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A Stochastic Analytic Hierarchy Process Based Weighting Model for Sustainability Measurement in an Organization

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Abstract**—**A weighted statistical stochastic based Analytical Hierarchy Process (AHP) model for modeling the potential barriers and enablers of sustainability for measuring and assessing the sustainability level is proposed. For context-dependent potential barriers and enablers, the proposed model takes the basis of the properties of the variables describing the sustainability functions and was developed into a realistic analytical model for the sustainable behavior of an organization. This thus serves as a means for measuring the sustainability of the organization. The main focus of this paper was the application of the AHP tool in a statistically-based model for measuring sustainability. Hence a strong weighted stochastic AHP based procedure was achieved. A case study scenario of a widely reported major Canadian electric utility was adopted to demonstrate the applicability of the developed model and comparatively examined its results with those of an equal-weighted model method. Variations in the sustainability of a company, as fluctuations, were figured out during the time. In the results obtained, sustainability index for successive years changed form 73.12%, 79.02%, 74.31%, 76.65%, 80.49%, 79.81%, 79.83% to more exact values 73.32%, 77.72%, 76.76%, 79.41%, 81.93%, 79.72%, and 80,45% according to priorities of factors that have found by expert views, respectively. By obtaining relatively necessary informative measurement indicators, the model can practically and effectively evaluate the sustainability extent of any organization and also to determine fluctuations in the organization over time.

Keywords**—**AHP, sustainability fluctuation, environmental indicators, performance measurement, environmental sustainability.

I. Introduction

SEVERE and continuous competition globally has provoked the necessity of improving the effectiveness and efficiency of systems, processes and products. This consequentially complicates and expands the range of variables that are usually examined in any improvement initiative. The reflection is seen in the current efforts geared at embedding sustainability principles in the aims, motives, and expectations of the society in all ramifications. Therefore, moving toward sustainability and also measurement methods must be vital for every organization. Nowadays practitioners and decision-makers try to find and design policy for supporting sustainable development [1] or addressing the current needs by considering the ability of future generations to fulfill their own demands [2]. For moving toward sustainable development, an organization must define appropriate policies and also methods. But most researchers only tried to define different aspects of sustainability and fewer studies have proposed an evaluation of policy [1].

Sustainability has two opposing paradigms, could be divided into weak and strong sustainability views. Weak sustainability is defined by the concept of sustainability of man-made for natural capital contains manpower, machinery and knowledge [3]. Strong sustainability approach, according to [4], supposes sustainability concept among natural form of capital (air, water, soil and vital things for living) and another form of capital (social, material, cultural, intellectual). Strong sustainability can be measured only in some specific situations. In these cases, natural resources cannot be ruined or change to other forms of resources. By this view, strong sustainability is seen as keeping the security of mankind [5].

Recent studies, especially [6], have all focused on the evaluation of general sustainability in terms of the challenges of modern-day society, which are usually divided into three pillars namely environmental, economic and social terms- the 3Ps. These 3Ps described the importance of sustainability acknowledging social, environmental, and economic. These 3Ps are appraised together in order to identify factors that improves managing and planning for human systems on a long-term basis.

One of the most important methodologies is sustainability assessment (SA). This method inculcates multidisciplinary (environmental, economic and social) elements with other cultural and value-based elements. It is widely known for its ability to support broader decision making and policy development. Other concepts, the Integrated Assessment and SA, have been utilized to bring in new appraising dimension to impact assessment that is tailored toward planning and decision making for sustainable advancement [7].

AHP applies to model complicated problems where appropriate factor weights are determined based on some criteria. Saaty [8], [9] presented criteria and alternatives to aim and motives establishing relationships. AHP on the other hand, consists of stratified puzzlement format, adjudication, pairwise comparisons, a unique method for finding weights, and test of stability [10]. There are many variables that either allow or disallow progress towards sustainability. These variables vary according to the organization's inherit situations. To adequately measure improvement in sustainability, enhanced knowledge of the context of the organization prevailing factors are necessary [11], [12]. Because of simplicity, AHP has been widely used by decision-makers in different areas such as Planning, Production,

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Optimization, and many more [13], [14].

This paper contributes to this requirement through the consideration of a special case of a weighted base stochastic model for realistic sustainability measurement. The model adopted a weighted stochastic approach to sustainability measurement and assessment, thereafter measures and assesses the sustainability of an organization from the strong sustainability perspective. In addition to Section I, Section II gave the theoretical considerations where the basic principle underlying the proposed sustainability, actual AHP model structure and the proposed stochastic AHP procedures. Section III presented a numerical illustration of the proposed approach; comments in Section IV conclude the article.

II. Theoretical Considerations

A. Basic Principles

Reference [15] noted about close probabilistic relation between the stability of natural capital and sustainability. Destroying natural resources may decline the amount of sustainability in different aspects. By this view, improving sustainability, especially environmental sustainability must be an important issue of organizations in these years [16]. This shows the importance of studies on finding methods of measuring sustainability by adopting a strong sense in preferable levels of a supply chain or individual companies.

Reference [17] mentioned that there is a competition between nature and human about restoring renewable resources with the ability to replenish or revived and consuming it. Because of more consuming than restoring, mankind always is the winner of this contest. The ecological footprint (EF) refers to the amount of reproductive area that mankind demands when consuming resources in a sustainable way and conversely, biocapacity (BC) is the quantity of existing reproductive supply within a specific area. EF and BC can be assumed as demand and supply by using an economic perspective. Surplus biocapacity (SB) as reported by [18] can be defined as the absolute value of the difference between EF and BC in a mathematical view. Selecting appropriate metrics for measuring and analyzing these concepts is vital. For instance, SB of an area can be obtained from the differences between EF of the area, its indoor production area of land and water ecologically productivity. The difference between the sustainability views (economic, environmental, and social) with various theoretical and practical methods of SA and measurement resulted in a big challenge for organizations and decision makers of supply chains [19].

According to the most usable description of sustainability as reported by [2] humanity has the ultimate power of ensuring sustainability by getting their present necessities without jeopardizing the needs of the next descendants. Moreover, impressions of EF and SB failed to fully establish and accounted for the range of environmental problems. This was also opined by [17] that nature seems not to have significant capacity to absorb some important obstacles of the environment and the thereby acts as contaminants and impurities of high-density materials. Reference [20] showed that the biological view of measuring the productivity of an area may not necessarily consider the resources in the absence of renew-ability of capacity. For instance, in the study of the amount of co_2 emissions from domestic gas consumption, cremated fuel remaining is not considered as a metric. Most of the metrics of EF and SB concepts are obtained according to analysis of a system in static situation; in this situation, every individual metric will lose its power to predictive future [21]. The development of this model, is therefore based on the fact that there will always be both effective factors of sustainability (barriers and enablers) which are the catalysts for the growth of organization necessary for its sustainability without hampering its capacity. With this in mind, organizational sustainability can be idealized in terms of its capacity to move progressively to subdue the challenges imposed on it. Consequentially, the capacity of the organization is manipulated by particular exterior or interior situations. Thus purposed model in this paper admits these facts that those catalysts vary between organizations.

It should be noted that not all factors imported in sustainability measurements are relevant therefore possible barriers and enablers to sustainability are usually at the instance of the prevailing conditions at the subjected organization. It is worthy of note that priority assigned to relevant variables changes over time. It becomes more complicated when different variables are given in diverse units or even in quality measures, then the correlation among the variables perhaps uncharted [22], [23] corroborated this by applying a probabilistically measurement method of sustainability insulated from probabilistic measures as a pragmatic and feasible approach. Conversely, accordingly, this model as propose relied on predicting success and failure in moving toward sustainability as being stochastic.

B. Model Structure

Factors that affect challenge and capacity are firstly determined. Thereafter, the probability distributions of these factors are computed for the sustainability of the organization. Here probability for a sustainable organization is equal that requires to subdue challenges are less than the organization's capacity. This assertion of [24] by statistical method for measuring sustainability is employed. Therefore:

$$Sus = P(H < C) \tag{1}$$

Sus refers to the sustainability of the organization, H is the organizational challenge and C is the capacity of the organization. If $f(h)$ will be probability density function (PDF) of challenge factors, then the equivalent cumulative distribution function (CDF) could be expressed as:

$$F(h) = \int_0^{\infty} f(h)dh \tag{2}$$

There is the same scenario for capacity factors of organization, so CDF and PDF of capacity factors could be shown as:

$$F(c) = \int_0^\infty f(c)dc \tag{3}$$

By these assumptions, sustainability of an organization can be defined as probability that challenges cannot surpass the organization's capacity. Then sustainability can be expressed as

$$Sus = P(H < C) = \int_0^\infty f(c)\left[\int_0^\infty f(h)dh\right]dc \tag{4}$$

h is the randomized challenge variable, c is the randomized capacity variables.

Sustainability performance when viewed economically can lead to reduction and controlling of environmental risks (green economics), which are considered to be the preliminary elements that affect challenge and capacity factors of an organization. Another assumption of this study is that both challenge and capacity factors are normally distributed. Therefore by considering this normality assumption, the sustainability of the organization can be expressed as:

$$Sus = \int_0^\infty \frac{1}{\sqrt{2\pi\sigma_c^2}} e^{\frac{-(c-\mu_c)^2}{2\sigma_c^2}} \left[\int_0^\infty \frac{1}{\sigma_h\sqrt{2\pi\sigma_h^2}} e^{\frac{-(h-\mu_h)^2}{2\sigma_h^2}} dh\right] dc \tag{5}$$

where μ_h and σ_h^2 are the mean value and variance of challenge factors, μ_c and σ_h^2 are the mean value and variance of capacity factors.

The proposed model is thereby simplified as expressed in (6)

$$Sus = \varphi\left(\frac{\mu_c-\mu_h}{(\sigma_c^2+\sigma_h^2)^{1/2}}\right) \tag{6}$$

By (6) with a standard normal table, the sustainability of the organization is hereby estimated.

Reference [25] applied model mentioned in (1) to measure sustainability in presence of exponentially challenges and capacity indicators and by using PDF of joint difference distribution of two exponential variables, it obtained:

$$Sus = \begin{cases} \dfrac{e^{y/\lambda_2}}{\lambda_1+\lambda_2} & y < 0 \\ \dfrac{e^{-y/\lambda_1}}{\lambda_1+\lambda_2} & y > 0 \end{cases} \tag{7}$$

where λ_1 and λ_2 are parameters of challenge and capacity Indicators.

Reference [26] extended and used mentioned idea to measure the sustainability of a supply chain.

C. Analytical Hierarchy Based Weighing Procedures

Step 1: Defining the Aim and Motive of the Model

According to Expert AHP questionnaires, analysis is carried out to establish the weights of the capacity and challenge factors.

Step 2: Selection Model Variables

The behaviors in the first hierarchy included challenge variables which are Percentage of transmission-line area fumigated with herbicides, Percentage of range of ditches and clogs fumigated by herbicides, Percentage of green Home Gas emitted compared with those previously reported, Percentage of emissions produced concomitantly along transporting and dispensing power proportionately to those circumvented by net of electricity exported, Percentage of leakage due to device fracture, Percentage of renewable energy produced in accordance with total energy produced, Percentage of energy harvested through thorough supervision and adequate enhancement schedules, Percentage of Sneaky hookups due to the dispensing arrangements, Percentage of remaining dangerous materials transferred from landfill, Percentage of salvaged oil being consumed internally

Step 3: Questionnaire Designing

The questionnaire is structured to promote pair-wise comparisons among the challenge and capacity variables separately. A popular nine-point scale for an AHP questionnaire as proposed by [27] was used and presented in Table I. Table II shows a simple example of the questionnaire, in which five factors are selected: Factors Ch1, Ch2, Ch3, Ch4, and Ch5. According to Table II, Ch1 is twice important as Ch2 with a ratio of ½. Row 1 corresponds to the ratio of Ch1 to Ch2. Similarly, the importance ratio of Ch1 to Ch3, Ch4, and Ch5 are 6, 5, and 5 respectively. The importance ratio of Ch2 to Ch3, Ch4, and Ch5 are 2, 3, and 2. The importance ratio of Ch3 to Ch4 and Ch5 is ½, and $^1/_3$, the ratio of Ch4 to Ch5 is 1. The same was repeated for capacity factors and was layout in Table II.

TABLE I
SAATY'S SCALE FOR PAIRWISE COMPARISON

The intensity of Relative Importance	Definition
1	Equivalent priority
3	The moderate priority of one factor over another
5	Essential or strong priority
7	Determined priority
9	Absolute priority
2,4,6,8	Intermediate values between the two neighboring scales

TABLE II
A SAMPLE QUESTIONNAIRE (CHALLENGE FACTORS)

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Ch1										√								Ch2
Ch1														√				Ch3
Ch1													√					Ch4
Ch1													√					Ch5
Ch2										√								Ch3
Ch2											√							Ch4
Ch2										√								Ch5
Ch3								√										Ch4
Ch3							√											Ch5
Ch4									√									Ch5

Step 4: Using a Questionnaire

After administering the questionnaires, a matrix of outcomes for pair-wise comparisons is constructed and presented in Table III. The matrix is a balanced and double-faced matrix for the pair-wise comparisons among factors.

TABLE III
A SAMPLE MATRIX OF IMPORTANCE RATIOS CONSTRUCTED BY THE DECISION OF ONE EXPERT

Challenge Factors	Capacity Factors
$\begin{bmatrix} 1 & 2 & 6 & 5 & 5 \\ 1/2 & 1 & 2 & 3 & 2 \\ 1/6 & 1/2 & 1 & 1/2 & 1/3 \\ 1/5 & 1/3 & 2 & 1 & 1 \\ 1/5 & 1/2 & 3 & 1 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 1/8 & 1/2 & 1/3 \\ 1 & 1 & 1/7 & 1/2 & 1/3 \\ 8 & 7 & 1 & 3 & 2 \\ 2 & 2 & 1/3 & 1 & 1/2 \\ 3 & 3 & 1/2 & 2 & 1 \end{bmatrix}$

Step 5: Consistency Index Tests

Consistency Index (CI) was estimated according to [27] as given in the expression

$$CI = \frac{\lambda_{max} - n}{n-1}$$

λ_{max} is the maximum eigenvalue of the matrix, n is the number of factors. Constituency Ratio (CR) as defined in [27] is

$$CR = \frac{CI}{RI}$$

Random Index (RI) is as given by Table IV. Maximum acceptable level of CR (Consistency ratio) is 0.1, otherwise it is rejected.

TABLE IV
VALUES OF RI

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

III. EXPLANATORY CASE STUDY ON THE APPLICATION OF THE MODEL

Widely reported Hydro-Quebec was used to illustrate the proposed model. The challenge and capacity factors were evaluated based on the environmental indicators reported in [28]. The identified indicators amounting to the challenge and capacity factors are summarized in Tables I and II, respectively. The sustainability of generating, transmitting and distributing between 2010 and 2016 was estimated separately for each year. The results were presented in Fig. 1 from where the sustainability of Hydro-Quebec in the period of 6 years (2010-2016) was determined. For instance, the outcome explains that with a probability of 80.45%, Hydro-Quebec successfully prevailed over its inherent challenges, and thus moved towards sustainability in 2016. For this consistency test, 8 experts passed based on challenge factors while 7 experts passed based on capacity factors and those that failed were excluded from taking part in further estimations. Index values with the weight values were combined to estimate the geometric means for both capacity and challenge factors. Furthermore, going by (6), in case the challenge and capacity variables are concurrently intensified, little or insignificant progress would be observed towards sustainability. Alternatively, if the factors are moved in the opposite directions, a move towards, or away from sustainability is expected as the case may be. Sustainability data stacked up in Tables V and VI display variations in terms of occurrence of fluctuations in challenge and capacity variables within the duration of operation (2010–2016) studied. Decision-makers may decide to assign different weights to the capacity and challenge factors they dimmed are having specific and significant importance to the factor concerned. Thus Table VII and Fig. 1 show the real weight for challenge and capacity factors on Hydro-Quebec sustainability over time.

TABLE V
NOTIFIED ENVIRONMENTAL PERFORMANCE INDEXES OF CHALLENGE FACTORS

Challenge factors	Year						
	2010	2011	2012	2013	2014	2015	2016
Area of transmission-line rights-os-way treated with herbicides (%)	0.2936	0.2205	0.028	0.0073	0.0040	0.0602	0.0208
Area of dikes and dams treated with herbicides (%)	0.2669	0.3848	54.19	0.4203	0.3202	0.4349	0.4924
CHG emissions from thermal electricity generation relative to total CHG emissions from all reported sources (%)	0.7903	0.7935	0.8023	0.7926	0.8019	0.7992	0.7899
Indirect emissions associated with power transmission and distribution relative to emissions avoided by next experts of electricity (%)	0.0249	0.0081	0.002	0.00085	0.0037	0.0019	0.00064
Spills due to equipment breakage (%)	0.56	0.515	0.57	0.62	0.60	0.59	0.51

TABLE VI
ENVIRONMENTAL PERFORMANCE DUE TO CAPACITY FACTORS

Capacity factors	Year						
	2010	2011	2012	2013	2014	2015	2016
Renewable energy generated relative to total energy generated (%)	0.9781	0.9791	0.9756	0.9984	0.9982	0.9845	0.9912
Energy saved through conservation and/or efficiency improvement plans (%)	0.1971	0.4026	0.3245	0.3641	0.3915	0.4412	0.3892
Underground hookups onh the distribution system (%)	0.36	0.40	0.42	0.41	0.46	0.43	0.46
Residual hazardous materials (RHMs) diverted from landfill (%)	0.95	0.94	0.95	0.96	0.93	0.95	0.97
Insulating oil recovered and reused internally (%)	0.91	0.888	0.8009	0.8116	0.9222	0.9334	0.8786

TABLE VII
SUMMARY TABLE COMBINING EXPERT QUESTIONNAIRE WITH WEIGHTED VALUES

Sustainability	Factors	Original weight value	AHP weight value
Challenge factors	Area of transmission-line rights-of-way treated with herbicides (%)	1	0.35
	Area of dikes and dams treated with herbicides (%)	1	0.22
	CHG emissions from thermal electricity generation relative to total CHG emissions from all reported sources (%)	1	0.12
	Indirect emissions associated with power transmission and distribution relative to emissions avoided by the next experts of electricity (%)	1	0.15
	Spills due to equipment breakage (%)	1	0.16
Capacity factors	Renewable energy generated relative to total energy generated (%)	1	0.08
	Energy saved through conservation and/or efficiency improvement plans (%)	1	0.1
	Underground hookups on the distribution system (%)	1	0.35
	Residual hazardous materials (RHMs) diverted from landfill (%)	1	0.19
	Insulating oil recovered and reused internally (%)	1	0.28

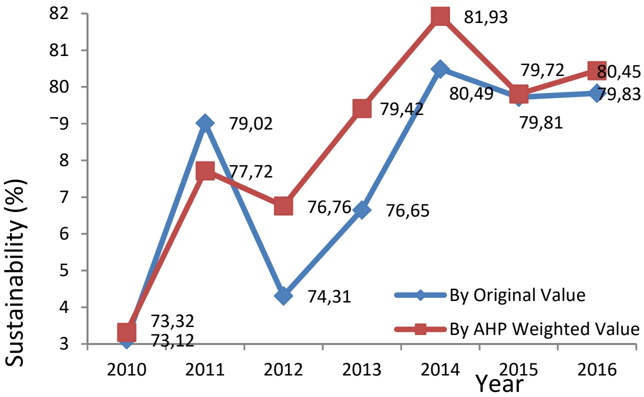

Fig. 1 Comparative sustainability obtained for Hydro-Quebec Company in the duration of 2010-2016 using the proposed models

Fig. 1 shows the sustainability progress made each year by Hydro-Quebec. The trend of challenge and capacity variables utilization is also presented. Similarly, fluctuations in the company's sustainability were easily evaluated over time. It should be emphasized that the proposed sustainability model can be well adapted for making comparisons between organizations operating within the same sector. This would however, necessitate that variable indicators are measured absolutely in the same method. Reference [24] also corroborates this assertion.

IV. CONCLUSION

The studies show that the model presents a simple and straight-forward approach to evaluate the sustainability performance of an organization. The model explicitly adopted stochastic based AHP procedures that consequently give relatively simple and informative data to sustainability. The model can be used practically for dynamic evaluation of the sustainability efficiency of any given organization over time thereby making the decision-making process more effective.

The proposed sustainability model can be applied for comparing the value of sustainability between organizations operating in the same sector with common indicators that are measured in the same way. However lack of adequate data comparability could make it difficult to perform comparisons between different organizations. Furthermore, given its effective and strong concepts coupled with its stochastic nature, the proposed AHP sustainability model can provide adequate informative data with uncertainty behaviors that have been previously obtained through the application of probability techniques in most ecological studies.

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