Evaluation of sustainable acid rain control options utilizing a fuzzy TOPSIS multi-criteria decision analysis model frame work

Onu Pascal U*, Quan Xie, Ling Xu, Orji Juliet, Eugene Onu

Key laboratory of industrial Ecology and Environmental Engineering (Ministry of Education, china), school of Environmental science and Technology, Dalian university of technology, 2 ling gong road, Dalian 116024, china.

Center for Clinical Care and Clinical Research Nigeria, 29 Mambilla Street, off Aso drive, Maitama Abuja.

Corresponding author: Onu Pascal U

E-mail address: ukapas@yahoo.com

Abstract:

Acid rain has evolved into a robust, diverse and dynamic spectra of studies in contemporary times. The significant role of rain water harvesting as a major source of water supply, especially in high harvesting potential regions like the Niger delta of Nigeria, the core area of oil exploratory activities and where gas flaring a major cause of acid rain is rife, prompts serious concerns. This study applies the superior, unique and exemplary features of fuzzy TOPSIS a multi-criteria decision analysis approach to aid the selection of sustainable acid rain control options intrinsic to society, under economic, environmental, social, technical, and institutional factors. It employs linguistic scales to solicit expert opinions, understanding acid rain dialogues as public policy issues saddled with numerous vagueness and complexity especially in achieving sustainability. Results from data aggregation, normalization and performance ratings, coupled with the weighted distance from the positive and negative ideal solutions indicated that solar as an alternative energy source ranked topmost while hydro and use of Nox burners ranked second and third respectively. The revelations are satisfactory logically and especially consistent with use of Nox burners ranking third, that Nigerian crude is sweet. Hence beyond the general clamor for total elimination of gas flaring, enforcing the use of pollution control devices like Nox burners and a shift to promoting investment in solar plants/ energy is considered viable.

Key words: MCDA, acid rain, fuzzy TOPSIS, Nigeria, sustainability

1. Introduction

Acid rain has kept pace with research in contemporary times. it has evolved into a robust, diverse and dynamic spectra of study embracing several models such as the MAGIC model, employed widely in north America and Europe (Cosby et.al 1985; Ferrier et.al 1995; Richard et.al 1998; Larssen and Carmichael 2000), GAINS Asia models (Momoe et.al 2013) RAINS, (Downing et.al 1997; Foell et.al 1995), for assessing long time changes in surface water and soils, the degree of their occurrence, impact, environmental effects and control. Extensive efforts on rain water acidity have been documented severally, in the UK (Ling et.al 2000; Roberts and Sheail 1993; McCormick 1989) in china (Xiuying et.al 2012; Negase and Silva 2007; Momoe et.al 2013), in Nigeria (Efe 2011; Nduka et.al 2008; Ezewaji et.al 2013), in north America and Europe (Fedric and Hans 2004; Hulton and Halkos 1995) where major milestones have been attained, in its control.

Acid rain is defined typically as rain water with a PH less than 5.6 affecting nature and human life in a variety of ways (Charlson and Rodhe 1982). It is also referred to as depositions in the form of rain fog, snow occurring downwind of areas where major emissions from anthropogenic activities take place (Botkimi and Keller 1998). Acknowledged link of Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions, as precursors to acidic precipitations are established (Rohde et.al 1995) nevertheless other compounds like NH_3 , Ca are recognized to also precipitate acidic rain. These compounds are transmitted majorly from power plants and petroleum exploratory activities (gas flaring) among others. Their adverse effect globally, on both animate and inanimate matter, has prompted measures both in technology, policy formulations, reforms and otherwise for its abatement.

Prevalent reports on its control measures however, have basically focused more on SO_2 reduction strategies. Presuming it to be the only cause of acidic depositions, as such proposing abatement measures aligned unidirectional, evident by (Momoe et.al 2013; Jorge and Genice 2007; Cailing et.al 2009; Algarib et.al 2007; Obanijesu et.al 2009) excepting a few studies like (Larssen and Carmichael 2000) who considered the importance of cation depositions, using MAGIC model to discuss temporal and spatial trend in acidic depositions in china. These measures have been categorized under three areas namely; fuel control, stack control and process modification (Algarib et.al 2007). Stack control measures are frequently applied industrially and involve pollution control devices to either destroy the pollutants or remove them from an exhaust stream before emission into the atmosphere (Milton 2005). Commonly proposed and adopted control options/measures include flue gas desulphurization (FGD), which is the most widely applied measure for SO_2 reduction (Cailing et.al 2009), switch to natural gas in power plants (for fuel control), utilizing NO_x burners, liming (liming injection technologies), washing coal to reduce Sulphur, use of catalytic converters to reduce vehicular emission, employing alternative sources of energy like hydro, nuclear (explored more in the US) thermal, and solar. For this study we consider, FGD, switch to natural gas plants, liming, coal washing, use of catalytic converters, use of NO_x burners, hydro, whilst additional preventive and control options, considered peculiar to Nigeria and most developing nations are, solar energy source, increasing advocacy campaigns on awareness of acid rain, and eliminating/quit gas flaring.

The oversight on other complimentary causative compounds like Nox which is produced upon burning fossil fuels, creates a bit of a loophole especially when considering mitigation options intrinsic to societies, like Nigeria where controversies exist as to the exact emissions responsible for acidic precipitations predominant in its Niger delta region, since its crude is recognized as sweet (low Sulphur content). This attention on acid rain hinges on the fact that Nigeria, as a developing nation is characterized by urbanization, increasing population and industrialization coupled with the strategic importance of rain water as a primary source of all water for which a large majority of the populace engage in the practice of rain water harvesting for water supply particularly in rural areas and high harvesting potential regions like the Niger delta.

Deciding or selecting however, on an appropriately best and sustainable control measure presents a very difficult task, because of diverse uncertainties, and imprecision surrounding the entire process. This is more so considering the numerous sustainability factors and ambiguity embedded in human rationality and judgement, which arouses a fundamental concern. In view of these challenges, and the fact that acid rain debate is a public policy issue characterized by great uncertainty and complexity (Ling et.al 2000), multi-criteria decision analysis (MCDA) becomes a pertinent approach for overcoming these shortcomings. Fuzzy TOPSIS (technique for order performance by similarity to ideal solution), a MCDA is adopted in this study to aid in selecting an ultimate acid rain control option under technical, economic, social, environmental and institutional criteria. This approach has unique features unprecedented to other MCDA methods in handling with ease both quantitative and qualitative data under demystified computations.

2. Literature review

Kheireldin and Fahmy 2001, articulates MCDA approaches as operating under two basic dimensions namely, providing insight into the nature of conflicts amongst objectives and arriving at a consensus around stakeholders rather than eliminating conflicts. A host of MCDA methods exist, because the ideas, algorithms, weights computation, extent of uncertainty encapsulated in the data set, and ability of stakeholder's participation in the processes varies. Amongst MCDA methods for which analytical hierarchy process (AHP) and technique for order performance by similarity to ideal solution (TOPSIS) is frequently used, fuzzy TOPSIS remains outstanding because it's easy to understand and effectively handles both qualitative and quantitative data in multi attribute decision making (MADM). Moreover unlike AHP, its computations are demystified and at no time can any criteria or alternative be dropped due to priority weights of criterion or alternative being zero

The TOPSIS method was pioneered by Hwang and Yoon 1981. Fuzzy TOPSIS is an extension of the TOPSIS method introduced to efficiently handle and resolve the fuzziness of the data involved in the decision making. This method is conceptualized on the basis that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that optimizes the benefit criteria and minimizes cost criteria, while the negative ideal solution reverses the case i.e. maximizes the cost criteria and minimizes the benefit criteria Wang and Elhag 2006. Typically, TOPSIS approach utilizes known and precise crisp values for criteria weights and alternative

ratings in the evaluation process. This creates some setbacks, since in most real life decision situations crisps data are inadequate for modelling. Hence the introduction of fuzzy TOPSIS, which employs linguistic variables to evaluate criteria weights and ratings of alternatives, thus making up for the deficiency in traditional TOPSIS.

Applications of fuzzy TOPSIS in varied endeavors abound in the literature. Amongst them are (Chen 2000), with example in system analysis for engineer selection in a software company, (Chu 2002) in solving facility location problem, (Chu and Lin 2003) for robot selection, (Sagafian and Hegazi 2005) by modifying the fuzzy TOPSIS method proposed a new distance measure where there is a group of decision makers in multi-criteria selection problems. (Chen and Lin 2006) dealing with the supplier selection problem in supply chain system. (Bottani and Rizzi 2006) proposing a multi-attribute approach for selection and ranking of a most suitable service provider. In Taiwan (Wang and Chang 2007) employed fuzzy TOPSIS to assist in the choice of initial training aircraft for the air force academy, while (Yang and Huang 2007) proposed a combination of TOPSIS and fuzzy TOPSIS in addressing plant layout design problem, yet still, in the hotel industry (Benitez et.al 2007) adopted fuzzy TOPSIS to measure quality of service rendered. Other studies with similar attributes include (Etugral and Karakasoglu 2008, Wang et.al 2003), while related studies in water engineering and supply field include (Bojan 2007, Marcia and Buros 1985, Marwan and Numan 2004, Nitirach and Villas 2011, Song et.al 2011; Jaber and Mohsen 2001; Okeola and Sule 2012).

However very sparse reports exist on acid rain mitigation measures utilizing MCDA approaches for decision support, such as that of (Algarib et.al 2007) who applied AHP, in choosing SO_2 emission reduction measures for a network of power stations in Kuwait, grouping alternatives into new refinery design, fuel substitution, FGD and energy conservation. (Zhang and Chang 2012), in china, employed TOPSIS to investigate the impact of acid rain on its socioeconomic vulnerability under a sensitivity and adaptive capacity indicator system. They concluded that Tibet, Qinghai and shanghai ranked topmost in vulnerability, while inner Mongolia, Xingjiang and Jilin ranked least, and that adaptive capacity indicator appeared more relevant than the sensitivity indicators in measuring vulnerability. Our work presents an elaborate and simple approach for ease in selecting appropriate acid rain control options. The advantages of TOPSIS over other MCDA methods include (Govindan et.al 2013):

- Unlike other MCDA e.g. (ELECTRE) it preferentially ranks alternatives with numerical values as well as simulates between alternatives providing a better understanding of differences.
- Provides infinite range of criteria and performance attributes
- Delineates from pairwise comparisons embraced by other MCDA thus effectively allows for large number of criteria and alternatives
- Upon addition or removal of an alternative, TOPSIS unlike other MCDA has the fewest rank reversals
- Employs a systematic procedure that is explicit with demystified computations
- Apt tradeoff and interaction between attributes are allowed and enhanced.

3. Methods

In this work, the longitudinal and cross-wise designs were adopted to collect data on performances of various acid- rain control options with respect to certain deducted sustainability criteria. The purpose was to effectively ascertain/ deduct the most important sustainability criteria and employ the deducted sustainability factors to rank the various acid- rain control options, thus finding the most sustainable acid- rain control option. The information used for the study was gathered from archival records and expert interviews. The experts considered in this study were 40 experts/ environmental managers and researchers in power, oil and gas sector at both government and private levels. For this study, 10 acid- rain control options (the use of flue gas desulphurization (FGD), catalytic converters for vehicles exhaust, conversion to natural gas plants, campaign awareness of acid rain, quit gas flaring, wash coal before use to reduce sulphur content, use of NO_x burners, alternative energy source (solar), alternative energy source (hydro) and liming) are considered as alternatives.

Two sets of questionnaires were issued to personnel for data collection; the first set of questionnaires was to deduct the relevant sustainability factors while the second set of questionnaires were fuzzy questionnaire used to ascertain the performances of acid- rain control options.

The modeling approach applied in this work comprises of a deduction process, and an integrated fuzzy logic and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS).

3.1 Deduction Process

The deduction process is employed to deduct the relevant sustainability factors for the acid- rain control options. The questionnaire design for ascertaining the relevant sustainability factors are stated in Table 1- 1.

Table 1- 1 Deduction Process for Classifying Sustainability Factors for Acid- Rain Control Options

Criteria	Sub- criteria	Relevant for Acid- rain control options	
Economic			
	Cost effectiveness	Yes	No
	Securing of investment resources	Yes	No
	Financial visibility	Yes	No
	Organization and management	Yes	No
	Customer service	Yes	No
	Quality	Yes	No
	Relationship	Yes	No
Environmental			
	Green design	Yes	No
	Pollution control	Yes	No
	Resource consumption and conservation	Yes	No
	Eco- design requirements	Yes	No
	Innovation	Yes	No
	Withdrawal	Yes	No
	Reliability	Yes	No
	Environmental competencies	Yes	No
	Vulnerability	Yes	No
	Availability	Yes	No
Institutional			
	Legal framework	Yes	No
	Policies	Yes	No
	Regulatory control	Yes	No
Social			
	Public health and safety	Yes	No
	Intergenerational equity	Yes	No
	Acceptability	Yes	No
	Rights of stakeholders	Yes	No
	Coverage	Yes	No
	Respect for policy	Yes	No
Technical			
	Access to advanced technology	Yes	No
	Expertise of employee	Yes	No
	Maturity of control option	Yes	No
	Operational efficiency	Yes	No

The responses of the targeted respondents are stated in Table 1- 2.

Table 1- 2 Responses to Deduction Process

Criteria	Sub- criteria	YES		NO	
		No. of responses	%of responses	No. of responses	%of responses
Economic					
	Cost effectiveness	40	100	-	-
	Securing of investment resources	-	-	40	100
	Financial visibility	-	-	40	100
	Organization and management	-	-	40	100
	Customer service	-	-	40	100
	Quality	40	100	-	-
	Relationship	-	-	40	100
Environmental					
	Green design	38	95	2	5
	Pollution control	35	87.5	5	12.5
	Resource consumption and conservation	-	-	40	-
	Eco- design requirements	-	-	40	100
	Innovation	40	100	-	-
	Withdrawal	-	-	40	100
	Reliability	40	100	-	-
	Environmental competencies	38	95	-	5
	Vulnerability	40	100	-	-
	Availability	38	95	-	5
Institutional					
	Legal framework	36	90	4	10
	Policies	-	-	40	100
	Regulatory control	3	7.5	37	92.5
Social					
	Public health and safety	39	97.5	-	2.5
	Intergenerational equity	4	10	36	90
	Acceptability	36	90	4	10
	Rights of stakeholders	6	15	34	85
	Coverage	4	10	36	90
	Respect for policy	40	100	-	-
Technical					
	Access to advanced technology	2	5	38	95
	Expertise of employee	5	12.5	35	87.5
	Maturity of control option	39	97.5	1	2.5
	Operational efficiency	37	92.5	3	7.5

The responses to the deduction process for sorting the sustainability factors relevant for acid- rain control options are converted to percentages. A threshold is set at 87% for the responses to the deduction process. Thus, the sustainability factors crucial for selection of acid- rain control options are stated in Table 1- 3.

Table 1- 3 Sustainability Factors Relevant for Acid-Rain Control Options

Criteria	Sub- criteria
Economic	Cost effectiveness
	Quality
Environmental	Green design
	Pollution control
	Innovation
	Reliability
	Environmental competencies
	Vulnerability
	Availability
Institutional	Legal framework
Social	Public health and safety
	Acceptability
	Respect for policy
Technical	Operational efficiency
	Maturity of control option

The sustainability factors relevant to acid- rain control options are employed to design fuzzy questionnaires. The fuzzy questionnaires were designed to ascertain the performances of the various acid- rain control options with regards to the relevant sustainability factors and distributed to managers/ researches in the power, oil and gas sector at both government and private levels.

3.2 Fuzzy Logic

The fuzzy linguistic scale employed in the design of fuzzy questionnaires has linguistic terms of very weak, weak, medium, good and very good with scores of 1, 2, 3, 4 and 5 and triangular fuzzy numbers of (0,0,0.25), (0,0.25,0.50), (0.25, 0.50, 0.75), (0.50, 0.75, 1.00) and (0.75,1.00, 1.00) respectively. The fuzzy linguistic scale for acid- rain control options performances is shown in Table 1- 4 below.

Table 1- 4 Fuzzy Linguistic Scale for Acid- Rain Control Option Performance

Linguistic Term	Score	Triangular fuzzy numbers
Very weak	1	(0, 0, 0.25)
Weak	2	(0, 0.25, 0.50)
Medium	3	(0.25, 0.50, 0.75)
Good	4	(0.50, 0.75, 1.00)
Very good	5	(0.75, 1.00, 1.00)

To obtain the information on the performances with respect to deducted sustainability factors, fuzzy design questionnaires were administered and the fuzzy linguistic scale in Table 1- 5 is applied to obtain the decision matrix with elements R_i , S_i and Z_{ij} , shown in Table 1- 5.

Table 1- 5 Performance of Acid- Rain Control Options with respect to Sustainability factor

Alternatives	Sub- Criteria			
	S_1	S_2	S_3	S_n
R_1	Z_{11}	Z_{12}	Z_{13}	Z_{1n}
R_2	Z_{21}	Z_{22}	Z_{23}	Z_{2n}
R_m	Z_{m1}	Z_{m2}	Z_{m3}	Z_{mn}

R_i is acid- rain control options.

S_i is sustainability sub- criteria.

Z_{ij} is deduced elite reactions/responses with regards to the sustainability factor respectively.

It should be noted that the membership function of the fuzzy set is applied in triangular form to obtain ideal solutions from group decisions. A triangular fuzzy number can be shown as $q = (a, b, c)$ and the triangular membership function $\tilde{u}_q$ is defined as Equation (1- 1). A diffuzification process known as CFCS process which is based on the determination of maximum and minimum fuzzy number range was used to diffuzify the fuzzy set into crisp values. It is deemed to be more effective by researchers for arriving at crisp values when compared to the centroid method (Gharakhani, 2012).

$$\tilde{u}_q(y) = \begin{cases} 0 & \text{if } y < a \\ \frac{(y-a)}{(b-a)} & \text{if } a \leq y \leq b \\ \frac{(c-y)}{(c-b)} & \text{if } b \leq y \leq c \\ 0 & \text{if } y > c \end{cases} \quad (1- 1)$$

According to the membership function $\tilde{u}_q$, the total score is calculated with the weighted average. Given that U represents a fuzzy set, the fuzzy evaluation is given by $q_{ij}^d = (a_{ij}^d, b_{ij}^d, c_{ij}^d)$ for decision makers $d = (1, 2, \dots, n)$ for the degree of influence of sub- criterion i on sub- criterion j . The CFCS method involves a five- step algorithm described as follows (Orji & Wei, 2015):

Step One: Normalization:

$$xa_{ij}^n = (a_{ij}^n - \min c_{ij}^n) / \Delta_{\min}^{max} \quad (1- 2)$$

$$xb_{ij}^n = (b_{ij}^n - \min c_{ij}^n) / \Delta_{\min}^{max} \quad (1- 3)$$

$$xc_{ij}^n = (c_{ij}^n - \min c_{ij}^n) / \Delta_{\min}^{max} \quad (1- 3)$$

$$\text{Where } \Delta_{\min}^{max} = \max a_{ij}^n - \min c_{ij}^n \quad (1- 4)$$

Step Two: Compute right (as) and left (cs) normalized values:

$$xas_{ij}^n = xa_{ij}^n / (1 + xa_{ij}^n - xb_{ij}^n) \quad (1- 5)$$

$$xcs_{ij}^n = xb_{ij}^n / (1 + xb_{ij}^n - xc_{ij}^n) \quad (1- 6)$$

Step Three: Compute total normalized crisp values:

$$x_{ij}^n = [xcs_{ij}^n (1 - xcs_{ij}^n) + xas_{ij}^n X xas_{ij}^n] / [1 - xcs_{ij}^n + xas_{ij}^n] \quad (1- 7)$$

Step Four: Compute crisp values:

$$u_{ij}^n = \min c_{ij}^n + x_{ij}^n X \Delta_{\min}^{max} \quad (1- 8)$$

Step Five: Integrate crisp values:

$$u_{ij} = 1/p (u_{ij}^1 + u_{ij}^2 + \dots + u_{ij}^p) \quad (1- 9)$$

The crisp values will serve as input data in the TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) that will be developed in the next section of this work.

3.3. Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)

The concept of TOPSIS is hinged on the principle of the measures of distance of the alternatives from the positive and negative ideal solutions. TOPSIS is considered a simplified multi- criteria decision making model and has been extensively applied in literature (Khamseh and Mahmoodi, 2014; Orji and Wei, 2015).

Typically, TOPSIS technique consists of the following steps:

Step 1: Develop a normalized decision matrix

The normalized decision matrix is developed with element B_{ij} which represents the normalized evaluation index for the alternative acid- rain control options as shown in Table 1- 6.

B_{ij} is computed as:

$$B_{ij} = \frac{k_{ij}}{\sqrt{\sum_{i=1}^m k_{ij}}} \quad (1-10)$$

If, $0 < k_{ij} > 1$

Where,

k_{ij} is the performance of each alternative with respect to each criterion.

Table 1- 6 Normalized Decision Matrix

Alternatives	Sub- Criteria			
	S_1	S_2	S_3	S_n
R_1	B_{11}	B_{12}	B_{13}	B_{1n}
R_2	B_{21}	B_{22}	B_{23}	B_{2n}
R_m	B_{m1}	B_{m2}	B_{m3}	B_{mn}

Step 2: The weighted normalized decision matrix V_{ij} is calculated as:

$$V_{ij} = B_{ij} \times \alpha_{ij} \quad (1-11)$$

Step 3: The ideal (H_j^+) and negative ideal (H_j^-) solutions are determined as:

$$H_j^+ = \{h_i^+ \dots h_n^+\} = [(max h_{ij} | i \in I'), (min h_{ij} | i \in I'')] \quad (1-12)$$

$$H_j^- = \{h_i^- \dots h_n^-\} = [(min h_{ij} | i \in I'), (max h_{ij} | i \in I'')] \quad (1-13)$$

Where I' is associated with advantage criteria, and I'' is associated with cost criteria.

Step 4: The separation measures (d_i^+ and d_i^-) are computed using the n- dimensional Euclidean distance for the alternatives as:

$$d_i^+ = \sqrt{\sum_{j=1}^n (h_{ij} - h_j^+)^2} \quad (1-14)$$

Where $i = 1, 2 \dots m$; h_j (in Equation 1- 14) = h_j^+

$$d_i^- = \sqrt{\sum_{j=1}^n (h_{ij} - h_j^-)^2} \quad (1-15)$$

Where $i = 1, 2 \dots m$; h_j (in Equation 1- 15) = h_j^-

Step 5: The relative closeness of the alternatives (R_j) to the ideal (R^*) solution is computed as:

$$P_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (1-16)$$

$$0 \leq P_i \leq 1$$

Where,

I' is associated with advantage criteria, and

I'' is associated with cost criteria.

Finally, the alternative acid- rain control options are ranked with respect to their relative closeness to the ideal solution in order of preference.

3.4 Sustainability criteria

The sustainability criteria's (economic, environmental, social, technical, institutional)and sub criteria adopted in this study include (Jiang et al 2009; Okeola and Sule 2012; Jaber and Mohsen 2001):cost effectiveness involves, investment, operation and maintenance cost, comprising of all cost of material or equipment purchase ,installation, employers wages, daily running expenses. Environmental competence implies, all knowledge or skill in the form of training etc., required and necessary for employees in effective management or control. Quality is the efficiency or pureness of removal of causative emissions via the control option chosen. Reliability, implies length of time control option/technology can last without failure under specified conditions, i.e. its ability to perform as designed. Vulnerability refers to the ease of exposure to spoil of the control option/measure. Availability consist of easily obtainable options/ measures. Green design is the considerations for proximity to dwelling areas, i.e. ease in enabling disassembling or recycling at end of technology life. Respect for policy refers to policy in terms of design and operation of preferred option vis-à-vis human and work place rights, such as whether they could lead to frequent court cases due to child labor, communal conflicts etc. Public health safety, this is imperative and emphasized to place checks on workers' health as regards injuries/accidents, diseases, hazards or even deaths, which ultimately adversely affects operating efficiency. Acceptability refers to the perception/reception of the locals/populace on selected option. Innovation is the uniqueness and extra value intrinsic to the region of the chosen control option, whilst pollution control is the effectiveness and preciseness of the option in reducing or eliminating the target pollutant emission. Operational efficiencies implies the amount of useful work/energy obtainable from the chosen option. Legal frame work translates to any existing or anticipated laws/regulations binding or linked/surrounding the selected control option. Maturity suggest the popularity at local, national or international levels or wide spread of the control option, i.e. whether it's only at a pilot scale level, laboratory scale, consolidated techniques/options etc.

4. Results and discussion

Data analysis was carried out using Microsoft EXCEL and MATLAB. Table 1- 7 shows the triangular fuzzy numbers for performance of acid- rain control options with respect to relevant sustainability factors for one of the experts.

Table 1- 7 Triangular Fuzzy Numbers of an Expert

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0,0,0.25)	(0, 0, 0.25)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.5)
GD	(0.50, 0.75, 1.00)	(0, 0, 0.25)	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.5, 0.75, 1)	(0, 0.25, 0.5)	(0, 0.25, 0.50)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
QI	(0, 0.25, 0.5)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0, 0.25, 0.50)	(0, 0.25, 0.50)	(0.75, 1, 1)
RFP	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0, 0.25, 0.5)
Acc	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.25, 0.5, 0.75)
EC	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0, 0, 0.25)
OE	(0, 0.25, 0.5)	(0, 0.25, 0.50)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)
PC	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1)
LF	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0, 0.25, 0.5)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)
Vu	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.5, 0.75)
MT	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0.25, 0.5, 0.75)
In	(0, 0, 0.25)	(0.50, 0.75, 1.00)	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0, 0.25, 0.5)
Re	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.25, 0.5, 0.75)
PH	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)
Av	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.50)	(0, 0.25, 0.5)	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.75, 1, 1)

(Please Note: GD is green design, QI is quality, RFP is respect for policy, Acc is acceptability, EC is environmental competencies, OE is operational efficiency, PC is pollution control, LF is legal framework, Vu is vulnerability, MT is maturity of control option, In is innovation, PH is public health, Av is availability).

The triangular fuzzy numbers of experts were normalized using CFCS process into crisp values as shown in Equations (1- 2), (1- 3), (1- 4) and (1- 5). Table 1- 8 shows the normalized triangular fuzzy numbers of an expert.

Table 1- 8 Normalized Triangular Fuzzy Numbers of an Expert

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	(0,0.7,1)	(0.66,1,1)	(0, 0.25, 0.5)	(0.33,0.66,1)	(0,0.7,1.7)	(1.7,1,1)	(0.25,0.4,1)	(0.5,1,1)	(0.25,0.4,1)	(0.33,0.66,1)
GD	(0.66,1,1)	(0,0.7,1.7)	(0.33,0.66,1)	(0,0.7,1)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(1.7,1,1)	(0.25,0.4,1)	(0.25,0.4,1)
QI	(0, 0.25, 0.5)	(0.33,0.66,1)	(0.25,0.4,1)	(0.7,1,1)	(0.33,0.66,1)	(0.33,0.66,1)	(0.7,1,1)	(0.5,1,1)	(0, 0.25, 0.5)	(1.7,1,1)
RFP	(0.66,1,1)	(0.25,0.4,1)	(0,0.7,1.7)	(0, 0.25, 0.5)	(0.33,0.66,1)	(0, 0.25, 0.5)	(1.7,1,1)	(0,0.7,1)	(0.33,0.66,1)	(0.25,0.4,1)
Acc	(0, 0.25, 0.5)	(0.66,1,1)	(0.25,0.4,1)	(0,0.7,1.7)	(0, 0.25, 0.5)	(0,0.7,1.7)	(0.5,1,1)	(0, 0.25, 0.5)	(0.33,0.66,1)	(0,0.7,1.7)
EC	(0,0.7,1)	(0,0.7,1.7)	(0.33,0.66,1)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0,0.7,1.7)	(0.25,0.4,1)	(0.25,0.4,1)	(0.66,1,1)	(0, 0.25, 0.5)
OE	(0.25,0.4,1)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0,0.7,1)	(0.7,1,1)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0.33,0.66,1)	(0, 0.25, 0.5)	(0.33,0.66,1)
PC	(0.33,0.66,1)	(0, 0.25, 0.5)	(0.66,1,1)	(0,0.7,1)	(0,0.7,1.7)	(0,0.7,1.7)	(0.25,0.4,1)	(0.7,1,1)	(0,0.7,1.7)	(0.25,0.4,1)
LF	(0, 0.25, 0.5)	(0.66,1,1)	(0.25,0.4,1)	(0.25,0.4,1)	(0.33,0.66,1)	(0.25,0.4,1)	(0.33,0.66,1)	(0.66,1,1)	(0.25,0.4,1)	(0.25,0.4,1)
Vu	(0,0.7,1.7)	(0,0.7,1)	(0.33,0.66,1)	(0, 0.25, 0.5)	(1.7,1,1)	(0, 0.25, 0.5)	(0,0.7,1)	(0.25,0.4,1)	(1.7,1,1)	(0.66,1,1)
MT	(0.5,1,1)	(0.25,0.4,1)	(0.25,0.4,1)	(0.25,0.4,1)	(0,0.7,1.7)	(0.5,1,1)	(0.25,0.4,1)	(0.33,0.66,1)	(0.7,1,1)	(0.25,0.4,1)
In	(0,0.7,1)	(0,0.7,1.7)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.66,1,1)	(0, 0.25, 0.5)	(0.7,1,1)	(0.25,0.4,1)	(0,0.7,1)
Re	(0.5,1,1)	(0.33,0.66,1)	(0,0.7,1.7)	(0.7,1,1)	(1.7,1,1)	(0.25,0.4,1)	(0.33,0.66,1)	(0,0.7,1)	(0.25,0.4,1)	(0, 0.25, 0.5)
PH	(0, 0.25, 0.5)	(0,0.7,1)	(0.5,1,1)	(0.5,1,1)	(0.25,0.4,1)	(0.7,1,1)	(0, 0.25, 0.5)	(0.7,1,1)	(0.25,0.4,1)	(1.7,1,1)
Av	(0.7,1,1)	(0.25,0.4,1)	(0,0.7,1)	(0, 0.25, 0.5)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0.25,0.4,1)	(0, 0.25, 0.5)	(0.33,0.66,1)	(0.25,0.4,1)

The left and right side normalized values were calculated using Equations (1- 6) and (1- 7) as shown in Table 1- 9.

Table 1- 9 Computed Right and Left Normalized Values of Triangular Fuzzy Numbers of an Expert

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	(0.3,0.2,0.5)	(0.2,1,0.5)	(0,0,0.7)	(0.2,1,0.55)	(0.8,1,1)	(0.7,0.3,0.4)	(0.2,0.3,0.9)	(0.42,0.3,0.4)	(0.5,0.7,1)	(0.2,1,0.5)
GD	(0.3,1,0.7)	(0.2,1,0.55)	(0.4,0.2,0.7)	(0.2,1,0.55)	(0,0,0.3)	(0.2,1,0.5)	(0.3,0.4,0.4)	(0.3,1,0.7)	(0.3,0.2,0.45)	(0.5,0.7,1)
QI	(0.2,1,0.5)	(0.3,0.2,0.45)	(0.3,0.4,0.4)	(0.3,1,0.7)	(0.5,0.7,1)	(0.3,0.2,0.5)	(0.4,0.2,0.6)	(0.4,0.2,1)	(0.3,0.24,0.4)	(0.3,1,0.7)
RFP	(0.3,0.4,0.4)	(0.3,0.2,0.45)	(0.2,0.3,0.9)	(0.8,1,1)	(0.3,0.2,0.72)	(0.7,1,0.7)	(0,0,0.3)	(0.2,0.3,0.49)	(0.7,0.3,0.4)	(0.2,1,0.5)
Acc	(0.8,1,1)	(0.5,0.7,1)	(0.4,0.2,1)	(0.42,0.3,0.4)	(0.3,1,0.7)	(0.4,0.2,1)	(0.3,0.2,0.45)	(0.33,0.2,0.4)	(0.2,1,0.55)	(0,0,0.7)
EC	(0.2,0.3,0.9)	(0.4,0.2,0.2)	(0.4,0.2,0.6)	(0,0,0.7)	(0.42,0.3,0.9)	(0.7,1,0.7)	(0,0,0.7)	(0.4,0.52,0.6)	(0,0,0.3)	(0.2,0.3,0.9)
OE	(0.5,0.7,1)	(0.42,0.3,0.49)	(0,0,0.3)	(0.3,0.2,0.5)	(0,0,0.7)	(0,0,0.7)	(0.2,1,0.5)	(0.34,0.42,0.2)	(0,0,0.7)	(0.4,0.2,1)
PC	(0.2,1,0.5)	(0,0,0.7)	(0.4,0.2,1)	(0.5,0.4,0.6)	(0.2,0.4,0.6)	(0,0,0.3)	(0.42,0.3,0.9)	(0.5,0.7,1)	(0.42,0.33,0.49)	(0.2,1,0.5)
LF	(0.3,0.4,0.4)	(0.4,0.52,0.6)	(0,0,0.3)	(0.2,1,0.55)	(0.4,0.52,0.6)	(0.2,0.3,0.49)	(0.7,0.33,0.4)	(0.4,0.3,0.4)	(0.3,0.2,0.45)	(0.2,1,0.5)
Vu	(0,0,0.3)	(0,0,0.7)	(0,0,0.7)	(0.8,1,1)	(0,0,0.3)	(0.7,0.33,0.4)	(0.2,1,0.5)	(0.8,1,1)	(0.33,0.24,0.4)	(0.3,0.4,0.4)
MT	(0.7,1,0.7)	(0.42,0.3,0.49)	(0.4,0.2,0.6)	(0.3,0.4,0.4)	(0.4,0.2,1)	(0.3,0.2,0.45)	(0.4,0.2,0.2)	(0.34,0.2,0.2)	(0.2,1,0.55)	(0.2,0.3,0.9)
In	(0.4,0.2,1)	(0.4,0.2,1)	(0.5,0.7,1)	(0.2,1,0.55)	(0.2,1,0.5)	(0.2,1,0.55)	(0.3,1,0.7)	(0.3,1,0.7)	(0,0,0.7)	(0.5,0.7,1)
Re	(0.2,1,0.55)	(0.4,0.52,0.6)	(0,0,0.7)	(0.3,1,0.7)	(0.3,0.24,0.4)	(0,0,0.7)	(0.2,1,0.5)	(0.4,0.2,0.6)	(0.2,1,0.55)	(0,0,0.7)
PH	(0.4,0.2,0.7)	(0,0,0.7)	(0,0,0.3)	(0.4,0.5,0.6)	(0,0,0.7)	(0.2,1,0.55)	(0.2,0.3,0.9)	(0.3,1,0.7)	(0.5,0.7,1)	(0.4,0.2,1)
Av	(0.7,0.3,0.4)	(0.2,1,0.5)	(0.7,0.3,0.4)	(0,0,0.7)	(0.4,0.2,0.6)	(0.5,0.7,1)	(0.4,0.2,1)	(0.7,0.3,0.4)	(0.5,0.7,1)	(0.4,0.2,0.6)

Table 1- 10 shows the normalized crisp values of an expert which was calculated using Equation (1- 8). The total normalized crisp values were calculated using Equation (1- 9). Then the crisp values were integrated using Equation (1- 10). The same process was employed to compute the total normalized crisp values of performances of acid- rain control options for all the experts.

Table 1- 10 Total Normalized Crisp Values of Fuzzy Numbers of an Expert

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	0.435	0.112	0.711	0.112	0.817	0.123	0.275	0.421	0.108	0.321
GD	0.234	0.455	0.445	0.504	0.988	0.466	0.896	0.907	0.421	0.217
QI	0.778	0.546	0.499	0.574	0.801	0.567	0.445	0.665	0.478	0.388
RFP	0.117	0.423	0.124	0.933	0.867	0.445	0.784	0.577	0.867	0.643
Acc	0.324	0.987	0.566	0.712	0.219	0.433	0.482	0.926	0.423	0.588
EC	0.554	0.675	0.775	0.922	0.346	0.422	0.577	0.439	0.788	0.344
OE	0.669	0.456	0.566	0.488	0.743	0.327	0.943	0.665	0.725	0.675
PC	0.125	0.889	0.574	0.334	0.556	0.456	0.392	0.284	0.629	0.427
LF	0.332	0.678	0.346	0.572	0.856	0.439	0.576	0.483	0.177	0.567
Vu	0.447	0.476	0.998	0.433	0.559	0.478	0.724	0.211	0.524	0.455
MT	0.322	0.334	0.914	0.975	0.453	0.548	0.293	0.472	0.425	0.566
In	0.341	0.997	0.234	0.843	0.667	0.588	0.419	0.384	0.348	0.112
Re	0.479	0.112	0.934	0.876	0.332	0.679	0.911	0.591	0.563	0.233
PH	0.664	0.774	0.234	0.716	0.119	0.685	0.543	0.432	0.645	0.456

Av	0.586	0.887	0.987	0.771	0.456	0.233	0.432	0.365	0.914	0.234
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A simple average method was then employed to estimate the average value for the performances of the various acid- rain control options with respect to sustainability factors. Table 1- 11 below shows the performances of the alternative acid- rain control options with regards specific sustainability criteria.

Table 1- 11 Performances of Acid- Rain Control Options with respect to Criteria

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	0.451	0.117	0.721	0.119	0.837	0.129	0.285	0.429	0.119	0.331
GD	0.232	0.465	0.449	0.514	0.978	0.476	0.891	0.927	0.419	0.237
QI	0.723	0.606	0.489	0.544	0.701	0.569	0.455	0.675	0.467	0.391
RFP	0.217	0.413	0.134	0.933	0.877	0.455	0.804	0.597	0.876	0.675
Acc	0.311	0.917	0.576	0.732	0.319	0.453	0.412	0.936	0.431	0.578
EC	0.514	0.671	0.785	0.922	0.463	0.492	0.587	0.499	0.778	0.354
OE	0.569	0.451	0.596	0.498	0.723	0.397	0.923	0.685	0.735	0.695
PC	0.135	0.859	0.554	0.334	0.565	0.496	0.399	0.304	0.629	0.437
LF	0.412	0.628	0.386	0.592	0.86	0.435	0.546	0.489	0.197	0.571
Vu	0.347	0.516	0.928	0.463	0.595	0.438	0.734	0.219	0.534	0.425
MT	0.302	0.314	0.904	0.985	0.457	0.558	0.297	0.47	0.452	0.571
In	0.361	0.897	0.284	0.893	0.669	0.588	0.439	0.39	0.345	0.119
Re	0.589	0.127	0.834	0.826	0.342	0.679	0.917	0.587	0.573	0.263
PH	0.564	0.779	0.134	0.736	0.129	0.685	0.549	0.435	0.647	0.465
Av	0.616	0.877	0.887	0.751	0.476	0.233	0.431	0.365	0.934	0.234

The performances of the various acid- rain control options were inputted in the TOPSIS model. The normalized decision matrix as shown in Table 1- 12 was calculated using the performances of the acid- rain control options and Equation (1- 10).

Table 1- 12 Normalized Decision Matrix of the Acid- Rain Control Options

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	0.544	0.701	0.334	0.597	0.675	0.675	0.345	0.419	0.734	0.804
GD	0.933	0.877	0.514	0.936	0.419	0.578	0.573	0.891	0.345	0.412
QI	0.732	0.319	0.489	0.499	0.391	0.354	0.647	0.455	0.573	0.587
RFP	0.922	0.463	0.455	0.685	0.675	0.695	0.804	0.804	0.546	0.923
Acc	0.311	0.723	0.453	0.304	0.578	0.437	0.412	0.412	0.734	0.399
EC	0.498	0.565	0.492	0.489	0.354	0.571	0.587	0.587	0.297	0.546
OE	0.592	0.86	0.397	0.219	0.695	0.425	0.923	0.685	0.263	0.695
PC	0.334	0.595	0.496	0.47	0.437	0.571	0.399	0.304	0.465	0.437
LF	0.463	0.457	0.435	0.39	0.571	0.119	0.546	0.489	0.549	0.571
Vu	0.985	0.669	0.438	0.587	0.425	0.498	0.734	0.219	0.546	0.425
MT	0.893	0.342	0.558	0.435	0.571	0.263	0.297	0.47	0.734	0.571
In	0.361	0.129	0.588	0.629	0.119	0.465	0.263	0.39	0.345	0.119
Re	0.826	0.476	0.679	0.197	0.263	0.571	0.465	0.587	0.573	0.263
PH	0.736	0.449	0.685	0.534	0.465	0.425	0.549	0.435	0.647	0.465
Av	0.751	0.489	0.233	0.452	0.234	0.571	0.431	0.365	0.923	0.234

Also, the weighted normalized decision matrix was computed using Equation (1- 11). Table 1- 13 shows the weighted normalized decision matrix of the various acid- rain control options.

Table 1- 13 Weighted Normalized Decision Matrix of Acid- Rain Control Options

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	0.544	0.701	0.334	0.597	0.675	0.675	0.345	0.419	0.734	0.804
GD	0.933	0.877	0.514	0.936	0.419	0.578	0.573	0.891	0.345	0.412
QI	0.732	0.319	0.489	0.499	0.391	0.354	0.647	0.455	0.573	0.587
RFP	0.922	0.463	0.455	0.685	0.675	0.695	0.804	0.804	0.546	0.923
Acc	0.311	0.723	0.453	0.304	0.578	0.437	0.412	0.412	0.734	0.399
EC	0.498	0.565	0.492	0.489	0.354	0.571	0.587	0.587	0.297	0.546
OE	0.592	0.86	0.397	0.219	0.695	0.425	0.923	0.685	0.263	0.695
PC	0.334	0.595	0.496	0.47	0.437	0.571	0.399	0.304	0.465	0.437
LF	0.463	0.457	0.435	0.39	0.571	0.119	0.546	0.489	0.549	0.571
Vu	0.985	0.669	0.438	0.587	0.425	0.498	0.734	0.219	0.546	0.425
MT	0.893	0.342	0.558	0.435	0.571	0.263	0.297	0.47	0.734	0.571
In	0.361	0.129	0.588	0.629	0.119	0.465	0.263	0.39	0.345	0.119
Re	0.826	0.476	0.679	0.197	0.263	0.571	0.465	0.587	0.573	0.263
PH	0.736	0.449	0.685	0.534	0.465	0.425	0.549	0.435	0.647	0.465
Av	0.751	0.489	0.233	0.452	0.234	0.571	0.431	0.365	0.923	0.234

The calculated average scores of weighted normalized decision matrix is shown on Table 1- 14. The positive and negative ideal solutions including were likewise computed using Equations (1- 12) and (1- 13).

Table 1- 14 Average Scores for the Weighted Normalized Decision Matrix

	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇	R ₈	R ₉	R ₁₀
Cost	0.654	0.821	0.343	0.48	0.695	0.661	0.367	0.423	0.754	0.571
GD	0.919	0.789	0.524	0.961	0.439	0.567	0.591	0.895	0.351	0.425
QI	0.852	0.523	0.491	0.509	0.401	0.363	0.663	0.475	0.603	0.571
RFP	0.945	0.643	0.545	0.691	0.715	0.671	0.779	0.798	0.566	0.119
Acc	0.611	0.913	0.415	0.324	0.628	0.439	0.403	0.445	0.773	0.498
EC	0.789	0.581	0.481	0.519	0.345	0.562	0.577	0.597	0.307	0.263
OE	0.782	0.816	0.497	0.232	0.695	0.441	0.931	0.695	0.261	0.465
PC	0.524	0.679	0.516	0.481	0.437	0.583	0.391	0.341	0.462	0.571
LF	0.643	0.657	0.466	0.387	0.571	0.129	0.561	0.489	0.545	0.425
Vu	0.895	0.679	0.483	0.579	0.425	0.477	0.723	0.223	0.541	0.571
MT	0.983	0.432	0.568	0.467	0.571	0.278	0.277	0.478	0.719	0.425
In	0.641	0.209	0.478	0.643	0.119	0.451	0.326	0.387	0.345	0.571
Re	0.876	0.351	0.769	0.207	0.263	0.598	0.441	0.579	0.571	0.119
PH	0.766	0.399	0.499	0.517	0.465	0.434	0.719	0.453	0.639	0.263

Av	0.563	0.498	0.314	0.425	0.124	0.578	0.411	0.353	0.919	0.465
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The positive and negative separation measures (d_i^+ and d_i^-) were calculated using the n-dimensional Euclidean distance for the alternative acid- rain control options in Equations (1- 14) & (1- 15). Finally, the relative closeness to the ideal solutions L_i (**TOPSIS index**) which is the total performance of the various acid- rain control options were computed using Equation (1- 16). The computed separation measures and relative closeness to the ideal solutions are shown in Table 1- 15.

Table 1- 15 Total Performances and Ranking of Alternative Acid- Rain Options

	d_i^+	d_i^-	$d_i^+ + d_i^-$	L_i	Ranking
R ₁ (Wash coal before use to reduce sulphur)	0.198	0.798	0.996	0.198	10
R ₂ (Quit gas flaring)	0.672	0.788	1.46	0.460	6
R ₃ (Campaign awareness of acid rain)	0.577	0.569	1.146	0.503	4
R ₄ (Use of NO _x burners)	0.721	0.674	1.395	0.516	3
R ₅ (Liming)	0.223	0.453	0.678	0.328	9
R ₆ (Solar as alternative energy source)	0.896	0.243	1.139	0.786	1
R ₇ (Conversion to natural gas plant)	0.456	0.549	1.005	0.453	7
R ₈ (Use of flue gas desulphurization)	0.566	0.713	1.279	0.442	8
R ₉ (Catalytic converters for vehicles-exhaust)	0.563	0.597	1.16	0.485	5
R ₁₀ (Hydro as alternative energy source)	0.766	0.432	1.198	0.639	2

From the results shown on Table 1- 15, the acid- rain control option that has the highest performance with respect to relevant sustainability factors is R₆ (Using solar as alternative energy source). Thus, the best sustainable acid- rain control option is R₆ (Using solar as alternative energy source). The second best sustainable acid- rain control option is R₁₀ (Using hydro as an alternative energy source). The third best sustainable acid- rain control option is R₄ (Use of NO_x burners). However, the least sustainable acid- rain control option is R₁ (Wash coal before use to reduce sulphur).

4.1 Acid rain deposition trend in Nigeria

Acid rain and gas flaring are two synonymous terms peculiar to the Niger delta of Nigeria, which represents the core area of crude oil exploratory activities. (Efe 2010b and 2011) reported the spatial variation of acid rain in the country as having an average PH of 5.3 increasing with about 0.5 northwards from the coast of Nigeria, most of which has been attributed to gas flaring (Ezenwaji et.al 2013, Anomohanran 2012, Edino et.al 2010, Ogunkoya and Efe 2003, Rim-Rukeh et.al 2005). It is worthy of mention that Nigeria ranks 2nd after Russia in gas flaring and 61st of 141 in the world of Nox emissions. Arguments however exist among major stakeholders, Shell Company especially, as to the major cause of acidic depositions in the country.

Figure 1 typically depicts the pattern of rain water acidity within the country (Efe 2011). Acid rain increasing with increased flares, i.e. the year with highest flares records the least rain

water PH. Figure 2 reveals the degree and influence of power plants concentration in the six geopolitical zones of the country. There is a clear concentration of power plants in the Niger delta region, i.e. South South (SS), with about 60% of the Nigerian independent power plants (NIPP) located in this region. (Adekomoya et.al 2016) established strong linkages between gas flaring and its impacts on energy growth and sustainability, attributing slow/poor growth to gas flared, especially since Nigeria's power sector(now switching to natural gas plants) currently depends largely on natural gas. Currently However, power supply is erratic and is generated mostly from thermal power stations about 60%, hydro 30%(Tallapragada, 2009), causing majority of the populace to rely on electricity generators, which further contributes to Nox emissions. Of all the power plants only 2(5.7%) have installed in them pollution control devices (Low Nox burners) one in the SS and the other in the south east (SE), belonging to a group of oil producing companies, and NIPP respectively. Most oil producing companies also do not have these abatement devices for controlling Nox and So₂ installed in their production facilities as their primary concerns is basically in the control of co₂ emissions since the Nigerian crude is considered sweet(i.e. free of So₂). Moreover, although switching to natural gas plants reduces significantly the amount of So₂ emissions as compared to either coal or thermal plants, its performance is decidedly more mixed in the area of Nox emissions, another major cause of acid rain. Figure 2 also reflects the lowest mean rain water PH of 4.98 to exist in the SS having the largest number of power plants, followed by the SE and SW with 5.26, and 5.29 with 3 and 4 power plants respectively. Although the NC has 6 power plants it has a mean rain water PH of 5.46, this is likely because three of this plants are hydro and 1 coal. NE, and NW have the highest rain water PH, and lowest number of power plants, having 1 and 2 respectively, all of which are still planned. The model results demonstrates therefore, a logically satisfactory outcome for possible appropriate control measures in abating the acid rain phenomena. Solar emerging topmost, appears reasonable especially since there is availability of the resource. Although usually involving high initial cost, as reflected in table 14 where the sustainability criteria of delicate importance for the topmost ranked option were RFP, cost, RE,PC,AV respectively, it is recognized as a viable option utilized in some parts of the world, and even in some parts of western Nigeria. On the other spectrum, delicate criteria for the least ranked option were MT, RFP, GD, VU, RE. It's also obvious from the average values on table 14 that the social factor is a reasonably favored criteria. Hydro and use of Nox burners, ranked second and third respectively.

Fig 1. Gas flared estimates in Nigeria and temporal spatial variation of mean rain water PH

Fig 2. Variation of acid rain with existing power plants in Nigeria

5. Conclusion

As long as rain falls and development continues acid rain debates would remain a contemporary issue. A wide range of acid rain control measures, consolidated and otherwise exist, depending on exact or contributory cause of acidic deposition, level/degree of exposure/vulnerability, climatic conditions, terrain, awareness and level of technological development. A key to achieving sustainability in abating acid rain which in most cases is intrinsic to societies, and hence requiring a soft path approach, borders around relevant stakeholder participation in the decision taking. we have thus in this study, considering the peculiarities of Nigeria as a major developing and oil producing nation, conducted an explicit and apt analysis employing fuzzy TOPSIS with linguistic scales to solicit expert opinions, whilst utilizing the CFCS method to rank acid rain control options such as FGD, catalytic converters, alternative energy sources like solar, and hydro, switch to natural gas fuel, coal washing, quitting gas flaring and increased awareness campaign on acidic deposition under economic, environmental, social, technical and institutional factors. Results obtained are satisfactory logically, with solar as an alternative energy source emerging topmost since there is good potential and indeed availability of the resource in the country. Use of Nox burners ranking third also demonstrates consistency with facts that Nigerian crude oil is sweet, hence relatively free of SO₂ and corroborates revelations on the studies of Ezenwaji et.al 2013, i.e identifying high concentrations of nitric acid in rain water in the Niger delta. Thus curbing acid rain phenomenon in the country would mean aligning efforts along these paths. Implications are also suggestive of policy makers and planners to place more consideration on investing adequately in solar power, beyond the aggressive clamor for total elimination of gas flaring as has been the case over the years. The method applied here is concise, superior and easily applicable for decision support among elites in prioritizing alternative options in varied endeavors.

Acknowledgement

The unprecedented support from the Onu's foundation is highly appreciated.

Competing interest

Authors declare no competing interest

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Fig 1. Map of Nigeria showing the study region

Fig 2. Fuzzy- TOPSIS based model for sustainable Ranking of Acid- rain Control Options

Fig 3. Gas flared estimates in Nigeria and temporal spatial variation of mean rain water pH

Fig 4. Variation of acid rain with existing power plants in Nigeria

Fig 5. Ranking order of sustainable acid rain control options

Fig 6a. Degree of importance for sustainability factors

Figure

Fig 6b. Degree of importance of sustainability criteria