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Fuzzy Risk-Based Life Cycle Assessment for Estimating Environmental Aspects in EMS

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***Abstract*—**Environmental aspects plays a central role in environmental management system (EMS) because it is the basis for the identification of an organization's environmental targets. The existing methods for the assessment of environmental aspects are grouped into three categories: risk assessment-based (RA-based), LCA-based and criterion-based methods. To combine the benefits of these three categories of research, this study proposes an integrated framework, combining RA-, LCA- and criterion-based methods. The integrated framework incorporates LCA techniques for the identification of the causal linkage for aspect, pathway, receptor and impact, uses fuzzy logic to assess aspects, considers fuzzy conditions, in likelihood assessment, and employs a new multi-criteria decision analysis method - multi-criteria and multi-connection comprehensive assessment (MMCA) - to estimate significant aspects in EMS. The proposed model is verified, using a real case study and the results show that this method successfully prioritizes the environmental aspects..

***Keywords*—**Environmental management system, environmental aspect, risk assessment, life cycle assessment.

I. Introduction

ENVIRONMENTAL management system (EMS) is used by an organization to develop and implement its environmental policy and to manage its environmental aspects. An environmental aspect is defined as an element of an organization's activities, or products, or services that can interact with the environment; an environmental impact is defined as any change to the environment, whether adverse or beneficial, wholly or partially resulting from environmental aspects (ISO 14001: 2004). An environmental aspect is considered to be significant, when it has, or can have, a significant environmental impact. The key to a successful EMS is the proper identification and evaluation of environmental aspects and their potential impacts, because the most significant environmental aspects play a crucial role in the formulation of effective environmental policy, in terms of the definition of objectives and targets, therein providing the basis for the entire EMS [1]. However, EMS does not provide a method for the assessment of environmental aspects, only some general guidelines. The methodological issues associated with the evaluation of aspects have been largely overlooked [1].

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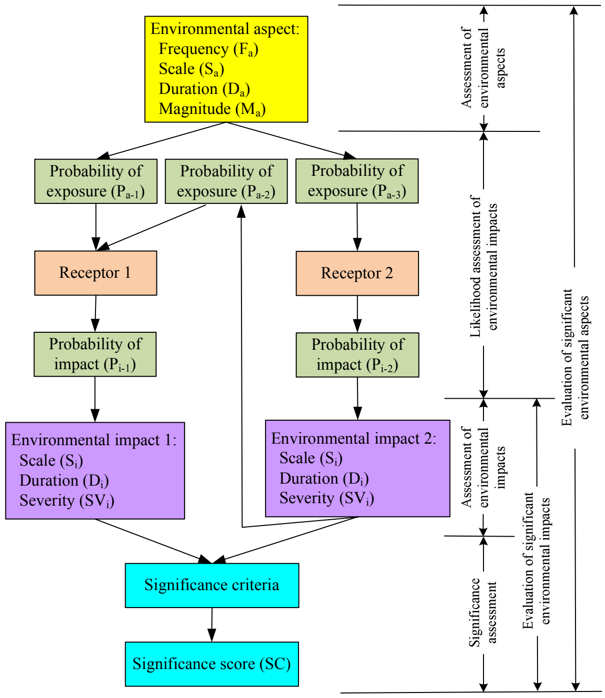

Fig. 1 Overview of the assessment of significant environmental aspects

An overview of the assessment of significant environmental aspects is illustrated in Fig. 1.The critical elements are aspects, exposure pathways, receptors and impacts. Receptors are considered, because impacts vary, according to different receptors and further investigation of the impact is not required, if no receptor or pathway exists. The causal linkage for aspect-pathway-receptor-impact can be identified through methods such as causal network analysis [2], or life cycle assessment (LCA), etc. It should be noted that an environmental aspect may cause several impacts and, sometimes, one impact can induce another. Once the cause-effect relationships are identified, a four-stage assessment is proposed, as follows (see Fig. 1). Firstly, the assessment of an environmental aspect includes its frequency, scale, duration, magnitude, etc. Secondly, the likelihood assessment of an environmental impact has two components: the probability of a receptor being exposed to the aspect and the probability of an impact resulting from exposure to the aspect. Thirdly, an environmental impact is assessed based on its scale, duration, severity, etc. Fourthly, the significance assessment covers the selection of significance criteria and the prioritization of environmental aspects/impacts, according to those criteria. Related work on the assessment of environmental aspects in EMS can be divided into three categories.

The first category employs risk assessment-based methods, to estimate the values of the frequencies or probabilities, scales, durations and severities of environmental aspects/impacts. Most researchers in this category use the multiplication of these values as the scoring method for the identification of significant aspects/impacts. These studies use risk assessment (RA), which can accurately identify abnormal, or accidental aspects, as well as the probabilistic causality of aspect, pathway, receptor and impact relationships. However, when evaluating the severity of an environmental impact, most lack a sound theoretical basis and tend to be over-subjective.

Another category of research advocates enhancing the theoretical foundation for the assessment of the severity of environmental impacts, by utilizing LCA-based methods. Although these LCA-based methods can provide global and regional scales for environmental impact, they cannot adequately represent abnormal, or accidental aspects and the probabilistic aspect-pathway-receptor-impacts relationships. The third category puts emphasis on significance criteria, such as socioeconomic factors, legal requirements, cleaner production opportunities, control of aspects and the concerns of interested parties. Although they consider more factors in determining significant aspects/impacts, their scoring methods do not use a more sophisticated decision theory, such as multi-criteria decision analysis (MCDA), but use simple addition, multiplication, or linear combination.

This study combines the benefits of the three categories of research by integrating RA-, LCA- and MCDA-based methods, to identify the probabilistic causality of aspect, pathway, receptor and impact relationships, to enhance the theoretical foundation and to strengthen decision-making. This integrated framework incorporates LCA techniques for the identification of the causal linkage for aspect-pathway-receptor-impact, uses fuzzy logic for the assessment of aspects, considers fuzzy conditions, in likelihood assessment, and employs a new MCDA method - multi-criteria and multi-connection comprehensive assessment (MMCA) - to estimate the significant aspects in EMS. Finally, a small waste recycling factory and a large plastics factory are as case studies, in order to demonstrate the use of the method.

II. Material and Methods

The integrated framework, combining RA-, LCA- and MCDA-based methods, comprises the following steps: (1) incorporating the LCA concept for the identification of the causal linkage of aspect-pathway-receptor-impact, (2) using fuzzy logic for assessing the severity of environmental aspects, (3) applying a severity ratio, to compare with standard values, (4) estimating the probability of the receptors being exposed to an aspect, (5) evaluating the probability of an impact being exposed an aspect, (6) using the vertex method to compute the risk of the impact and (7) employing the multi-criteria and multi-connection comprehensive assessment (MMCA) to establish significance criteria and prioritize environmental aspects, accordingly.

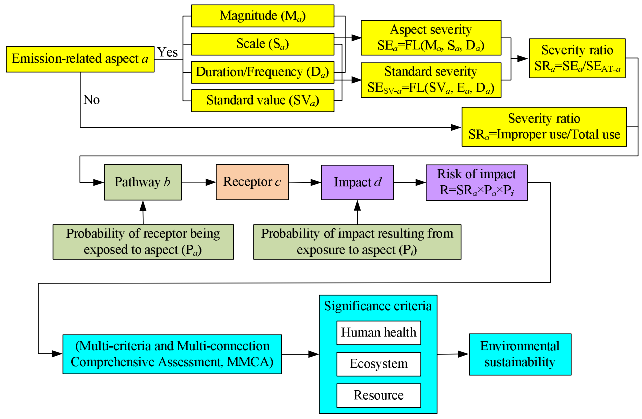

Fig. 2 Integrated framework

A. Study Area

A large plastics factory, established in 1958, covers approximately 178.9 hectares of an industrial zone of Yunlin County, Taiwan. It is the world's largest plastics processing factory, generating plastic products, petrochemical raw materials, electronic materials, polyester fiber products, etc. Its major air pollutants are SO_X, NO_X, VOCs, CO, TSP and noise and the primary water pollutants in the treated wastewater are BOD and PO_4^{3-}. The emissions of SO_X, NO_X, VOCs, CO and TSP are, respectively, 838.6 tons, 886.4 tons, 291.2 tons, 3,047.9 ton and 272.5 tons per year. This results in concentrations in emission pipes of 54.35 ppm, 48.09 ppm, 46.48 ppm, 432.31 ppm and 29.59 mg/m3, respectively. Noise is 65.80 dB(A) and the treated wastewater is discharged into the sea, at the rate of 187,638 CMD, with legal concentrations of BOD and PO_4^{3-} (30 and 4 mg/L). The details of the environmental aspects are listed in TABLE I.

TABLE I
Environmental Aspects For A Large Plastics Factor

Environmental aspect	Magnitude	Unit
Emission of NO_X	48.09	ppm
Emission of TSP	29.59	mg/m^3
Emission of SO_X	54.35	ppm
Emission of VOCs	46.48	ppm
Generation of noise	65.80	dB(A)
Emission of CO	432.31	ppm
Emission of PO_4^{3-}	4.00	mg/L
Emission of BOD	30.00	mg/L

A. Incorporating the LCA concept, to identify aspect-pathway-receptor-impact

The starting point for the evaluation of the significance of an environmental aspect is to identify the possible exposure pathways (midpoint effects) and the subsequent impacts (endpoint effects), caused by the environmental aspect, and thereby to determine the importance of the impacts. Existing LCA methods provide such a basis for the identification of the cause-effect relationship between aspects, exposure pathways, receptors and impacts.

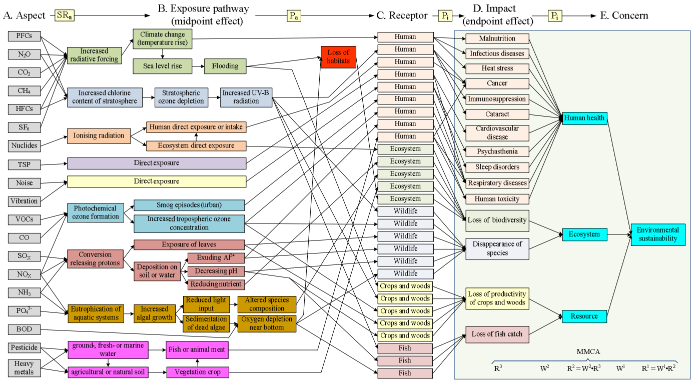

Fig. 3 Overview of the causal relationships between aspects, pathways, receptors and possible impacts

B. Using fuzzy logic for aspect assessment

The severity of an environmental aspect (SE_a) is determined by its magnitude (M_a), scale (S_a) and duration (D_a). The magnitude of an environmental aspect refers to the concentration of a pollution source, usually measured in ppm, mg/L, or mg/m3. The geographical scale is expressed as the area where the concentration at any point is higher than one-third of its magnitude (M_a). The temporal factor is measured by the duration of the emission of the pollution, within one year.

Appraising the severity of an environmental aspect can be a subjective decision-making process and is performed using fuzzy logic [3], in this study. Fuzzy logic can be thought of as a tool with the ability to compute with words, when modeling qualitative human thought processes, in the analysis of complex systems and decisions. Fuzzy logic uses qualitative perception-based reasoning, represented by "IF-THEN" fuzzy rules. To evaluate the severity of environmental aspects, 19 rule bases, containing 513 fuzzy rules, were produced. These 19 rule bases and their corresponding membership functions were constructed, based on expertise, and the fuzzy inference systems were implemented with MATLAB Fuzzy Logic Toolbox.

C. Applying severity ratio to compare with standard values

To better interpret the outputs of fuzzy logic, all outputs are divided by the severities derived from their respective standard values, to become the severity ratios (SR_a). The severities of environmental aspects that reach standard values, which can be viewed as thresholds, are therefore designated as 100.0; other severity ratios are the proportions compared with the standard values.

D. Evaluating the probability of the receptors being exposed to an aspect

Further investigation is not required, if no actual, or potential pathway exists, between an environmental aspect and the receptor [4]. For example, heavy metal contamination of soil does not pose a risk to humans, if there are no residents near the site. Evaluating the probability of a receptor being exposed to a midpoint effect (P_a), caused by an aspect, can result in a precise number, or a probability distribution, if sufficient information is available. Otherwise, it can be assigned through expertise, or experience, which is usually fuzzy and expressed as a possibility distribution [3].

E. Assessing the probability of an impact resulting from exposure to an aspect

T The probability of an impact (endpoint effect) resulting from exposure to an aspect (P_i) is related to the percentage of humans, ecosystems, crops and woods, wildlife, or fish production that sustains an impact, when exposed to an aspect. Even if exposed to the same midpoint effect, the likelihood of the impact is probabilistic and relies on the likely susceptibility of an individual receptor to the effect. Assessing P_i represents an extremely complicated task, which is plagued by uncertainty, because the relevant knowledge of toxicology, epidemiology and ecology is still incomplete. Therefore, it is represented as a precise number, or a probability distribution, once the relevant knowledge is available; otherwise, it can be assigned, subjectively, through expertise, or experience.

TABLE II
PROBABILITIES OF RECEPTORS BEING EXPOSED TO ASPECTS (Pa) AND THE PROBABILITIES OF IMPACTS RESULTING FROM EXPOSURE TO ASPECTS (Pi)

Receptor	Pathway	P_a	Impact	P_i
Human	Climate change	(0.5, 0.8, 1.0)	Malnutrition	(0.0, 0.1, 0.2)
			Infectious diseases	(0.2, 0.3, 0.4)
			Heat stress	(0.2, 0.3, 0.4)
	Ozone depletion	(0.3, 0.6, 0.9)	Cancer	(0.2, 0.3, 0.4)
			Immunosuppression	(0.1, 0.2, 0.3)
			Cataract	(0.0, 0.1, 0.2)
	Ionising radiation	(0.1,0.3,0.5)	Cancer	(0.6, 0.7, 0.8)
	TSP (direct effect)	(0.6,0.9,1.0)	Cardiovascular disease	(0.0, 0.1, 0.2)
			Respiratory diseases	(0.3, 0.5, 0.7)
	Noise & Vibration (direct effect)	(0.2, 0.5, 0.8)	Psychasthenia	(0.1, 0.3, 0.5)
			Sleep disorders	(0.1, 0.3, 0.5)
	Photochemical smog	(0.3, 0.6, 0.9)	Respiratory diseases	(0.1, 0.3, 0.5)
	Increased tropospheric ozone concentration	(0.4, 0.7, 1.0)	Respiratory diseases	(0.2, 0.4, 0.6)
	Acidification	(0.5, 0.8, 1.0)	Human toxicity	(0.0, 0.1, 0.2)
	Ecotoxicity	(0.3, 0.6, 0.9)	Human toxicity	(0.1, 0.2, 0.3)
			Cancer	(0.1, 0.2, 0.3)
Ecosystem	Climate change	(0.5, 0.8, 1.0)	Loss of biodiversity	(0.1, 0.2, 0.3)
	Ionising radiation	(0.0, 0.2, 0.4)	Loss of biodiversity	(0.4, 0.7, 1.0)
	Acidification	(0.4, 0.7, 1.0)	Loss of biodiversity	(0.0, 0.1, 0.2)
	Eutrophication	(0.3, 0.6, 0.9)	Loss of biodiversity	(0.0, 0.2, 0.4)
	Ecotoxicity	(0.3, 0.6, 0.9)	Loss of biodiversity	(0.1, 0.3, 0.5)
Crops and woods	Climate change	(0.5, 0.8, 1.0)	Loss of productivity of crops and woods	(0.1, 0.3, 0.5)
	Ozone depletion	(0.3, 0.6, 0.9)	Loss of productivity of crops and woods	(0.0, 0.2, 0.4)
	Increased tropospheric ozone concentration	(0.1, 0.4, 0.7)	Loss of productivity of crops and woods	(0.1, 0.3, 0.5)
	Acidification	(0.4, 0.7, 1.0)	Loss of productivity of crops and woods	(0.2, 0.4, 0.6)
Wildlife	Ozone depletion	(0.1, 0.4, 0.7)	Disappearance of species	(0.0, 0.1, 0.2)
	Increased tropospheric ozone concentration	(0.5, 0.8, 1.0)	Disappearance of species	(0.1, 0.3, 0.5)
	Acidification	(0.4, 0.7, 1.0)	Disappearance of species	(0.0, 0.2, 0.4)
	Eutrophication	(0.2, 0.5, 0.8)	Disappearance of species	(0.0, 0.2, 0.4)
Fish production	Ozone depletion	(0.5, 0.8, 1.0)	Loss of fish catch	(0.0, 0.2, 0.4)
	Acidification	(0.5, 0.8, 1.0)	Loss of fish catch	(0.0, 0.1, 0.2)
	Eutrophication	(0.4, 0.7, 1.0)	Loss of fish catch	(0.0, 0.2, 0.4)

F. Using the vertex method to compute risk of an impact

The vertex method was proposed by Dong and Shah [5], to compute functions of fuzzy variables, and is applied, herein, to obtain R. The vertex method is based on the α-cut technique, from fuzzy set theory, and the interval analysis. Using α-cut, each fuzzy variable characterized by a convex membership function is converted into a group of intervals associated with various α-values. Intervals with the same α-value, from all fuzzy variables, are processed by interval analysis. This results in an interval function, with the α-value.

G. Evaluating the significance of a risk

Whether a risk is significant depends on the degree of human concern about the risk. This study proposes a new MCDA method, the multi-criteria and multi-connection comprehensive assessment (MMCA), to evaluate the significance of a risk, according to these concerns.

III. Results and discussion

A. Results

The severities of all environmental aspects (SE_a) are listed in the second to fourth columns of Table III and their severity ratios (SR_a) are summarized in the last column of the table. The results of SE_a show that the emissions of PO_4^{3-} and BOD and the noise, singly underlined in Table III, are very high, because their magnitudes are very close to the standard values. The impacts of the environmental aspects are summarized in the second column of Table IV.

TABLE III
EVALUATIONS OF THE SEVERITY OF ENVIRONMENTAL ASPECTS, FOR A LARGE PLASTICS FACTORY

Environmental aspect	M_a	S_a(km^2)	D_a(yr)	SE_a	SE_{SV}	SR_a
Emission of NO_X	48.09 (ppm)	12.56	1.00	27.20	70.8	38.42[6]
Emission of TSP	29.59 (mg/m^3)	12.56	1.00	19.80	70.8	27.97[8]
Emission of SO_X	54.35 (ppm)	12.56	1.00	21.20	70.8	29.94[7]
Emission of VOCs	46.48 (ppm)	12.56	1.00	42.30	70.8	59.75[4]
Generation of noise	65.80 (dB(A))	0.01	1.00	62.80	70.8	88.70[3]
Emission of CO	432.31 (ppm)	12.56	1.00	28.60	70.8	40.40[5]
Emission of PO_4^{3-}	4.00 (mg/L)	2.01	1.00	64.30	68.7	93.60[1]
Emission of BOD	30.00 (mg/L)	2.01	1.00	63.30	67.7	93.50[2]

Note: Superscript denotes the sequence order.

Their vectorized risks, R_i^3, together with their defuzzification, d(R_i^3), are listed in the last two columns of the table. It can be seen that the disappearance of species, due to “emission of BOD”, respiratory diseases, caused by “emission of NOX”, and respiratory diseases, caused by “emission of CO”, all singly underlined in Table IV, are the top three impacts. The concerns caused by environmental aspects are summarized in the second column of TABLE V and their vectorized risks, R_i^2, together with their defuzzification, d(R_i^2), are listed in the last two columns of the table. According to the results for R_i^2, the principle concern is damage to human health, caused by “emission of CO”, the second most important concern is damage to the ecosystem, caused by “emission of BOD”, and the third most important concern is damage to human health, caused by “emission of VOCs”, all of which are singly underlined in Table V. The final values for environmental sustainability, as shown in Table V, indicate that “emission of BOD,” “generation of noise” and “emission of PO_4^{3-}”, which are all singly underlined in Table VI, are the environmental aspects in most urgent need of improvement.

TABLE IV
RISK EVALUATIONS FOR THE ENVIRONMENTAL IMPACTS, FOR A LARGE PLASTICS FACTORY

Environmental aspect	Impact	Vectorized risk of impact R_i^3	d
Emission of NO_X	Respiratory diseases	[0.69 0.60 0.35 0.00 0.00]	2.11[2]
	Human toxicity	[0.89 0.27 0.00 0.00 0.00]	1.61[22]
	Loss of biodiversity	[0.84 0.41 0.15 0.00 0.00]	1.89[11]
	Disappearance of species	[0.76 0.50 0.00 0.00 0.00]	1.73[17]
	Loss of productivity of crops and woods	[0.72 0.54 0.00 0.00 0.00]	1.75[15]
Emission of TSP	Respiratory diseases	[0.63 0.64 0.00 0.00 0.00]	1.80[13]
Emission of SO_X	Human toxicity	[0.92 0.22 0.00 0.00 0.00]	1.57[23]
	Loss of biodiversity	[0.93 0.18 0.00 0.00 0.00]	1.54[25]
	Disappearance of species	[0.80 0.52 0.00 0.00 0.00]	1.63[21]
	Loss of productivity of crops and woods	[0.68 0.65 0.04 0.00 0.00]	1.71[18]
	Loss of fish catch	[0.91 0.26 0.00 0.00 0.00]	1.55[24]
Emission of VOCs	Respiratory diseases	[0.44 0.95 0.60 0.19 0.00]	2.05[4]
	Disappearance of species	[0.67 0.67 0.07 0.00 0.00]	1.88[12]
	Loss of productivity of crops and woods	[0.82 0.46 0.00 0.00 0.00]	1.71[18]
Generation of noise	Sleep disorders	[0.67 0.73 0.20 0.00 0.00]	2.01[5]
	Psychasthenia	[0.67 0.73 0.20 0.00 0.00]	2.01[5]
Emission of CO	Respiratory diseases	[0.56 0.86 0.34 0.00 0.00]	2.10[3]
	Disappearance of species	[0.75 0.52 0.00 0.00 0.00]	1.74[16]
	Loss of productivity of crops and woods	[0.87 0.35 0.00 0.00 0.00]	1.66[20]
Emission of PO_4^{3-}	Disappearance of species	[0.78 0.57 0.01 0.00 0.00]	1.78[14]
	Loss of fish catch	[0.72 0.67 0.13 0.00 0.00]	1.93[9]
	Loss of biodiversity	[0.69 0.72 0.19 0.00 0.00]	1.99[7]
Emission of BOD	Loss of biodiversity	[0.69 0.71 0.18 0.00 0.00]	1.98[8]
	Disappearance of species	[0.79 0.57 0.41 0.00 0.00]	2.14[1]
	Loss of fish catch	[0.72 0.67 0.13 0.00 0.00]	1.92[10]

Note: Superscript denotes the sequence order.

B. Discussion

In the case study, two life cycle impact assessment models; “Eco-indicator 99 (Goedkoop and Spriensma, 2001)” and “IMPACT 2002+ (Jollie et al., 2003)”, were used to evaluate the environmental aspects. The results show a different order for the environmental aspects than that obtained by this study, as shown in the last two columns of TABLE VI. The emission of NO_x is now found to be the most important aspect, followed by “emissions of SO_x and CO”. Both are doubly underlined in TABLE VI. However, the top three aspects identified by this study - the emissions of PO_4^{3-}, the generation of noise and the emission of BOD - cannot be evaluated accurately, using the two LCA methods. Furthermore, the two LCA methods cannot adequately determine the probabilities of the receptors being exposed to the aspects (P_a) and the probabilities of the impacts that result from exposure to the aspects (P_i)

TABLE V
RISK EVALUATIONS FOR CONCERNS, FOR A LARGE PLASTICS FACTORY

Environmental aspect	Concern	Vectorized risk of impact R_i^2	d
Emission of NO_X	Human health	[0.17 0.09 0.04 0.00 0.00]	1.92[5]
	Ecosystem	[0.80 0.45 0.08 0.00 0.00]	1.82[10]
	Resource	[0.79 0.46 0.00 0.00 0.00]	1.71[12]
Emission of TSP	Human health	[0.16 0.10 0.00 0.00 0.00]	1.69[13]
	Ecosystem	[0.00 0.00 0.00 0.00 0.00]	0.00
	Resource	[0.00 0.00 0.00 0.00 0.00]	0.00
Emission of SO_X	Human health	[0.09 0.02 0.00 0.00 0.00]	1.55[18]
	Ecosystem	[0.91 0.24 0.00 0.00 0.00]	1.59[17]
	Resource	[0.85 0.32 0.00 0.00 0.00]	1.64[15]
Emission of VOCs	Human health	[0.06 0.09 0.03 0.00 0.00]	2.03[3]
	Ecosystem	[0.32 0.32 0.03 0.00 0.00]	1.86[9]
	Resource	[0.42 0.24 0.00 0.00 0.00]	1.69[13]
Generation of noise	Human health	[0.11 0.12 0.03 0.00 0.00]	1.99[4]
	Ecosystem	[0.00 0.00 0.00 0.00 0.00]	0.00
	Resource	[0.00 0.00 0.00 0.00 0.00]	0.00
Emission of CO	Human health	[0.08 0.07 0.04 0.00 0.00]	2.09[1]
	Ecosystem	[0.36 0.25 0.00 0.00 0.00]	1.72[11]
	Resource	[0.44 0.18 0.00 0.00 0.00]	1.64[15]
Emission of PO_4^{3-}	Human health	[0.00 0.00 0.00 0.00 0.00]	0.00
	Ecosystem	[0.73 0.65 0.10 0.00 0.00]	1.90[7]
	Resource	[0.35 0.33 0.07 0.00 0.00]	1.91[6]
Emission of BOD	Human health	[0.00 0.00 0.00 0.00 0.00]	0.00
	Ecosystem	[0.74 0.64 0.29 0.00 0.00]	2.06[2]
	Resource	[0.35 0.33 0.06 0.00 0.00]	1.90[7]

Note: Superscript denotes the sequence order.

TABLE VI
RISK EVALUATION FOR ENVIRONMENTAL SUSTAINABILITY, FOR A LARGE PLASTICS FACTORY

Environmental aspect	Vectorized risk of impact R^1	d	LCA-1	LCA-2
Emission of NO_X	[0.59 0.34 0.04 0.00 0.00]	1.78[5]	202,6708[1]	11,505[1]
Emission of TSP	[0.05 0.03 0.00 0.00 0.00]	1.69[7]	0	4226[4]
Emission of SO_X	[0.62 0.20 0.00 0.00 0.00]	1.60[8]	971,530[2]	6,504[2]
Emission of VOCs	[0.27 0.22 0.02 0.00 0.00]	1.81[4]	3651[4]	27[5]
Generation of noise	[0.04 0.04 0.01 0.00 0.00]	1.99[2]	--	--
Emission of CO	[0.29 0.17 0.01 0.00 0.00]	1.74[6]	62,295[3]	797[3]
Emission of PO_4^{3-}	[0.37 0.33 0.06 0.00 0.00]	1.89[3]	0	0
Emission of BOD	[0.37 0.33 0.12 0.00 0.00]	2.00[1]	0	0

Note: LCA-1: Eco-indicator 99 (Unit: Pt); LCA-2: IMPACT 2002+ (Unit: Pt); superscript denotes the sequence order.

IV. CONCLUSIONS

This study proposed an integrated tool, combining RA, LCA and MMCA, in order to determine the probabilistic causality of the aspect-pathway-receptor-impact relationships, to enhance the theoretical foundation and to strengthen decision-making, when assessing environmental aspects for an EMS, via the following steps: incorporation of the LCA concept for the identification of aspect-pathway-receptor-impact relationships, use of fuzzy logic for aspect assessment, use of a severity ratio, for comparison with standard values, evaluation of the probability of a receptor being exposed to a midpoint effect, assessment of the probability of an impact resulting from exposure to the aspect, use of the vertex method, to compute the risk of the impact, and evaluation of the significance of the risk, through multi-criteria and multi-connection comprehensive assessment (MMCA). The proposed model was also verified, using a real case studies, a large plastics factory. The results showed that the proposed method successfully prioritizes the environmental aspects, on a more solid theoretical basis. This study encountered two difficulties and further work is still required, to overcome these. The first was the determination of the probabilities of midpoint effects (e.g. climate change), resulting from environmental aspects (e.g. CO2 emission). This type of probability was neglected in this study, because some of them are still subject to scientific debate. The second difficulty was in gathering sufficient epidemiological studies to allow accurate determination of the probability of an impact resulting from exposure to an aspect. Subjective judgment was used, when assigning probabilities to these impacts.

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