Evaluation of the green supply chain management practices: A novel neutrosophic approach

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\textbf{A B S T R A C T}

To attain competitive advantages and promote environmental performance, a proactive approach called green supply chain management (GSCM), has been extensively employed. In this paper, we use the robust ranking technique with neutrosophic set to handle practices and performances in GSCM. We evaluate GSCM practices using the robust ranking technique in order to detect practices leading to better economic and environmental performances. We employ the neutrosophic set theory to handle vague data, imprecise knowledge, incomplete information and linguistic imprecision. The efficiency of the proposed method is evaluated by using the first case study from petroleum industry in Egypt and the second case study from manufacturing firm in China. The results display that “reverse logistics”, “supplier environmental collaboration”, “carbon management” are the significant in GSCM practices. Both case studies verified that our proposal could be adopted for effectiveness and improvement. Our work could help managers and decision makers to become more environmentally responsible.

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1. Introduction

In the past years, we witnessed an increased importance of the green supply chain management (SCM) operations of companies, conjugated to their general interest in environmental aspects. Legal environmental provisions, stakeholder pressures and globalization pushed enterprises and organizations to develop environmental practices and performances. Similarly, policies from the governments and increased public awareness may create demands for achieving better environmental management. Thus, organizations and enterprises are often obliged to improve their green image by performing environmental practices [1]. In recent years, the industry and academia have increased interests in GSCM [2], and particularly in integration of supply chain and natural environmental concerns in GSCM. This can be achieved by enforcing multiple green practices, like reverse logistics, green design, green purchasing, reuse, recycling and environmental technologies [3]. It is necessary to acquire a prospective competitive advantage and efficiency of GSCM by analyzing the interrelationships between the green practices and performances. There is a shortage of studies on GSCM practices and performances.

The mutual relations between them should emphasize the need for further research. Rajeev et al. refer to the lack of studies linking GSCM practices, economic and environmental performances in [4]. Additionally, Rao et al. [5] determined a potential connection between green GSCM initiatives and improved economic performance.

Therefore, the aim of this research is to evaluate GSCM practices and performances, and to rank their importance using neutrosophic set with robust ranking technique approach.

The neutrosophic set is a generalization of the IFS considering the degrees of truthiness, falsity and indeterminacy. Actually, criteria are related and have a degree of intrusion relationships directly or indirectly. In this case, it is very complex for decision makers and experts to aver intrusion between criteria to gain a particular objective [6]. There are a few of methods qualified for handling mutuality between criteria.

The main achievements of this research are:

- Considering the significance of GSCM practices and performances and interdependent relations with an integrated neutrosophic set with robust ranking technique to achieve GSCM efficiency.
- Recognizing a comprehensive roster of GSCM practices and performances.
- The first case study of petroleum industry in Egypt is used to elect the best green practice, in order to improve environmental

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and economic performance. The second case study of a
manufacturing firm in China is to validate our work can be
adopted in a different context and measure the extent of
improvements.

Neutrosophic numbers are employed in this research to explicit
experts’ preferences. The connotation of neutrosophic set was
suggested by Smarandache [7] generalizing the concept of IFSS. The
neutrosophic set is an extension of Atanassov intuitionistic fuzzy
set, where the membership and non-membership of an element in
a group is defined as a number between 0 and 1. Neutrosophic set
added another step further by examining the membership, the
indeterminacy membership and the non-membership of an
element of a given set as a number (0–1) [8]. Compared to
Atanassov intuitionistic fuzzy set, the neutrosophic set is very
effective in dealing with incomplete information and vague data.
Hence, experts and decision makers use neutrosophic set to
discern information in an uncertain environment [9].

The neutrosophic set received attentions from many researchers,
developing, improving and expanding the neutrosophic theory
[10–13]. Furthermore, it is a prerequisite to gain experts’ opinions
to estimate direct influences. However, crisp or deterministic
numbers cannot illustrate the linguistic imprecision and ambiguity
of experts’ opinions. Consequently, to cope with this drawback, we
use neutrosophic numbers [13]. The neutrosophic set introduces
the indeterminacy degree, which helps experts to explicit their
opinions more accurately [7].

In this research, the robust ranking technique, employed in
many papers [14–17] for easier and faster ordering of results, is
used to rank the information obtained from experts.

The paper is organized as follows: Section 2 passes in review
the green supply literature. Section 3 illustrates the preliminaries
of neutrosophic set. Section 4 explains the procedure solution. In
Sections 5 and 6, we describe two supporting case studies to
demonstrate the practicality of the method, with results and
analysis. In Section 7, we present discussion and finally, we
conclude our research with summary of research contributions
and future work.

2. Literature review

2.1. Green supply chain management (GSCM)

In the last decade, GSCM witnessed remarkable growth varying
from practical development to empirical and theoretical
researches [18–20]. Hervani characterized GSCM as a combination
of green design, materials management, green purchasing,
supplier environmental collaboration and reverse logistics
to

 hinder the loop. Over the years, the definition of GSCM varied.
Srivastava determined GSCM as a collection of environmental
consequences into SCM, including green design, selection of
materials, manufacturing and product end-of-life [21]. According
to [21], GSCM can decrease the negative effects (air, water, and land
pollution) and garbage of resources (energy, materials, and
products) of industrial activity. Many researchers and students
described scrupulous GSCM practices using real case studies for
implementation [22–24]. Table 1 epitomizes recent definitions of
GSCM practices.

2.2. GSCM practices

According to this paper, there are different green practices
through which the green supply chain can be achieved [27].

2.2.1. Reverse logistics

There are many products with remaining value, but not used at
the end of lifespan. Reverse logistics is the collection of products
and materials used by customers and users for reuse, recycling, or
other purposes. This process treats these materials as valuable
industrial inputs rather than being disposed of in the form of waste
[25]. The following figure shows the practice of reverse logistics
(Fig. 1).

2.2.2. Green purchasing

Companies can supply design directives for suppliers through
incorporating green principles into purchasing, which have
environmental requirements for the green purchased materials.
Green purchasing encompasses topics like serious material
minimization, refuse reduction and environmental material
substitution. Therefore, organizations have to ensure suppliers’
environmental performance and environmentally friendly materi-
als [28].

2.2.3. Carbon management

With rising environmental and climate variation worries in the
green supply chain, companies admitted the carbon issue as one of
the remarkable practice in GSCM [2]. Companies began utilizing
the outcomes of carbon footprint to reduce energy consumption
and manufacturing costs.

2.3. Case studies as a research method

Case studies have been used extensively in research. When
theories have been developed and expanded into a list of
guidelines, policies, examples and best practices, they can be
developed into a structured method. One of such a method is

| Expression, term                  | Definition                                                                 |
|-----------------------------------|---------------------------------------------------------------------------|
| Reverse logistics                 | Reverse logistics is the collection of products and materials used by customers and users for reuse, recycling, or other purposes. This process treats these materials as valuable industrial inputs rather than being disposed of in the form of waste. |
| Internal environmental management | Internal environmental management is the practice of evolving green supply chain management as a strategic organizational essential through involvement and favor of the involuntary from senior and mid-level managers [25]. |
| Green purchasing                  | Green purchasing converges on collaboration with suppliers for the aim to enhancing products that are environmentally sustainable [25]. |
| Cooperation with customers        | Collaboration with customers requires working with customers to design cleaner production processes that produce environmentally prospective products with green packaging [25]. |
| Environmental performance         | Environmental performance relates the ability of manufacturing plants to decline air resurrections, effluent waste, and solid wastes, and the ability to decrease consumption of hazardous and toxic materials [25]. |
| Economic performance              | Economic performance relates to the manufacturing plant’s capability to minimize costs related with purchased materials, energy consuming, waste evacuation, waste discharge, and mulchs for environmental episodes [24]. |
| Operational performance           | Operational performance connects to the manufacturing plant’s capabilities to more efficiently produce and convey products to customers [26]. |
| Organizational performance        | Organizational performance, financial and marketing performance of the organization as contrasted to the industry rate [26]. |
known as case studies [38,39]. They can represent how theories can be developed into lessons learned and real life examples. It is a common way to demonstrate how to blend theories and practices.

Case studies can be adopted and illustrated in our paper as follows. First, neutrosophic research is often focused on the theoretical development and its expansion on several models. The use of case studies can support its validity and theoretical contributions. Second, case studies can also represent how researchers can blend theories and practical solutions together. If the proposed solution can be demonstrated to address identified challenges, it can offer more meaningful research contributions.

The case studies are selected based on the development of the countries, suitability of the research agenda, existing needs in the area of research and the applicability for the potential real life contributions. For example, this research is relevant for the development countries, since they need to develop economy while maintaining an acceptable level of sustainability and green supply chain. Egypt was chosen since it is a better economy in Africa, and green supply chain has played a more important role. Similarly, China has become a strong merging economy. The use of green supply chain has become more important to maintain a good environment and reduce impacts caused by pollution and wastes. Neutrosophic research can be effectively used and illustrated, so that the selection of green suppliers can be consistent, fair, transparent and easy to follow. These two case studies will be presented in Sections 5 and 6 respectively.

3. Preliminaries

In this section, we give the definitions of neutrosophic sets, single valued neutrosophic sets, trapezoidal neutrosophic numbers, and discuss about the operations on trapezoidal neutrosophic numbers.

Definition 1. [17] Let $X$ be a space of points, $x \in X$. A neutrosophic set $A$ in $X$ is defined by a truth-membership function $T_\alpha(x)$, an indeterminacy-membership function $I_\alpha(x)$ and a falsity-membership function $F_\alpha(x)$ on $X$, $T_\alpha(x)$, $I_\alpha(x)$ and $F_\alpha(x)$ are real functions. The neutrosophic set $A$ is a real valued or real nonstandard valued subset of $X$. That is, $T_\alpha(x)$ and $F_\alpha(x)$ are standard or real nonstandard valued functions with $0 \leq T_\alpha(x) + I_\alpha(x) + F_\alpha(x) \leq 3$.

Definition 2. [29–32] Let $X$ be a universe of discourse. A single valued neutrosophic set $A$ over $X$ is an object taking the form $A = \{ (x, T_\alpha(x), I_\alpha(x), F_\alpha(x)) : x \in X \}$. The intervals $T_\alpha(x)$, $I_\alpha(x)$ and $F_\alpha(x)$ represent the truth-membership degree, the indeterminacy-membership degree and the falsity membership degree of $x$ to $A$, respectively. For convenience, a SVN number is represented by $A = (a, b, c)$, where $a, b, c \in [0,1]$ and $a + b + c \leq 3$.

Definition 3. [33,34] Suppose $\alpha_0, \theta_0, \beta_0 \in [0,1]$ and $a_1, a_2, a_3, a_4 \in R$, $a_1 \leq a_2 \leq a_3 \leq a_4$. Then, a single valued trapezoidal neutrosophic number $\tilde{a} = (a_1, a_2, a_3, a_4)$ is a special neutrosophic set on the real line set $R$, its truth-membership, indeterminacy-membership and falsity-membership functions are defined as:

\[
T_\tilde{a}(x) = \begin{cases} 
\alpha_2 (x - a_1) & (a_1 \leq x \leq a_2) \\
\frac{a_2 - a_1}{a_2 - a_1} & (a_2 \leq x \leq a_3) \\
\alpha_3 (a_3 - x) & (a_3 \leq x \leq a_4) \\
0 & \text{otherwise}
\end{cases}
\] (1)

\[
I_\tilde{a}(x) = \begin{cases} 
\frac{a_2 - x + \theta_0 (x - a_1)}{(a_2 - a_1)} & (a_1 \leq x \leq a_2) \\
\frac{x - a_3 + \theta_0 (a_4 - x)}{(a_4 - a_3)} & (a_2 \leq x \leq a_3) \\
\frac{a_3 - x}{a_3 - a_4} & (a_3 \leq x \leq a_4) \\
1 & \text{otherwise},
\end{cases}
\] (2)

\[
F_\tilde{a}(x) = \begin{cases} 
\frac{a_2 - x + \beta_0 (x - a_1)}{(a_2 - a_1)} & (a_1 \leq x \leq a_2) \\
\frac{x - a_3 + \beta_0 (a_4 - x)}{(a_4 - a_3)} & (a_2 \leq x \leq a_3) \\
\frac{a_3 - x}{a_3 - a_4} & (a_3 \leq x \leq a_4) \\
1 & \text{otherwise},
\end{cases}
\] (3)

where $\alpha_0, \theta_0$ and $\beta_0$ typify the maximum truth-membership degree, the minimum indeterminacy-membership degree and the minimum falsity-membership degree, respectively. A single valued trapezoidal neutrosophic number $\tilde{a} = (a_1, a_2, a_3, a_4)$ of $\tilde{a}$ represents an ill-defined quantity of the range, which is approximately equal to the interval $[a_2, a_3]$.

1. Definition 4. [30,34] Let $\tilde{a} = (a_1, a_2, a_3, a_4)$ and $\tilde{b} = (b_1, b_2, b_3, b_4)$ be two single valued trapezoidal neutrosophic numbers, and $\mathcal{T} \neq 0$ be any real number. Then, the addition of two trapezoidal neutrosophic numbers:

$$
\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) = (a_1 + \alpha_0 a_{a_1}, \theta_0 \theta_{a_1}, \beta_0 \beta_{a_1})
$$

2. Subtraction of two trapezoidal neutrosophic numbers:

$$
\tilde{a} - \tilde{b} = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1) = (a_1 + \alpha_0 a_{a_1}, \theta_0 \theta_{a_1}, \beta_0 \beta_{a_1})
$$
3. Inverse of trapezoidal neutrosophic numbers:

\[
\tilde{a}^{-1} = \left( \frac{1}{a_2} \frac{1}{a_1} \frac{1}{a_2} \frac{1}{a_1} \right) \alpha_a, \theta_a, \beta_a
\]

where (\(\tilde{a} \neq 0\))

4. Multiplication of trapezoidal neutrosophic numbers by constant value:

\[
T\tilde{a} = \begin{cases} 
\langle \langle T a_1, T a_2, T a_2, T a_4 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (T > 0) \\
\langle \langle T a_4, T a_3, T a_2, T a_1 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (T < 0)
\end{cases}
\]

5. Division of two trapezoidal neutrosophic numbers:

\[
\tilde{a}/\tilde{b} = \begin{cases} 
\langle a_1, a_2, a_3, a_4 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 > 0, b_4 > 0) \\
\langle a_2, a_3, a_4, a_1 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 < 0, b_4 > 0) \\
\langle a_4, a_2, a_3, a_1 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 < 0, b_4 < 0)
\end{cases}
\]

6. Multiplication of trapezoidal neutrosophic numbers:

\[
\tilde{a} \tilde{b} = \begin{cases} 
\langle a_1 \tilde{b}_1, a_2 \tilde{b}_2, a_3 \tilde{b}_3, a_4 \tilde{b}_4 \rangle, \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 > 0, b_4 > 0) \\
\langle (a_1 \tilde{b}_4, a_2 \tilde{b}_3, a_3 \tilde{b}_2, a_4 \tilde{b}_1) , \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 > 0, b_4 > 0) \\
\langle (a_4 \tilde{b}_1, a_3 \tilde{b}_2, a_2 \tilde{b}_3, a_1 \tilde{b}_4) , \alpha_a, \theta_a, \beta_a \rangle & \text{if } (a_4 < 0, b_4 < 0)
\end{cases}
\]

4. Neutrosophic set with robust ranking technique approach

Smarandache [29] introduced the neutrosophic set theory. Neutrosophy addresses vagueness, uncertainty, and indeterminacy of values.

In this section, we give the steps of the proposed model based on the neutrosophic set and robust ranking technique, as presented in Fig. 2.

4.1. The general steps of the proposed method

**Step 1:** Collecting data about the status of destination.

1. Selecting three experts (the reviewer expert, the first expert and the second expert).
2. Identifying the relevant practices and performances used in green supply.

**Step 2:** Making pairwise comparison matrices between relevant practices and performances of green supply.

1. Identifying practices (RL, GD, GP, CM, SEC, ENP, ECP, CEC).

2. Presenting each practice in order of a trapezoidal neutrosophic number \(\{l_{xy}, m_{xy}, d_{xy}, u_{xy}\}\).
3. Making comparisons between practices by the first expert and the second expert, as presented in Table 2, and focusing on consensus judgments only on \((n-1)\) using a scale \((0,1)\) [35].
4. Determining the maximum truth-membership degree \((\alpha)\), the minimum indeterminacy-membership degree \((\beta)\) and the minimum falsity membership degree \((\theta)\) in matrices for the first and second expert, as shown in Table 3.
5. Calculating the crisp values, as presented in Table 4, using the following formulas:

**Score function:**

\[
S(\tilde{a}_i) = \frac{1}{16} [l_{o1} + m_{d1} + m_{d1} + u_{p1}] \times (2 + \alpha - \theta - \beta)
\]

**Accuracy function:**

\[
A(\tilde{a}_i) = \frac{1}{16} [l_{o1} + m_{d1} + m_{d1} + u_{p1}] \times (2 + \alpha - \theta - \beta)
\]

**Step 3:** Calculating the average of all matrices.

Calculating the average for each row, firstly for the first expert, secondly for the second expert, as shown in Table 5, using Eq. (6).

\[
\text{row}_{nm} = \frac{\text{CrispV}_{1n} + \text{CrispV}_{2n} + \ldots + \text{CrispV}_{mn}}{n}
\]

**Step 4:** Merging of avg1 and avg2.

Merging of avg1 from expert 1 and of avg2 from expert 2 in \(\hat{A}_U, \hat{A}_L\), then putting the standard number in trapezoidal neutrosophic number, as presented in Table 6.

**Step 5:** Applying the robust ranking technique.

Lastly, we apply the robust ranking technique according to the following equations.

as \(\hat{A} = (l, a, b, \tilde{r})\)

using of \(\hat{A}_V = \hat{L} + (a - \hat{L}) y, \tilde{r} - (\tilde{r} - b) y\)

\[
R(\hat{A}) = \frac{1}{2} \int_{0}^{1} \hat{A}_V \hat{A}_V^T dy
\]

\[
R(\hat{A}) = \frac{1}{2} \int_{0}^{1} [\hat{L} + (a - \hat{L}) y, + (\tilde{r} - (\tilde{r} - b) y)] dy
\]

where \(y = [0,1]\).

**Step 6:** Drawing diagram of the result.

- Making the decision.

5. An Illustrative example

In this section, we describe the proposed method for evolving green practices in a green supply chain using robust ranking with neutrosophic set. This section has three subsections: (1) the case study, (2) the calculation process, (3) the analysis of practices (Figs. 3–7).

5.1. Case study one

The General Petroleum Company – GPC operates in the Egyptian petroleum sector, which was established in 1957 as a state-owned company (“public sector”), with a paid-up of LE 498.
Table 2
The pairwise comparison matrix between practices and performances selected from green supply.

| Practice | RL | GD | GP, CM, SEC, CEC, ENP | ECP |
|----------|----|----|-----------------------|-----|
| RL       | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}})\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{21}})\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{31}})\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{41}})\) |
| GD       | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}})\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{22}})\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{32}})\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}})\) |
| GP, CM, SEC, CEC, ENP | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}})\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{21}})\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{31}})\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}})\) |
| ECP      | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}})\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{21}})\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{31}})\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}})\) |

Table 3
The \(a, \beta\) and \(\theta\) degree in comparison matrix between practices.

| Practice | RL | GD | GP, CM, SEC, CEC, ENP | ECP |
|----------|----|----|-----------------------|-----|
| RL       | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}}; \alpha, \beta, \theta)\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{21}}; \alpha, \beta, \theta)\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{31}}; \alpha, \beta, \theta)\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}}; \alpha, \beta, \theta)\) |
| GD       | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}}; \alpha, \beta, \theta)\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{22}}; \alpha, \beta, \theta)\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{32}}; \alpha, \beta, \theta)\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}}; \alpha, \beta, \theta)\) |
| GP, CM, SEC, CEC, ENP | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}}; \alpha, \beta, \theta)\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{22}}; \alpha, \beta, \theta)\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{32}}; \alpha, \beta, \theta)\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}}; \alpha, \beta, \theta)\) |
| ECP      | \((l_{01}, m_{d_{11}}, m_{d_{12}}, u_{p_{11}}; \alpha, \beta, \theta)\) | \((l_{02}, m_{d_{21}}, m_{d_{22}}, u_{p_{21}}; \alpha, \beta, \theta)\) | \((l_{03}, m_{d_{31}}, m_{d_{32}}, u_{p_{31}}; \alpha, \beta, \theta)\) | \((l_{04}, m_{d_{41}}, m_{d_{42}}, u_{p_{42}}; \alpha, \beta, \theta)\) |

Table 4
The result of crisp values of matrices.

| Practice | RL | GD | GP, CM, SEC, CEC, ENP | ECP |
|----------|----|----|-----------------------|-----|
| RL       | CrispV1 | CrispV2 | ... | CrispV11 |
| GD       | CrispV12 | CrispV22 | ... | CrispV12 |
| GP, CM, SEC, CEC, ENP | ... | ... | ... | ... |
| ECP      | CrispVIn | CrispV2n | ... | CrispVn |

Table 5
Calculating the average for each row.

| Practice name | Avg. |
|---------------|------|
| RL            | Value|
| GD            | Value|
| GP            | Value|
| CM            | Value|
| SEC           | Value|
| CEC           | Value|
| ENP           | Value|
| ECP           | Value|

Table 6
Putting the standard number in trapezoidal neutrosophic number.

| Practice name | Expert 1 Avg. | Expert 2 Avg. | \([\text{AL}, \text{UL}]\) | \((l, a, b, \bar{r})\) |
|---------------|---------------|---------------|----------------|----------------|
| RL            | ...           | ...           | ...             | ...             |
| GD            | ...           | ...           | ...             | ...             |
| GP            | ...           | ...           | ...             | ...             |
| CM            | ...           | ...           | ...             | ...             |
| SCE           | ...           | ...           | ...             | ...             |
| CEC           | ...           | ...           | ...             | ...             |
| ENP           | ...           | ...           | ...             | ...             |
| ECP           | ...           | ...           | ...             | ...             |

levels of the production process as a proactive approach to gain profit and market share by reducing environmental leverage and improving ecological efficiency. The government has encouraged environmental co-partnership by supporting organizations to start and improve their GSCM. Hence, to consider and develop GSCM practices and performances, General Petroleum Company was selected as case study.

5.2. The calculation process of the neutrosophic set using robust ranking technique

Every company should consider developing in growth of green supply. Nowadays, any company seeks to apply green supply practices and performances at all levels of production, as a proactive approach in order to attain profit, but at the same time reducing environmental impact. In this paper, we determine some green supply categories. There are many green supply practices that we deal with: green practices: RL = reverse logistics; GD = green design; GP = green purchasing; CM = carbon management; SEC = supplier environmental collaboration; ENP = environmental performance; ECP = economic performance; CEC = customer environmental collaboration. Therefore, we need to understand every components of green practices and how they affect one another, by making a matrix for these components. In the last section, we compared matrices to evaluate each criterion based on points of views from experts, using the neutrosophic scale of 0, 1. In order to collect data, we interviewed three professional experts (one of them being expert in research and environmental management, another being expert in logistics and development, and the last one, to review the other two experts’ opinions). The data collected from the three experts were analyzed by neutrosophic set and robust ranking method. The steps that were conducted are the following:
Step 1. Choosing the experts.
In this step, we selected the group of experts consisting in three experts (the reviewer expert, the first expert and the second expert).

Step 2. Identification of practices and performances.
We sorted out seven evaluation criteria as selected by the team of experts, namely: green practices: RL = reverse logistics; GD = green design; GP = green purchasing; CM = carbon management; SEC = supplier environmental collaboration.

Fig. 4. Schematic diagram of using robust ranking in neutrosophic environment.

Fig. 5. Main practices in green supply.

Fig. 6. Group of experts.

Fig. 7. The result of comparing average.
Table 7
Linguistic terms and the identical trapezoidal neurotrophic numbers.

| Linguistic term         | Neurotrophic Trapezoidal Scale |
|-------------------------|--------------------------------|
| Absolutely low influence| \((0.1, 0.1, 0.1, 0.1; 0.5, 0.3, 0.3)\) |
| Low influence           | \((0.2, 0.3, 0.4, 0.5; 0.6, 0.2, 0.2)\) |
| Slightly low influence  | \((0.3, 0.4, 0.5, 0.6; 0.7, 0.1, 0.1)\) |
| Fairly low influence    | \((0.4, 0.5, 0.6, 0.7; 0.8, 0.0, 0.0)\) |
| Medium influence        | \((0.5, 0.6, 0.7, 0.8; 0.7, 0.3, 0.3)\) |
| Fairly high influence   | \((0.6, 0.7, 0.8, 0.9; 0.8, 0.2, 0.3)\) |
| High influence          | \((0.7, 0.8, 0.9, 1.0; 0.9, 0.1, 0.1)\) |
| Very strong influence   | \((0.8, 0.9, 1.0, 1.0; 0.9, 0.0, 0.0)\) |
| Absolutely high influence| \((1.0, 1.0, 1.0, 1.0; 1.0, 0.0, 0.0)\) |

Note: ENP = environmental performance; ECP = economic performance; CEC = customer environmental collaboration.

Step 3. Formation of pairwise comparisons matrices between practices in green supply are based on trapezoidal neurotrophic numbers, not triangular numbers.

1. Using the linguistic terms and linguistic variables, as shown in Tables 7–9.
2. Pairwise comparisons matrices to evaluate each practice and performance in green supply against each other, as shown in Tables 10 and 14.
3. Determining of membership, the maximum truth membership degree \(\alpha\), the minimum indeterminacy membership degree \(\theta\) and the minimum falsity membership degree \(\beta\), developed by experts, as shown in Tables 11 and 15.
4. Calculating the crisp value for each matrix applied by every expert, as shown in Tables 12 and 16.
5. Calculating the average of each row in all matrices for each expert, as shown in Tables 13 and 17 (Tables 14–16).

Table 8
Linguistic variables for experts.

| Linguistic variable       | Trapezoidal Numbers |
|---------------------------|---------------------|
| Very low (VL)             | \((0.0, 0.1, 0.2, 0.1)\) |
| Low (L)                   | \((0.1, 0.3, 0.4, 0.5)\) |
| Medium (M)                | \((0.3, 0.4, 0.5, 0.7)\) |
| High (H)                  | \((0.5, 0.7, 0.9, 0.9)\) |
| Very High (VH)            | \((0.7, 0.6, 0.9, 1.0)\) |

Step 4. Integrating the avg 1 and avg 2.
We integrate the values of Tables 13 and 17 as lower and upper value [\(\text{LU}, \text{UL}\)]; then, the reviewer expert reviews the results from

Table 9
Importance weight for experts.

| Experts                          | Linguistic variable | Importance weights | Crisp weights |
|----------------------------------|---------------------|--------------------|---------------|
| Expert 1 (Log. and dev. purchasing) | Medium             | \((0.3, 0.4, 0.5, 0.7)\) | 0.4           |
| Expert 2 (Res. and environmental manag.) | High               | \((0.5, 0.7, 0.6, 0.9)\) | 0.7           |
| Expert 3 (Reviewer)              | Medium             | \((0.3, 0.4, 0.5, 0.7)\) | 0.4           |

Table 10
Relation matrix (Data collected from expert in Logistics and development, purchasing).

| Practice name | RL     | GD     | GP     | CM     | SEC    | CEC    | ENP    | ECP    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| RL            | 0.5    | 0.0    | 0.5    | 0.0    | 0.5    | 0.0    | 0.5    | 0.0    |
| GD            | 0.2    | 0.0    | 0.3    | 0.1    | 0.2    | 0.0    | 0.3    | 0.1    |
| GP            | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    |
| CM            | 0.3    | 0.4    | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    |
| SEC           | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    | 0.2    | 0.3    | 0.4    |
| CEC           | 0.4    | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    |
| ENP           | 0.6    | 0.7    | 0.8    | 0.9    | 0.1    | 0.2    | 0.3    | 0.4    |
| ECP           | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    | 0.2    |

Table 11
Relation matrix between operators with the \(\alpha, \beta \text{ and } \theta\) degrees.

| Practice name | RL     | GD     | GP     | CM     | SEC    | CEC    | ENP    | ECP    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| RL            | 0.5    | 0.0    | 0.5    | 0.0    | 0.5    | 0.0    | 0.5    | 0.0    |
| GD            | 0.2    | 0.0    | 0.3    | 0.1    | 0.2    | 0.0    | 0.3    | 0.1    |
| GP            | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    | 1.0    |
| CM            | 0.3    | 0.4    | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    |
| SEC           | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    | 0.2    | 0.3    | 0.4    |
| CEC           | 0.4    | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    |
| ENP           | 0.6    | 0.7    | 0.8    | 0.9    | 0.1    | 0.2    | 0.3    | 0.4    |
| ECP           | 0.5    | 0.6    | 0.7    | 0.8    | 0.9    | 1.0    | 0.1    | 0.2    |
expert 1 and expert 2, and put these values in trapezoidal neutrosophic numbers (Tables 18 and 19).

Step 5. Applying of robust ranking technique.
We apply the equation (robust ranking) to obtain the value of R ($\bar{R}$), then ordering operators using robust ranking.

Step 6. Drawing diagram of the result.
The diagram depicted in Fig. 8 ranking of the result.

Table 12 The crisp values of relation matrix

| Practice name | RL     | GD     | GP     | CM     | SEC    | CEC    | ENP    | ECP    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| RL            | 0.500  | 0.624  | 0.574  | 0.431  | 0.048  | 0.193  | 0.341  | 0.048  |
| GD            | 0.193  | 0.500  | 0.371  | 0.341  | 0.574  | 0.193  | 0.624  | 0.574  |
| GP            | 0.750  | 0.048  | 0.500  | 0.624  | 0.281  | 0.750  | 0.341  | 0.754  |
| CM            | 0.281  | 0.341  | 0.281  | 0.500  | 0.574  | 0.281  | 0.431  | 0.341  |
| SEC           | 0.574  | 0.431  | 0.750  | 0.048  | 0.500  | 0.574  | 0.371  | 0.281  |
| CEC           | 0.371  | 0.371  | 0.281  | 0.341  | 0.371  | 0.500  | 0.574  | 0.341  |
| ENP           | 0.431  | 0.574  | 0.574  | 0.431  | 0.281  | 0.371  | 0.500  | 0.624  |
| ECP           | 0.341  | 0.281  | 0.371  | 0.371  | 0.574  | 0.431  | 0.281  | 0.500  |

5.3. Analyzing the practices in green supply

In this case study, we integrate and analyze the collected data from three experts (the reviewer expert, the first expert and the second expert). The aim is to find out the evaluation of practices and performances in green supply. Our results can determine the most important practices that should be developed from the chart in Fig. 8, the lowest value of practices and performances in green supply in this case is the Reverse Logistics (RL), and the highest value is Green Purchasing (GP).

6. Another supporting case study in China

This section presents another supporting case study to illustrate how our work can make direct research contributions independent of countries and locations. A green manufacturing firm was closely involved. They followed our recommendations and we then presented the results and analysis. Firm A is a manufacturing supplier for automated machineries in Suzhou, China. Suzhou Industrial Park (SIP) is a well-known industry area that has contributed significantly to the economic development of Suzhou, which has become one of the new first tier cities in China. Firm A manufactures automated machines, which can work efficiently and more than 16 h a day for building components, making parts of the products and assembling components into products. They employed more than 400 people. The automated machineries and its product-making processes make very low carbon production. The products are very environmentally friendly, since they use intelligent algorithms to increase productivity and reduce generation of a lot of carbon dioxide after the end of each manufacturing process. We followed all the steps in Section 5. The only difference is that we keep track of the improvements over a period of six months. It is important to measure the benefits before and after adopting our proposal. The aim is to identify the level of

Table 13 The row average of matrix

| Practice name | Avg   |
|---------------|-------|
| RL            | 0.35  |
| GD            | 0.42  |
| GP            | 0.46  |
| CM            | 0.39  |
| SEC           | 0.44  |
| CEC           | 0.38  |
| ENP           | 0.47  |
| ECP           | 0.40  |

Table 14 Relation Matrix (Data collected from expert in Research and Environmental Management)

| Practice name | RL     | GD     | GP     | CM     | SEC    | CEC    | ENP    | ECP    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| RL            | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| GD            | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| GP            | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| CM            | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| SEC           | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| CEC           | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| ENP           | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| ECP           | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |

Table 15 Relation matrix between operators with the $\alpha, \beta$ and $\theta$ degrees

| Practice name | RL     | GD     | GP     | CM     | SEC    | CEC    | ENP    | ECP    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| RL            | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| GD            | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| GP            | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| CM            | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| SEC           | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| CEC           | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
| ENP           | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.023  | 0.040  | 0.505  |
| ECP           | 0.023  | 0.040  | 0.505  | 0.505  | 0.023  | 0.040  | 0.505  | 0.505  |
improvements and allow direct comparisons before and after adopting our proposal.

Figs. 9 and 10 show scores before and after adopting our proposal for six months. There are overall improvements between 10% and 17%. This is important for green suppliers to illustrate the level of improvement and our proposal as a valid recommendation. Similarly, Figs. 11 and 12 show the scores before and after adopting

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Table 16 The crisp values of relation matrix

| Practice name | RL       | GD   | GP   | CM   | SEC  | CEC  | ENP | ECP |
|---------------|----------|------|------|------|------|------|-----|-----|
| RL            | 0.500    | 0.624| 0.048| 0.341| 0.048| 0.193| 0.341| 0.048|
| GD            | 0.193    | 0.500| 0.371| 0.141| 0.574| 0.193| 0.624| 0.574|
| GP            | 0.750    | 0.048| 0.500| 0.624| 0.281| 0.750| 0.341| 0.371|
| CM            | 0.281    | 0.341| 0.281| 0.500| 0.574| 0.281| 0.431| 0.431|
| SEC           | 0.574    | 0.341| 0.750| 0.048| 0.500| 0.574| 0.371| 0.281|
| CEC           | 0.371    | 0.371| 0.281| 0.341| 0.371| 0.500| 0.574| 0.341|
| ENP           | 0.341    | 0.371| 0.574| 0.431| 0.281| 0.371| 0.500| 0.624|
| ECP           | 0.341    | 0.281| 0.371| 0.371| 0.431| 0.281| 0.500| 0.500|

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Table 17 The row average of matrix

| Practice name | Avg |
|---------------|-----|
| RL            | 0.27|
| GD            | 0.41|
| GP            | 0.45|
| CM            | 0.39|
| SEC           | 0.43|
| CEC           | 0.39|
| ENP           | 0.43|
| ECP           | 0.39|

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Table 18 The result of comparing average

| Practice name | Expert 1 Avg. | Expert 2 Avg. | [\(\overline{A_U}, \overline{A_L}\)] | \((L, a, b, r)\) |
|---------------|---------------|---------------|----------------------------------|-----------------|
| RL            | 0.35          | 0.27          | [0.27, 0.35]                     | (0.27, 0.28, 0.30, 0.35) |
| GD            | 0.42          | 0.41          | [0.41, 0.42]                     | (0.41, 0.41, 0.412, 0.42) |
| GP            | 0.46          | 0.45          | [0.45, 0.46]                     | (0.45, 0.45, 0.452, 0.46) |
| CM            | 0.39          | 0.40          | [0.39, 0.40]                     | (0.39, 0.391, 0.392, 0.40) |
| SEC           | 0.44          | 0.43          | [0.43, 0.44]                     | (0.43, 0.431, 0.432, 0.44) |
| CEC           | 0.38          | 0.39          | [0.38, 0.39]                     | (0.38, 0.381, 0.382, 0.39) |
| ENP           | 0.47          | 0.43          | [0.43, 0.47]                     | (0.41, 0.44, 0.46,0.47) |
| ECP           | 0.40          | 0.39          | [0.39, 0.40]                     | (0.39, 0.391, 0.392, 0.40) |

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Table 19 The result of robust ranking

| Practice name | \(R(\overline{A})\) | Order of operators using robust ranking |
|---------------|---------------------|---------------------------------------|
| RL            | 0.30                | RL                                    |
| GD            | 0.41                | CM                                    |
| GP            | 0.45                | CM                                    |
| CM            | 0.39                | GD                                    |
| SEC           | 0.43                | ECP                                   |
| CEC           | 0.38                | SEC                                   |
| ENP           | 0.44                | ENP                                   |
| ECP           | 0.41                | GP                                    |
our proposal for six months. All the scores are higher in Fig. 12 in all aspects. There is an improvement between 8% and 13%. We have the same result, GP > ENP > SEC > ECP > GD > CM > CEC > RL, like the first case study.

Results in Figs. 7 and 12 show that Green Purchasing (GP) scored the highest. This is because all suppliers require the purchasing activities as their main focus. This allows them to sell their products and services to existing and new customers. In this process, it also makes direct influences on manufacturing. The more sale orders are made, the more products are then manufactured. Additionally, transportation and supply chain activities are also significantly raised due to the increased GP activities. This case study can demonstrate that our proposal can help green supply chain.

7. Discussion

Many organizations consider a significant strategic topic integrating environmental measures into SCM. GSCM is important for organizations and enterprises to enhance competitive advantages, market share and profitability. Nowadays, organizations and companies should implement GSCM practices into their business operations due to increased community concerns and strict regulations. Some research outputs indicate how GSCM practices can improve an organization’s approach for environments.

Organizations can reach balanced economic and environmental performance through analysis of interrelated problems. Organizations and enterprises should consider the importance of GSCM practices and how it could affect their economic and environmental performance in business operations. Case studies can provide suitable methodologies to validate our approach. Therefore, we presented two case studies with different sectors and different countries to show that our work can be adopted with consistency. The first case study includes the implementation in a petroleum manufacturing company, and the second case study involve with manufacturing firm for automated machineries. Our steps to obtain results were discussed and different aspects of GSCM were demonstrated. Results and analysis could call for attention to reverse logistics, supplier environmental collaboration, and carbon management.

Our research contributions include as follows. First, we can demonstrate a logical, structured and step-by-step neutrosophic research approach to determine the selection of the green supply chain. Second, the use of case studies can be further support the validity of our research contributions, since we can blend theories and real-life examples well. We have analyzed issues in Egypt and China, and have demonstrated our recommendations and practical solutions, particularly for GSCM cases and practices.

Our research is not free from limitations, since we only employed a limited number of experts. The first recommended approach could include using more experts to validate, so that other researchers could repeat the proposed method using multiple experts. The second recommendation is to develop algorithms to help predict the future trends and perspectives. For example, the use of Organizational Sustainability Modeling (OSM) and Reuse Strategic Decision Pattern Framework can be used to predict the future trends, business performance and risk [36,37].

8. Conclusion and future work

GSCM practices and performances could be developed using neutrosophic set and robust ranking technique. In this paper, we proposed an approach for GSCM to develop robust ranking technique by implementing neutrosophic set to avoid unclear, vague and inexact opinions. An effective GSCM practice should develop firstly “reverse logistics”, followed by “supplier environmental collaboration”, and finally “carbon management”. By following our steps carefully, the organization could improve performance through establishing good GSCM practices and performances. Two case studies were illustrated to show our approach can be validated in different context. The major contribution of both case studies consists in integrating the neutrosophic set and the robust ranking technique, in order to determine the best practices for GSCM implementation in petroleum industry.

Our conclusion was that GSCM practices could reduce waste, cost declines, offer economic advantages and better resources use. Therefore, GSCM practices could play an important role in the development of organizations toward economic and environmental benefits. Applying the neutrosophic set in this research helped us to handle vague data, imprecise knowledge, incomplete information and linguistic imprecision. Support of two case studies could consolidate the validity of our approach and demonstrated our case could be adopted. We could also compare the extents of improvement between before and after adopting our recommendations.

Future directions include the use of algorithms to predict the future trends. This can blend theories and simulations better and quicker. Similarly, the use of analytics can be developed together with neutrosophic research to make it an intelligent service. For the future work, we plan to blend our current work with algorithms to simulate predictive modeling and user behavior analysis. Predicting the trends and business performance can be essential for all the stakeholders and decision-makers.

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