension, company C seems to perform better than the others, particularly in terms of the number of customer complaints and the sugar yield. Regarding the latter, although company A has a maximum yield higher than C, its minimum is significantly lower. The high degree of uncertainty is the major weak point for company A for the quality performance. This company is not only unable to provide information for some indicators, but many aspects of its quality performance (the yield, the percentage of production shutdown, and the CCS) also fluctuate between different plants. Although the best values that company A achieves in most internal quality indicators are better than those of company C, as stated, its worst values from some plants are poorer.

When considering the ranking orders between companies B and C, the weight sets from eight of the nine DMs enable C to be ranked higher than B; only the weight set from DM3 is different. This is a consequence of the fact that DM3 assigns a significantly higher weight to the environmental dimension when compared to other people, and this is the aspect for which company B receives higher performance in general. However, when considering the interval expected utilities of companies B and C from Table 6, the minimum utilities of the former company are still lower than the maximum utilities of the latter in all of the nine cases. This means the ranking order between these two companies is still not robust because the uncertainty in belief assignment still remains. As stated by Omann (2006, pp.4–7), different sets of weights greatly influence the ranking order when the gap between the performances of the alternatives is small. Clearly, this statement applies when comparing companies B and C, but not for company A which considerably outperforms the others.

Overall, the discussions in this section illustrate that the aggregated results and the ranking orders for each dimension are consistent with the evidence gathered from the data collection processes. This supports the ability of the ER model to justify itself in determining reasonable and intuitively acceptable results. The results also indicate that the variation of weights among people in top management and experts within the Thai sugar industry only has a small impact on the ranking order of the three sample companies. This implies that, although different top managers and experts suggest different directions for enhancing corporate sustainability, it is possible to obtain a consensus among them when judging and ranking the sustainability of the companies. However, this may not be the case for middle managers from different departments/divisions of the companies. It is likely that managers in a specific section may examine the company's sustainability based mainly on the benefits for and concerns of their own sections, whereas the top management and external experts are likely to compromise more in their views or consider sustainability from a broader perspective.

The analysis using the ER approach can be done more thoroughly than as being shown in this paper. For instance, the aggregated belief distributions at the criteria and dimensional levels should be also considered in order to intensively analyze the strengths and weaknesses of each company, rather than focusing on only the overall sustainability performance. Furthermore, sensitivity analysis for the changes of weights should be conducted for further investigations and discussions. Note that, in cases when weights cannot be determined precisely, the following equations about intervals of weights can be incorporated as additional conditions for optimization.

$$w_i^- \leqslant w_i \leqslant w_i^+,\ i = 1, \ldots, L \tag{37}$$

$$\sum_{i=1}^{L} w_i = 1,\ i = 1, \ldots, L \tag{38}$$

When applying equations (37) and (38), variables required as the inputs of the aggregation process are the interval weights for each criterion, including the minimum (w_i^-) and maximum (w_i^+) values.

6 Conclusion

The ER approach is considered as an effective and practical method for the assessment of corporate sustainability. Its algorithm strictly conforms to conjunctive reasoning which is appropriate when all sources of information are considered as reliable. In sustainability performance assessment, information from all criteria is assumed to be reliable and needs to be taken into account, and the aim is to look for support from all criteria rather than from only one of them. When compared to Dempster's rule, the ER algorithm manages the issue of counterintuitive results by eliminating the assumption that each criterion has a dominating role or an absolute power to accept its own proposition and disregard different opinions due to other criteria (Tchamova & Dezert, 2012). The ER algorithm takes into account the relative weights of criteria, and this implies that none of them are dominating but each plays a relative role which is equal to its relative importance (Yang &Xu, 2011, pp.7–15; Yang & Xu, 2013). This compensatory situation is considered as more consistent with the general nature of business performance assessment. The adoption of belief structures in the ER approach allows an assessor to assign his/her belief degrees to several assessment grades, rather than be forced to believe in only one grade. The ER algorithm then provides a method of aggregation in which useful information and various forms of uncertainties and incompleteness in the original assessment data are still preserved for further analysis (Wang et al., 2006b; Yang et al., 2001; Yang, Xu, Xie, Maddulapalli, 2011). As stated by Singh, Murty, Gupta, & Dikshit, (2012), the inclusion of uncertainty enhances the robustness of a composite score and minimizes inaccuracies. It also increases transparency and frames a guideline for policy discussions.

According to the ER approach using the assessment grades as pieces of evidence, subjective bias from the assessment of qualitative criteria can be minimized since the assessment is explicitly linked to the accumulated evidence. That means the application of the ER approach to corporate sustainability assessment is not simply an application of its mathematical formulations to aggregate the scores. Instead, an original approach is taken, based on the compilation of evidence-based performances linked to the assessment grades and the utilities. In other words, the assessment grades and the rules of equivalence for each indicator/item need to be identified empirically when constructing the assessment framework for a new area.

The application to the actual data from three companies confirms the applicability of ER approach in the assessment of sustainability performance. The proposed aggregation method is effective not only for performance comparison across several companies but also for self-assessment of a single company. The combined degrees of belief and the obtained expected utility enable companies to set targets for improvement, to determine benchmarking standards, and to track their progress toward sustainable development policies. The interval of the results can be also used as a base for reducing uncertainties in their performance measurement system or the incompleteness of the available information. The model can be generalized to any cases of multiple criteria assessment. It is workable even with incompleteness and uncertainties in weighing criteria and assessing performances, and also with qualitative criteria which are difficult to measure quantitatively.

Appendix 1 *Weights Elicited from the Nine DMs (DM1–DM9)*

Criteria	Sub-criteria	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9
Contribution to environmental impacts	Air emission	0.833	0.300	0.667	0.588	0.667	0.588	0.500	0.541	0.714
	Liquid effluent	0.083	0.500	0.267	0.235	0.200	0.294	0.450	0.432	0.143
	Solid waste disposal	0.083	0.200	0.067	0.176	0.133	0.118	0.050	0.027	0.143
Resource consumption	Energy consumption	0.588	0.435	0.625	0.588	0.500	0.556	0.350	0.278	0.526
	Water consumption	0.176	0.348	0.188	0.294	0.400	0.278	0.150	0.167	0.184
	Land used	0.235	0.217	0.188	0.118	0.100	0.167	0.500	0.556	0.289
Profitability	Profit	0.588	0.444	0.556	0.412	0.500	0.459	0.556	0.474	0.474
	Market share	0.412	0.556	0.444	0.588	0.500	0.541	0.444	0.526	0.526
Costs and investments	Expenditure on environmental improvement and protection	0.116	0.152	0.230	0.202	0.294	0.182	0.149	0.211	0.094
	Expenditure on external social development	0.233	0.174	0.161	0.162	0.088	0.221	0.178	0.211	0.094
	Expenditure on process maintenance and improvement	0.116	0.130	0.092	0.162	0.206	0.078	0.149	0.105	0.313

cont.

Criteria	Sub-criteria	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9
Costs and investments	Expenditure on supplier support and improvement	0.233	0.217	0.218	0.162	0.235	0.260	0.198	0.211	0.313
	Expenditure on employee health and safety management	0.116	0.130	0.115	0.152	0.088	0.130	0.149	0.105	0.094
	Expenditure on employee training and education	0.186	0.196	0.184	0.162	0.088	0.130	0.178	0.158	0.094
External society	Supplier support and collaboration	0.588	0.556	0.588	0.667	0.667	0.541	0.526	0.556	0.714
	Society and local community concerns	0.412	0.444	0.412	0.333	0.333	0.459	0.474	0.444	0.286
Internal society	Fairness on employee wages and benefits	0.278	0.215	0.243	0.068	0.286	0.238	0.192	0.200	0.213
	Employee involvement	0.167	0.177	0.270	0.169	0.200	0.190	0.137	0.200	0.181
	Employee health and safety	0.222	0.203	0.216	0.288	0.229	0.214	0.274	0.200	0.213
	Employee training and education	0.194	0.253	0.189	0.339	0.200	0.190	0.233	0.200	0.181
	Employee turnover	0.139	0.152	0.081	0.136	0.086	0.167	0.164	0.200	0.213
Internal quality	Manufacturing productivity	0.227	0.227	0.500	0.435	0.364	0.281	0.246	0.300	0.286
	Internal quality failure	0.091	0.136	0.050	0.043	0.073	0.105	0.328	0.100	0.036
	Process stability	0.227	0.182	0.250	0.217	0.291	0.263	0.262	0.200	0.321
	Raw material quality	0.455	0.455	0.200	0.304	0.273	0.351	0.164	0.400	0.357

Dimensions	Criteria	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9
Environment	Contribution to environmental impacts	0.100	0.217	0.150	0.455	0.318	0.250	0.217	0.250	0.240
	Resource consumption	0.500	0.348	0.350	0.227	0.227	0.333	0.348	0.250	0.360
	Environmental management	0.400	0.435	0.500	0.318	0.455	0.417	0.435	0.500	0.400
Economic	Profitability	0.625	0.769	0.741	0.667	0.645	0.556	0.588	0.556	0.704
	Costs and investments	0.313	0.192	0.222	0.200	0.323	0.389	0.294	0.333	0.246
	Loss from non-compliance with laws and regulations	0.063	0.038	0.037	0.133	0.032	0.056	0.118	0.111	0.049
Social	External society	0.385	0.389	0.350	0.217	0.541	0.488	0.381	0.500	0.357
	Internal society	0.513	0.556	0.500	0.435	0.405	0.390	0.476	0.400	0.321
	Conformance to international standards of business conduct	0.103	0.056	0.150	0.348	0.054	0.122	0.143	0.100	0.321
Quality	Internal quality	0.435	0.222	0.375	0.476	0.375	0.340	0.444	0.455	0.400
	External quality	0.217	0.333	0.208	0.238	0.208	0.283	0.333	0.318	0.200
	Quality management	0.348	0.444	0.417	0.286	0.417	0.377	0.222	0.227	0.400

General attribute	Dimensions	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9
Sustainability performance	Environment	0.200	0.179	0.400	0.308	0.182	0.230	0.364	0.143	0.222
	Economic	0.400	0.286	0.200	0.231	0.364	0.328	0.273	0.476	0.278
	Social	0.200	0.179	0.200	0.308	0.182	0.328	0.182	0.190	0.222
	Quality	0.200	0.357	0.200	0.154	0.273	0.115	0.182	0.190	0.278

Appendix 2 *Aggregated Interval Belief Degrees Using the Weights from the Nine DMs (DM1–DM9)*

Company A												
DMs	None		Poor		Fair		Good		Excellent		*H*	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DM1	0.058	0.058	0.026	0.056	0.094	0.180	0.173	0.265	0.523	0.591	0.035	0.036
DM2	0.050	0.051	0.016	0.039	0.062	0.128	0.166	0.239	0.616	0.668	0.020	0.020

cont.

Company A												
DMs	None		Poor		Fair		Good		Excellent		*H*	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DM3	0.043	0.044	0.012	0.042	0.070	0.154	0.146	0.233	0.629	0.705	0.013	0.014
DM4	0.036	0.037	0.023	0.063	0.049	0.149	0.096	0.200	0.674	0.755	0.017	0.018
DM5	0.048	0.050	0.028	0.068	0.069	0.178	0.138	0.250	0.586	0.681	0.018	0.018
DM6	0.049	0.050	0.021	0.039	0.059	0.105	0.112	0.162	0.677	0.715	0.031	0.031
DM7	0.077	0.078	0.021	0.047	0.070	0.140	0.127	0.200	0.593	0.656	0.037	0.038
DM8	0.052	0.053	0.026	0.056	0.078	0.162	0.127	0.214	0.593	0.661	0.036	0.037
DM9	0.058	0.060	0.024	0.067	0.060	0.179	0.128	0.254	0.593	0.694	0.012	0.012

Company B												
DMs	None		Poor		Fair		Good		Excellent		*H*	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DM1	0.095	0.172	0.046	0.158	0.153	0.328	0.202	0.347	0.267	0.283	0.000	0.000
DM2	0.088	0.136	0.037	0.111	0.140	0.239	0.239	0.318	0.357	0.368	0.000	0.000
DM3	0.104	0.151	0.030	0.107	0.135	0.223	0.226	0.276	0.385	0.393	0.000	0.000
DM4	0.101	0.139	0.035	0.102	0.134	0.224	0.175	0.232	0.440	0.450	0.000	0.000
DM5	0.099	0.173	0.039	0.170	0.140	0.306	0.204	0.315	0.300	0.319	0.000	0.000
DM6	0.077	0.118	0.030	0.096	0.152	0.292	0.204	0.323	0.363	0.380	0.000	0.000
DM7	0.090	0.143	0.029	0.104	0.138	0.242	0.213	0.287	0.388	0.403	0.000	0.000
DM8	0.079	0.143	0.037	0.153	0.155	0.354	0.191	0.349	0.288	0.308	0.000	0.000
DM9	0.092	0.160	0.036	0.138	0.141	0.280	0.208	0.302	0.343	0.359	0.000	0.000

Company C												
DMs	None		Poor		Fair		Good		Excellent		*H*	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DM1	0.063	0.077	0.109	0.154	0.089	0.207	0.227	0.364	0.329	0.472	0.000	0.000
DM2	0.058	0.071	0.125	0.152	0.084	0.152	0.158	0.240	0.463	0.552	0.000	0.000
DM3	0.152	0.169	0.074	0.099	0.072	0.127	0.238	0.311	0.365	0.441	0.000	0.000
DM4	0.101	0.122	0.115	0.144	0.073	0.116	0.166	0.219	0.460	0.518	0.000	0.000
DM5	0.063	0.080	0.124	0.171	0.088	0.185	0.225	0.332	0.346	0.458	0.000	0.000
DM6	0.082	0.112	0.103	0.167	0.071	0.159	0.221	0.296	0.384	0.464	0.000	0.000
DM7	0.116	0.135	0.076	0.108	0.060	0.125	0.182	0.258	0.454	0.537	0.000	0.000
DM8	0.054	0.071	0.139	0.193	0.078	0.187	0.200	0.313	0.361	0.482	0.000	0.000
DM9	0.073	0.087	0.113	0.150	0.092	0.167	0.195	0.276	0.407	0.494	0.000	0.000

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