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Sustainability performance measurement for Libyan Iron and Steel Company using Rough AHP

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Abstract

The iron and steel industry play a major role in the Libyan urbanization. The iron and steel products are the main driving forces in the construction manufacturing sector in Libya. This research suggested a set of indicators to evaluate the sustainability of iron and steel industry in Libya using rough AHP model. Rough AHP analyses the relative importance of the criteria based on their preferences given by experts. The research results show that the most important criterion is costs followed by emission and waste. We have found that the rough AHP model can play an important role in improving indicators that quantify the advance towards sustainable development, especially when it is in a situation where complex environments (i.e., Libya) exist.

Keywords: Steel industry, Rough AHP, sustainability, performance.

1. Introduction

Sustainability is continuously gaining significance among industrial decision makers and scholars [1]. Industrial sustainability is the ultimate goal of modern society, particularly so for the iron and steelmaking industries. Sustainability measures have been shown to have positive effects on economic and financial performance, and it costs surprisingly little to implement cost-effective measures in firms [2]. Fruehan [3] defines sustainable steelmaking goals as (i) reduction of greenhouse gas emissions; (ii) conservation of natural resources; (iii) reduction of volatile emissions; (iv) reduction of landfill waste; and (v) reduction of hazardous waste. The author further recommends improved sustainability through step reduction in consumption and emissions and/or introduction of new, breakthrough innovative technologies, such as Ultra Low CO2 Steelmaking [4]. From an industry perspective [5], the sustainability of the steel industry is challenged by a declining knowledge transfer, with reducing student numbers enrolled in science and engineering courses at the university level. Singh et al. [6] provide a comprehensive approach to developing a methodology for sustainability assessment of steel companies and highlight the importance of applying sets of indicators that quantify the progress towards sustainable development. A range of indicators were proposed that defined emissions of pollutants and greenhouse gases, consumption of power, raw materials and water, hazardous waste generation and noise pollution. However, there is still a strong requirement to standardise the sustainability indicators so that different iron and steelmaking technologies can be compared to each other, as well as to other industrial activities.

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With world-wide communities having increasingly known the severity of climate change, the pressure for reduction of industrial emissions has become more prominent. The iron and steel companies rank as the third biggest CO2 emitter in China [7, 8]. In today's competitive manufacturing sector, it is a challenge to provide high-quality parts while be environmentally sustainable. Awareness of sustainability is growing fast, in Libya just as in the rest of the world. In order to support firms in their attempts to increase the sustainability of their operations, deep investigations are needed. There is limited research on sustainability aspects of the Libyan industry and no comprehensive set of indicators for Libyan firms. The aim of this work is to explore this gap and develop and evaluate a comprehensive system for the Libyan industry. The rest of the research is divided into five sections. The second section explains the Libyan iron and steel industry. The third section represents the method used, while the fourth section represents the case study. The research ends with conclusions and guidelines for future research.

2. Iron and Steel Industry

Iron and steel production are one of the most important and fundamental industrial processes in Libya. The Libyan Iron and Steel Company (LISCO) is one of the largest iron and steelmaking companies operating in North Africa [9]. Based in Misrata city about 210 km to the east of the city of Tripoli, it is funded and owned by the Libyan government. The production capacity of the company is about 1,324,000 tons of liquid steel [10]. In the last two decades, the company had almost met the demand on its products in the local market, and managed to compete globally. LISCO is an ISO-certified integrated steel plant and has won awards for quality from European bodies and entities. Because it is a cheap and an environmentally friendly, LISCO uses the local gas as fuel for production. LISCO use Brazilian, Canadian and Swedish steel pellets as raw material. The process of the steel making at LISCO is a long process begins by downloading the raw materials that arrived at the port. The primary ingredient in LISCO processed steel is oxide pellets (iron ore), which arrives from various suppliers from around the world. Each supplier supplies a different quality and with different chemical composition. The iron ore, therefore, must be stored in separate piles based on supplier. The iron and steel industry involve a series of closely linked process steps, including the preparation of raw materials, iron-making, steelmaking and finishing processes. The Steel Melt Shops (SMS1) Consists of three electric arc furnaces 90 tons each, two Billet casters and a Bloom caster. The shop has a design capacity of 630,000 tons/year of Billets and Blooms. Similarly, The Steel Melt Shops (SMS2) consists of three electric arc furnaces 90 tons each, and two Slab casters. The shop has a design capacity of 611,000 tons/year of Slabs. This molten steel to come out in the form of billets and slabs, the molten passed several operations. After the molten steel was poured in to ladle, it goes through the flow control dish, and then to the Mould. After that it will start the process of cooling and it is heading for a rolling process. The output of this stage, which is billets, bloom and slabs, is the input to the next stage which is the final stage of the manufacture of iron and steel.

Due to increasing energy scarcity and pressures from climate change, Libyan Iron and Steel Company has struggled to implement practices to reduce its energy consumption and CO2 emissions. However, it is not clear whether these practices can improve the environmental or economic performance of the company. The determinants that drive or hinder the implementation of these practices are also not known. According to [11] study, it was found that the most significant environmental impact was damage to human health, which was related to coke consumption in the blast furnace and iron ore consumption in the sinter plant. The largest energy demand in the entire steel production system occurred in the blast furnace system production, and the major source of environmental impacts was the consumption of fossil fuels. The same study indicated that the use of alternative fuels could reduce greenhouse gas emissions, but the use of charcoal increased other impact categories such as land use and total energy demand. Pollution prevention methods related to raw material substitution in iron-making processes should be applied to reduce the environmental impacts of the iron and steel industry.

In general, various hazardous air pollutants emitted from iron and steel industry can be classified into four categories: (1) acidic gaseous pollutants; (2) incomplete combustion, (3) particulate matter; and (4) toxic heavy metals [7]. Therefore, detailed information about the past and present emission situation of various hazardous air pollutants from LISCO has been rather limited. The waste treatment systems in LISCO, as other Libyan industries, led to piling up of mountains of solid waste in the different sites around the company cite. The waste such as slags, dusts, scrap and sludges accumulated even in the open areas. The LISCO controls the whole system of their waste, starting from the collection, transportation process, and ending by damping sites. Furthermore, the LISCO has some equipment and the infrastructures such as trucks and final dumping site. Currently, waste is mostly dumped in the damping sites and they leave it in open areas. Consequently, the resulting pollutions can cause many hygienically and environmentally problems. The collection and disposal of the waste are the responsibility of the LISCO which has no clear recycling policy, and therefore, provide unreliable services. When the dumping sites are filled with solid wastes, the only solution for LISCO is reclamation of the waste dumps. This improper management of wastes can lead to serious health problems as a result of large black lands, and contamination of water.

Florén et al [12] add knowledge on how raw materials should be managed in iron and steelmaking companies. They indicate that the understanding of raw materials management from a holistic perspective is largely lacking, and extant research does not provide qualified advice to companies on this area of research. Goffin et al., [13] have indicated that supplier management is one of the key issues of supply chain management, because the total cost of raw materials constitutes the final cost of a product, and most of the companies have to spend a considerable amount of their budget on them. In most industries, the cost of raw materials constitutes the main cost of a product, such that in some cases it can account for up to 70% [3]. Thus, the financial department can play a key role in firm's efficiency and effectiveness since the department has a direct effect on final cost reduction and profitability of a company by selecting suitable suppliers. In this regard, the importation of raw material is important step to maintain and improve its market share in a competitive environment. Quality and cost of the final products are intimately connected to the proper selection of supplier of sponge iron to the direct reduction, mega-scale factories. As above mentioned, LISCO usually imports sponge iron from India, Brazil, Canada, Sweden. Suppliers from other countries also consider LISCO as a potential customer. Since suppliers have variable strengths and weaknesses in terms of sustainability, careful assessment and evaluation by the client is crucial before orders could be placed.

Recently, supplier evaluation and selection have received considerable attention in the literature [14-20]. Supplier selection is a multi-criteria problem which includes both qualitative and quantitative factors [21]. Generally, the criterion for supplier selection is highly depended on individual industries and companies. Therefore, different companies have different management strategy, enterprise culture and competitiveness. Furthermore, company background causes huge difference and impacts supplier selection. Thus, the identification of supplier selection criteria is largely requiring domain expert's assessment and judgement. In order to select the best supplier, it is necessary to make a trade-off between these qualitative and quantitative factors (weights) some of which may conflict [22]. The supplier selection problem includes both qualitative and quantitative factors [21]. Traditional supplier selection methods are often based on the quoted price, which ignores the significant direct and indirect costs associated with sustainability of purchased materials. Uncertainty occurs because we can never know exactly what will happen in the future. We can select the best supplier based on quoted price and do every possible analysis, but there is always uncertainty about indirect costs associated with sustainability, and others. One of the key problems in supplier selection is to find the best supplier among several alternatives according to various criteria, such as environmental effect, cost, risk, and others. After identifying the criteria, a systematic methodology is required to integrate experts' assessments in order to find the best supplier. At the present, various methods have been used to supplier selection, such as the analytic network process (ANP) [23] and the analytical hierarchy process (AHP) [23, 24]. Recently, supplier evaluation and selection have received significant attention from various researchers in the literature [6, 14-18, 24].

3. Methods

3.1 Analytical Hierarchy Process

Sustainable supply chain management using AHP has received much attention from community and scholars over the past decade. AHP is a common multi-criteria decision making (MCDM) method. It is developed by Saaty [25, 26] to provide a flexible and easily understood way of analyzing complex problems. It breaks a complex problem into hierarchy or levels, and then making comparisons between all possible pairs in a matrix to give a weight for each factor and a consistency ratio [24]. According to [16] it has been found that AHP method was used more than any other MCDM methods. However, the methodology of AHP is focused on weighting the relative importance of criteria, while dependencies among criteria are neglected. For example, Chan and Chan [27], Chan et al. . [28], and Jiang et al. [29] used AHP to evaluate and select suppliers.

Mathematically, AHP is capable of provide an easily understandable method to practitioners; however, it is insufficient to explain uncertain conditions in especially pair-wise comparison stage. Most of human's judgments are not represented as exact numbers. Since some of the evaluation criteria are subjective and qualitative in nature, it is very difficult for the decision-maker to express the preferences using exact numerical values and to provide exact pair-wise comparison judgments. As a result, to tackle these problems, AHP has been integrated with other methods, including ANN [30], fuzzy set theory [31, 32], and grey relational analysis [33-35], and a combination between different methods [36]. It seems, however, that the growth of AHP applications may derive more from a simplification perspective rather than from a robust theoretical mathematical perspective.

3.2 Operating with rough numbers

In rough set theory, any misty idea can be represented as a couple of exact concepts based on the lower and upper approximations [37, 38]. This is shown in Figure 1.

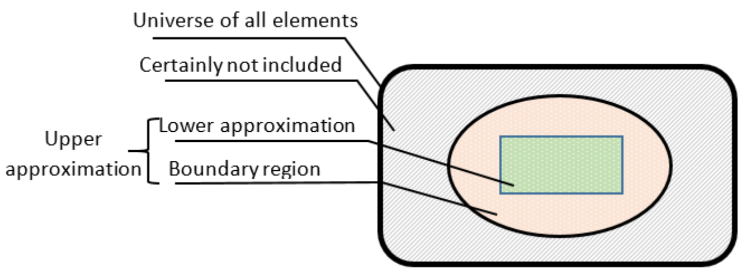

Figure 1. Elementary concept of rough set theory

Suppose U is the universe that consist all the objects, Y is an arbitrary object o f U, R is a set o f t classes (G_1G_2; ... ;G_t) which include all the objects in U, R (G_1G_2; ... ;G_t). If these classes are ordered as $G_1<G_2<...<G_t$, then V Y e U, G_q e R, 1 < q < t the lower approximation ($\underline{Apr}(G_q)$), upper approximation ($\overline{Apr}(G_q)$) and boundary region ($Bnd(G_q)$) of class G_q are according (Zhu et. al., 2015) defined as:

$$\underline{Apr}(G_q) = U\{Y \in U/R(Y) \leq G_q\} \quad (1)$$

$$\overline{Apr}\ (G_q) = U\{Y \in U/R(Y) \geq G_q\} \quad (2)$$

$$Bnd\ (G_q) = U\{Y \in U/R(Y) \neq G_q\} = \{Y \in U/R(Y) \geq G_q\} = \{Y \in U/R(Y) \leq G_q\} \quad (3)$$

Then G_q c can be shown as rough number ($RN(G_q)$), whichis determined by its corresponding lower limit ($\underline{Lim}\ (G_q)$)and upperlim it($\overline{Lim}\ (G_q)$), where:

$$\underline{Lim}\ (G_q) = \frac{1}{M_L}\sum R\ (Y)|\ Y\ \in \underline{Apr}(G_q) \quad (4)$$

$$\overline{lim}\ (G_q) = \frac{1}{M_U}\sum R\ (Y)|\ Y\ \in \overline{Apr}(G_q) \quad (5)$$

$$RN(G_q) = [\underline{Lim}\ (Gq), \overline{lim}\ (Gq)] \quad (6)$$

Where M_l,M_u are the numbers of objects that consist in $\underline{Apr}(G_q)$ and $\overline{Apr}\ (G_q)$, respectively.

Difference between them is expressed as rough boundary interval($IR\ Bnd(Gq)$):

$$(IR\ Bnd(Gq) = \overline{lim}\ (Gq) - \underline{Lim}\ (Gq) \quad (7)$$

Operation for two rough number $RN\ (\alpha) = [\underline{Lim}\ (\alpha), \overline{lim}\ (\alpha)]$ and $RN\ (\beta) = [\underline{Lim}\ (\beta), \overline{lim}\ (\beta)]$ according to [39] are:

Addition (+) of two rough numbers $R(\alpha)$ and $RN(\beta)$

$$RN\ (\alpha) + RN\ (\beta) = \left[\underline{Lim}\ (\alpha) + \underline{Lim}\ (\beta), \overline{lim}\ (\alpha) + \overline{lim}\ (\beta)\right] \quad (8)$$

Subtraction (-) of two rough numbers $R(a)$ and $RN(\beta)$

$$RN\ (\alpha) - RN\ (\beta) = \left[\underline{Lim}\ (\alpha) - \overline{lim}\ (\beta), \overline{lim}\ (\alpha) - \underline{Lim}\ (\beta)\right] \quad (9)$$

Multiplication (x) of two rough numbers $R(a)$ and $RN(\beta)$

$$RN\ (\alpha) \times RN\ (\beta) = \left[\underline{Lim}\ (\alpha) \times \underline{Lim}\ (\beta), \overline{lim}\ (\alpha) \times \overline{lim}\ (\beta)\right] \quad (10)$$

Division (÷) of two rough numbers R(a) and RN(b)

$$RN\ (\alpha) \div RN\ (\beta) = \left[\underline{Lim}\ (\alpha) \div \overline{lim}\ (\beta), \overline{lim}\ (\alpha) \div \underline{Lim}\ (\beta)\right] \quad (11)$$

Scalar multiplication of rough number R(a), where μ is a nonzero constant

$$\mu \times RN\ (\alpha) = \left[\underline{\mu \times Lim}\ (\alpha), \mu \times \overline{lim}\ (\alpha)\ \right] \quad (12)$$

3.3 Rough Analytic Hierarchy Process

Zhai et al. [40] proposed a new concept of rough number to quantify vague experts' perceptions based on the basic principles of rough sets. A rough number has lower and upper limits that denote boundaries of an interval, and it merely relies on the original data without the need for auxiliary information. Rough AHP [41] measure consistency of preferences while managing and manipulating decision-making involving subjective judgments. This research combines rough AHP where rough number handles subjectivity and AHP handles hierarchy evaluation. The detailed procedure of Rough AHP consists of the following steps [39]:

1: Identify the goal of research, after that criterion and at end potential solutions. In this step forming a hierarchical structure is needed like in conventional AHP.

2: Forming a group of pair-wise comparison matrices which of the eth expert is expressed as:

$$B_e = \begin{bmatrix} 1 & x_{12}^e & \cdots & x_{2\,m}^e \\ x_{21}^e & 1 & \cdots & x_{1m}^e \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^e & x_{m2}^e & \cdots & 1 \end{bmatrix} \quad (13)$$

Where $x_{gh}^e (1 \le g \le m, 1 \le h \le m, 1 \le e \le s)$ is the relative importance of criterion g on criterion h given by expert e, m represent the number of criteria, while 5 represent the number of DM.

Determine the max. Eigenvalue λ_{max}^e of B_e, then compute CI = (λ_{max}^e — n) / (n — 1)
Determine the consistency index (RI) according to n. Compute the consistency ratio CR=CI/RI.

After that group, comparison m atrix $\tilde{B}$ is expressed as:

$$\tilde{B} = \begin{bmatrix} 1 & \tilde{x}_{12}^e & \cdots & \tilde{x}_{2\,m}^e \\ \tilde{x}_{21}^e & 1 & \cdots & \tilde{x}_{1m}^e \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^e & \tilde{x}_{m2}^e & \cdots & 1 \end{bmatrix} \quad (14)$$

Where $\tilde{x}_{gh}$ $\{x_{gh}^1, x_{gh}^2, ..., x_{gh}^s\}$, $\tilde{x}_{gh}$ is the sequence of relative importance of criterion g on criterion h .
3: Forming a rough comparison matrix.
All the elements x_{gh}^e in $\tilde{B}$ must be translate into rough number RN (x_{gh}^e) using Equations (1) - (6):

$$RN\,(x_{gh}^e) = \left[x_{gh}^{eL}, x_{gh}^{eU}\right] \tag{15}$$

Where x_{gh}^{eL} is the lower limit of RN (x_{gh}^e), while (x_{gh}^{eU}) is the upper limit.
Then the rough sequence RN ($\tilde{x}_{gh}$) is represented as:

$$RN\left(\tilde{x}_{gh}\right) = \left\{\left[x_{gh}^{1L}, x_{gh}^{1U}\right], \left[x_{gh}^{2L}, x_{gh}^{2U}\right], \dots \dots \dots, \left[x_{gh}^{sL}, x_{gh}^{sU}\right]\right\} \tag{16}$$

After that it is converted into an average rough number $R\,N\left(x_{gh}\right)$ by Equations (8) - (12):

$$R\,N\left(x_{gh}\right) = \left[x_{gh}^L, x_{gh}^U\right] \tag{17}$$

$$x_{gh}^L = \frac{x_{gh}^{1L} + x_{gh}^{2L} + \cdots + x_{gh}^{sL}}{s} \tag{18}$$

$$x_{gh}^U = \frac{x_{gh}^{1U} + x_{gh}^{2U} + \cdots + x_{gh}^{sU}}{s} \tag{19}$$

Where x_{gh}^L is the lower limit o f $R\,N\left(x_{gh}\right)$ and x_{gh}^U is the upper limit.
Then the rough comparison m atrix M is expressed as:

$$M = \begin{bmatrix} [1,1] & [x_{12}^L, x_{12}^U] & \cdots & [x_{1m}^L, x_{1m}^U] \\ [x_{21}^L, x_{21}^U] & [1,1] & \cdots & [x_{1m}^L, x_{1m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [x_{2m}^L, x_{2m}^U] & [x_{1m}^L, x_{1m}^U] & \cdots & [1,1] \end{bmatrix} \tag{20}$$

4: Determination the rough weight wg of each criterion:

$$w_g = \left[\sqrt[m]{\prod\nolimits_{h=1}^{m} x_{gh}^L}, \sqrt[m]{\prod\nolimits_{h=1}^{m} x_{gh}^U}\right] \tag{21}$$

$$w_g' = w_g / max(w_g^u) \tag{22}$$

Where w_g' is the weights of criteria in normalization form.

There are a number of papers that uses rough AHP method for making of the multi-criteria models, for example evaluating university web sites [42], design concept evaluation [43], traffic accessibility [44], and supplier evaluation [45, 46],

4. Case study

Establishing the criteria for sustainable supply chain performance measurement has been a popular area of research in the recent years. Bhattacharya et. al [47] proposed intra-organisational collaborative decision-making approach to depict a green supply chain performance measurement framework. Long et al. [48] proposed a sustainability assessment system for the Chinees steel industry. They evaluated it using data from financial and sustainability reports of four leading Chinese iron and steel companies. Strezov et al. [49] evaluated the sustainability measures of the three major iron and steel production technologies, the blast furnace, the electric arc furnace and direct reduced iron. Pan et al. [50] adopted an improved emergy based method and a set of indicator system for the evaluation of sustainability of steel production industry. Singh et al. [6] used AHP to evaluate the impact of an organization’s sustainability performance.

Figure 2 shows the proposed indicators for sustainability measurement in LISCO. The indicators based on 13 sub-criteria grouped in three groups of criteria.

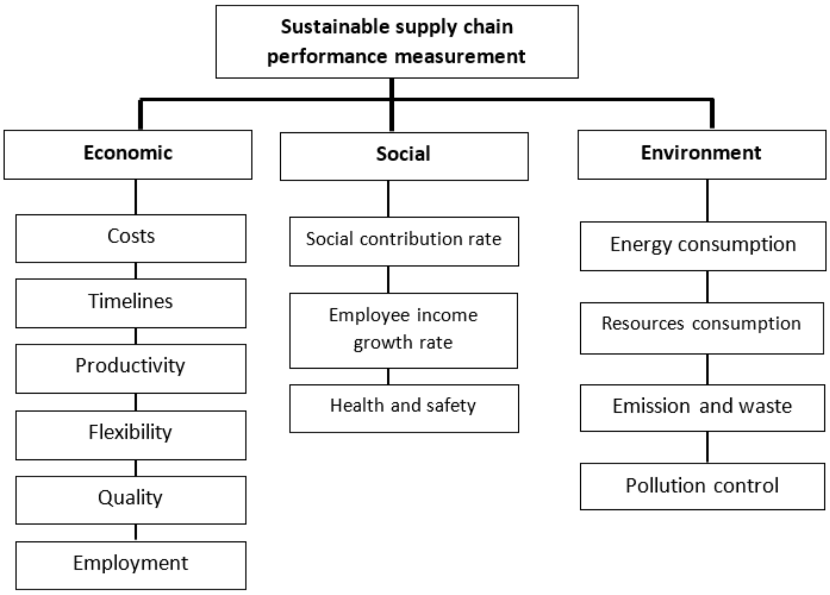

Figure 2. The proposed indicators for sustainability measurement in LISCO

The authors ask three experts to fill the survey. The results for pair wise comparisons of economic criteria are shown below, where DM refers to decision maker.

$$DM_1 = \begin{bmatrix} 1 & 1 & 2 & 3 & 4 & 3 & 2 \\ 1 & 1 & 2 & 3 & 4 & 3 & 2 \\ \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{3} & 1 & \frac{1}{2} & \frac{1}{4} \\ \frac{1}{3} & \frac{1}{3} & 3 & 1 & 4 & \frac{1}{3} & 1 \\ \frac{1}{4} & \frac{1}{4} & 1 & \frac{1}{4} & 1 & \frac{1}{2} & 1 \\ \frac{1}{3} & \frac{1}{3} & 2 & 3 & 2 & 1 & 2 \\ \frac{1}{2} & \frac{1}{2} & 4 & 1 & 1 & \frac{1}{2} & 1 \end{bmatrix}$$

$$DM_2 = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{2} & \frac{1}{4} & \frac{1}{2} & \frac{1}{2} & 2 \\ 3 & 1 & \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{2} & 2 \\ 2 & 2 & 1 & 1 & \frac{1}{2} & \frac{1}{4} & 1 \\ 4 & 2 & 1 & 1 & \frac{1}{2} & \frac{1}{4} & \frac{1}{2} \\ 2 & 1 & 2 & 2 & 1 & \frac{1}{2} & 1 \\ 2 & 2 & 4 & 4 & 2 & 1 & 2 \\ 1 & \frac{1}{2} & 1 & 2 & 1 & \frac{1}{2} & 1 \end{bmatrix}$$

$$DM_3 = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} & \frac{1}{4} & \frac{1}{2} \\ 3 & 1 & 1 & \frac{1}{2} & 1 & 1 & 2 \\ 3 & 1 & 1 & 1 & \frac{1}{2} & \frac{1}{3} & 1 \\ 5 & 2 & 1 & 1 & \frac{1}{3} & \frac{1}{4} & \frac{1}{2} \\ 3 & 1 & 2 & 3 & 1 & \frac{1}{2} & 1 \\ 4 & 1 & 3 & 4 & 2 & 1 & 2 \\ 2 & \frac{1}{2} & 1 & 2 & 1 & \frac{1}{2} & 1 \end{bmatrix}$$

The consistency ratios are 0.09, 0.09, and 0.07 respectively. That means the pairwise comparisons are satisfactory (CR<0.1).

Using the equation (13), the group comparison matrix is formed like follows.

$$\tilde{E} = \begin{bmatrix} 1,1,1 & 1,\frac{1}{3},\frac{1}{3} & 2,\frac{1}{2},\frac{1}{3} & 3,\frac{1}{4},\frac{1}{5} & 4,\frac{1}{2},\frac{1}{3} & 3,\frac{1}{2},\frac{1}{4} & 2,1,\frac{1}{2} \\ 1,3,3 & 1,1,1 & 2,\frac{1}{2},1 & 3,\frac{1}{2},\frac{1}{2} & 4,1,1 & 3,\frac{1}{2},1 & 2,2,2 \\ \frac{1}{2},2,3 & \frac{1}{2},2,1 & 1,1,1 & \frac{1}{3},1,1 & 1,\frac{1}{2},\frac{1}{2} & \frac{1}{2},\frac{1}{4},\frac{1}{3} & \frac{1}{4},1,1 \\ \frac{1}{3},4,5 & \frac{1}{3},2,2 & 3,1,1 & 1,1,1 & 4,\frac{1}{2},\frac{1}{3} & \frac{1}{3},\frac{1}{4},\frac{1}{4} & 1,\frac{1}{2},\frac{1}{2} \\ \frac{1}{4},2,3 & \frac{1}{4},1,1 & 1,2,2 & \frac{1}{4},2,3 & 1,1,1 & \frac{1}{2},\frac{1}{2},\frac{1}{2} & 1,1,1 \\ \frac{1}{3},2,4 & \frac{1}{3},2,1 & 2,4,3 & 3,4,4 & 2,2,2 & 1,1,1 & 2,2,2 \\ \frac{1}{2},1,2 & \frac{1}{2},\frac{1}{2},\frac{1}{2} & 4,1,1 & 1,2,2 & 1,1,1 & \frac{1}{2},\frac{1}{2},\frac{1}{2} & 1,1,1 \end{bmatrix}$$

The calculation of matrix M is performed using the equations showed in the third step. For instance, the element of row number six and column number three $\tilde{x}_{63}$ is considered.

$$\tilde{x}_{63} = \{2,4,3\}$$

$$\underline{Lim}\,(2) = 2, \overline{lim}\,(2) = \frac{1}{3}(2+3+4) = 3, \underline{Lim}\,(3) = \frac{1}{2}(2+3) = 2.5, \overline{lim}\,(3) = \frac{1}{2}(3+4) = 3.5, \underline{Lim}\,(4) = \frac{1}{3}(2+3+4) = 3, \overline{lim}\,(4) = 4$$

$$RN(x_{63}^1) = RN(2) = [2;3];\; RN(x_{63}^2) = RN(3) = [2.5;3.5];\; RN(x_{63}^3) = RN(4) = [3;4]$$

Using the equations 17, 18, and 19

$$x_{63}^L = \frac{x_{63}^1 + x_{63}^2 + x_{63}^3}{3} = \frac{2+2.5+3}{3} = 2.5$$

$$x_{63}^U = \frac{x_{63}^1 + x_{63}^2 + x_{63}^3}{3} = \frac{3+3.5+4}{3} = 3.5$$

Then the rough sequence in $\tilde{E}$ is converted into a rough number (RN_{63})= [2.5;3.5]

The rough comparison matrix is formed as follows by calculating all elements as shown previously.

$$M = \begin{bmatrix} [1;1] & [0.41;0.70] & [0.56;1.40] & [0.53;1.93] & [0.79;2.62] & [0.63;2.00] & [0.81;1.56] \\ [1.89;2.78] & [1;1] & [0.81;1.56] & [0.78;1.89] & [1.33;2.67] & [0.92;2.17] & [2.00;2.00] \\ [1.19;2.78] & [0.81;1.56] & [1;1] & [0.63;0.93] & [0.56;0.78] & [0.30;0.43] & [0.58;0.92] \\ [1.87;4.20] & [1.07;1.81] & [1.22;2.11] & [1;1] & [0.79;2.62] & [0.26;0.30] & [0.56;0.78] \\ [1.04;2.42] & [0.58;0.92] & [1.44;1.89] & [1.04;2.42] & [1;1] & [0.50;0.50] & [1;1] \\ [1.20;3.04] & [0.70;1.54] & [2.50;3.50] & [3.44;3.89] & [2.00;2.00] & [1;1] & [2.00;2.00] \\ [0.81;1.56] & [0.50;0.50] & [1.33;2.67] & [1.44;1.89] & [1;1] & [0.50;0.50] & [1;1] \end{bmatrix}$$

Based on equations (21) and (22) the rough weights can be determined as follows:

$$w = \{[0.65;1.48];[1.16;1.91];[0.67;1.01];[0.83;1.38];[0.89;1.26];[1.62;2.21];[0.87;1.10]\}$$

$$w' = \{[0.29;0.67];[0.53;0.87];[0.30;0.46];[0.38;0.63];[0.41;0.57];[0.73;1.00];[0.40;0.50]\}$$

Figure 3 shows the obtained values for rough numbers for the economic sub criteria.

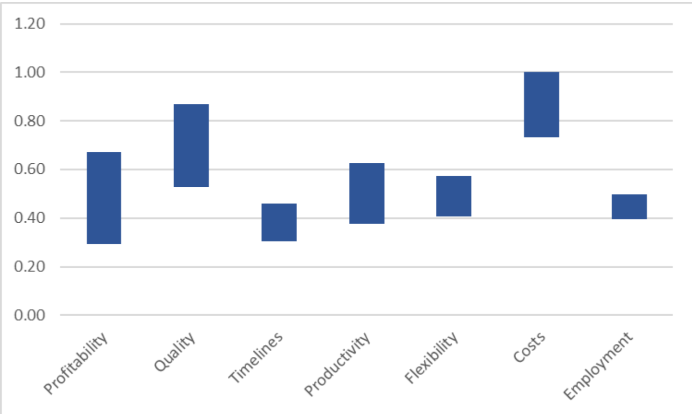

Figure 3. Sub-criteria values for the economic group of criteria obtained using Rough AHP method.

Figure 4 shows the rough number values of all sub-criteria. The criterion costs is ranked first followed by emission and waste.

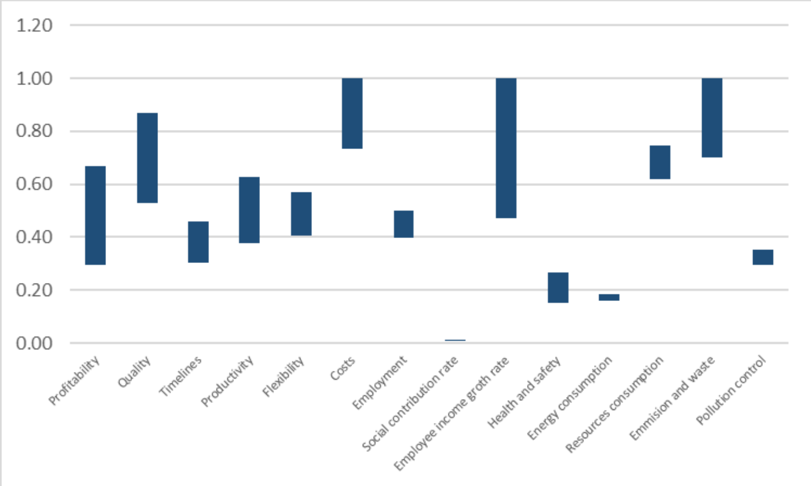

Figure 4. Rough number values of all sub-criteria.

The outcome of the work has been analysed to provide managerial implications for sustainability assessment of steel firms in Libya. According to the results as illustrated in Figures 3 and 4, Criterion costs are the most preferred indicators, because they have the highest value. Emission and waste are the next selected indicator in this case study. Hence, it can be seen from these results that direct cost and the emission and waste are the most crucial criteria for a steelmaking company (as suggested by the results obtained in Figure 4). According to the results, we can understand that the Rough AHP method is stable and efficient to deal with multi-criteria decision-making problems.

5. Conclusion

The aim of this research is to select the best supplier in the LISCO in Libya using Rough AHP method. With an increasing awareness of sustainability aspects, both from academic sector and industrial sector, we believe that a sustainable decision making technique for selecting the best suppliers should improve a supply chain competence and to help companies maintain a strategically competitive position. The results showed that Rough AHP method was capable of enhancing quality decision by making its process more rational, explicit and efficient. In a future work, this efficient method can be generalised to other businesses throughout Libya to facilitate the sustainability performance measurement and consequently, provide the firm with a robust system while be environmentally sustainable.

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