Introducing A Conditional ‘Willingness To Pay’ Index As A Quantifier For Environmental Impact Assessment

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Abstract. The optimal concentration C_{opt} of a pollutant in the environment can be determined as an equilibrium point in the trade off between (i) environmental cost, due to impact on man/ecosystem/economy, and (ii) economic cost for environmental protection, as it can be expressed by Pigouvian tax. These two conflict variables are internalized within the same techno-economic objective function of total cost, which is minimized. In this work, the first conflict variable is represented by a Willingness To Pay (WTP) index. A methodology is developed for the estimation of this index by using fuzzy sets to count for uncertainty. Implementation of this methodology is presented, concerning odor pollution of air round an olive pomace oil mill. The ASTM E544-99 (2004) ‘Standard Practice for Referencing Suprathreshold Odor Intensity’ has been modified to serve as a basis for testing, while a network of the quality standards, required for the realization/application of this ‘Practice’, is also presented. Last, sensitivity analysis of C_{opt} as regards the impact of (i) the increase of environmental information/sensitization and (ii) the decrease of interest rate reveals a shifting of C_{opt} to lower and higher values, respectively; certain positive and negative implications (i.e., shifting of C_{opt} to lower and higher values, respectively) caused by socio-economic parameters are also discussed.

Keywords: Willingness To Pay (WTP), environmental impact assessment, fuzzy reasoning, conditional index.

INTRODUCTION

The optimal concentration C_{opt} of a pollutant in the environment can be determined as an equilibrium point in the trade off between (i) environmental cost, K_1 (C), due to impact on man/ecosystem/economy, and (ii) economic cost, K_2 (C), for environmental protection, as it can be expressed by Pigouvian tax. These two conflict variables are internalized within the same techno-economic objective function of total cost $K(C)$, which is minimized. The first of them is an increasing function of C, with an increasing rate (i.e., $dK_1/dC>0$, $d^2K_1/dC^2>0$), since the impact is disproportionally higher in the region of high C-values. The second of them is a decreasing function of C, with an increasing algebraic or a decreasing absolute rate (i.e., $dK_2/dC<0$, $d^2K_2/dC^2>0$ or $d|dK_2/dC|/dC<0$), since the economic cost is higher in the region of low C-values, signifying high efficiency achieved by disproportionally higher input of resources due to the validity of the Law of diminishing returns. In case of increase of (i) information diffused into the population and (ii) consequent sensitization, the K_1-curve moves upwards to K'_1, becoming steeper since the difference from the initial position is larger in the region of high C-values, where the environmental impact is stronger; as a result, C_{opt} is shifting to C'_{opt}, where $C'_{opt}<C_{opt}$, as shown in Fig. 1a. It is worthwhile noting that the K_1-increase is expected as a function of time, since the public becomes more informed and more sensitive because of income increase and modern educational trends. On the other hand, a decrease of interest rate i implies decrease of subsidy optimal value I_{opt} (and consequent increase of capital cost for the investor [1, 2]), since $\partial I_{opt} / \partial i > 0$, as it is shown in the Appendix; consequently, K_2 moves upwards to K'_2 becoming also steeper since the difference from the initial position is larger in the region of low C-values, where the economic cost is disproportionally higher due to the validity of the Law of diminishing returns; as a result, C_{opt} is shifting to C''_{opt}, where $C''_{opt}>C_{opt}$ (see Fig. 1b).

The environmental cost can be represented, in a rather subjective way, by ‘Willingness To Pay’ (WTP), which is defined as the maximum amount of money a person would be willing to pay/sacrifice/exchange in order to get rid off a polluting source. The assignment of values on this index is performed by experts, who make their estimates under uncertainty, which is higher when measurements of the impact of the corresponding pollutant are impossible, due to the subjective nature of the implied result on human. In this work, we present the design/utilization of

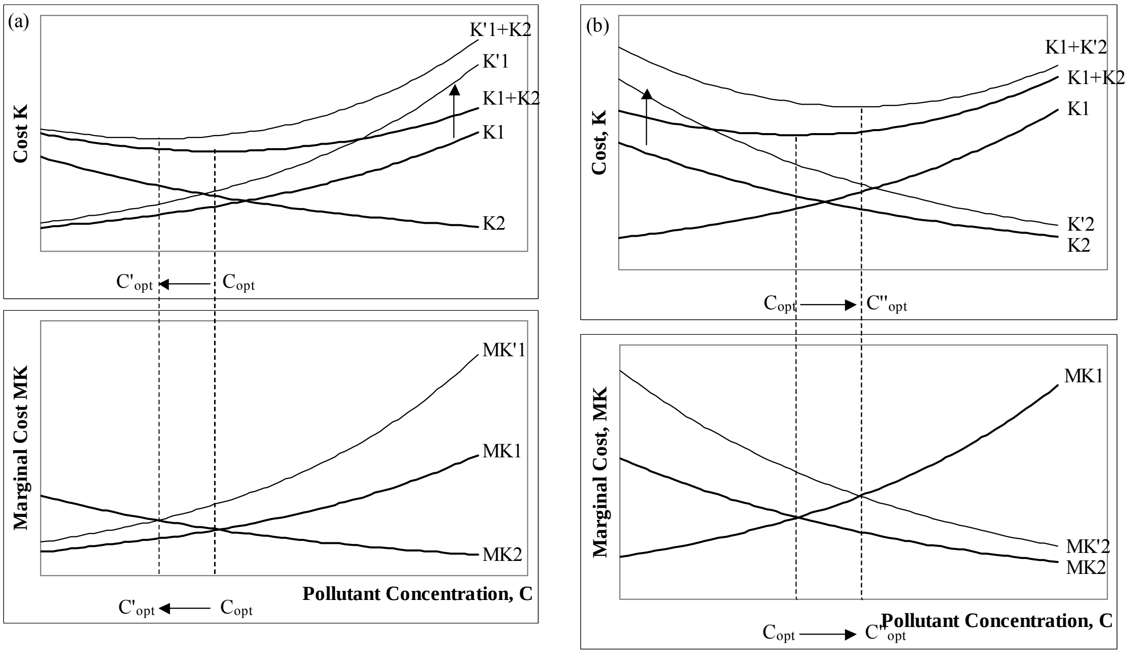


FIGURE 1. The dependence of environmental cost K_1 and economic cost K_2 on pollutant concentration C; the shifting of optimal value C_{opt} is also shown in the case of (a) information diffusion and consequent sensitization of the public, and (b) decrease of interest rate, implying decrease of subsidy and consequent increase of capital cost for the investor.

conditional WTP index based on fuzzy reasoning, capable to count for uncertainty under a variety of conditions that influence decisively the experts' opinion, as e.g., in the case of odor pollution of air, where the application of standard practices, like the ASTM E 544-99(2004), is based on odor intensity referencing scales made of crisp numbers, standing for pollutant concentrations, usually following a geometric progression scale.

METHODOLOGY

For the purpose described above, we have developed a methodological framework, under the form of an algorithmic procedure including 8 activity stages and 4 decision nodes (for their interconnection, see Fig. 2):

1. Determination of (i) the borders of the geographical area under consideration and (ii) the interval of values for each pollutant and physical parameter that may appear in this area (including frequency and impact on human/ecosystems/infrastructure).
2. Experimental design.
3. Performance of observations and measurements in both modes, laboratory (after sampling) and *in situ*.
4. Design/development of the corresponding stochastic model.
5. Selection of panelists/experts, i.e., individuals capable to assign subjective values on indices representing environmental impact.
6. Fuzzy partition (by panelists, possibly aided/guided by algorithmic procedures as described in technical literature) for the universe of each set of values corresponding to input-output variables, after associating each of these values with a class.
7. Determination (by panelists) of conditional statements in the form of fuzzy rules as follows: IF x is P THEN y is Q, where x and y are linguistic variables, P and Q are linguistic values defined by fuzzy sets on the universe of discourse X and Y, respectively.
8. Implementation by testing through selected specimen runs.

A. Do the interval limits justify further investigation?
B. Are there enough numerical data for statistical inference?

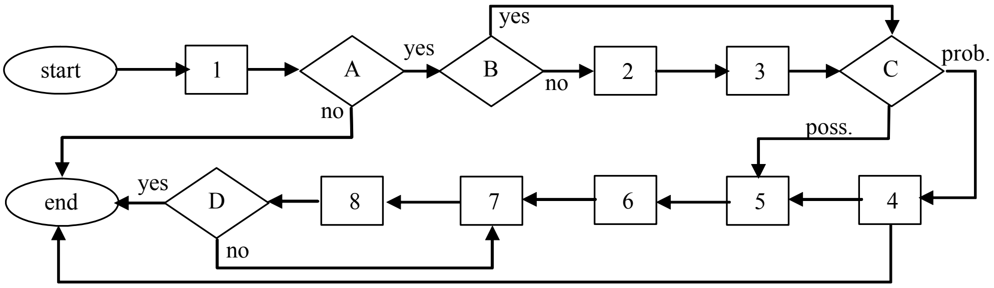


FIGURE 2. The methodological framework, we have developed under the form of an algorithmic for estimating a conditional index as a quantifier for environmental impact assessment.

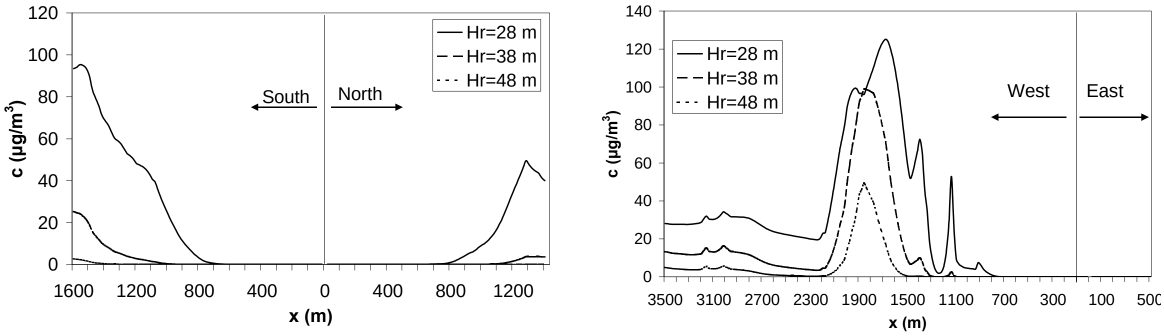
C. Are the kind and the quality of the collected data more appropriate for probabilistic or possibilistic processing?
D. Are the results of testing satisfactory?

IMPLEMENTATION AND CONCLUDING REMARKS

The methodology described above has been implemented in the case of measuring odor intensity. The odorant considered was associated with particles emitted from the chimney of an olive pomace oil mill in Crete [3]. The ranges taken into account for fuzzy partitioning of input variables (concentration C, temperature T, humidity H, wind velocity W) were determined by measurements *in situ* and by estimating the parameter values of the corresponding model. For example, the range for concentration was extracted by applying a double Gaussian model of dispersion (see Fig. 3). A simple two-input one-output case is presented in Fig. 4, where, for normalized (0-100%) fuzzy inputs C [33, 46, 65] and T [48, 51, 54], we obtain, after defuzzification (by using the method of centroid), the crisp value N=61.5% as output.

TABLE 1. The Fuzzy Rules Defined as Conditional Statements in IF-THEN Form (3-Scale Partitioning).

IF C	**IF T**	**THEN N**	**IF C**	**IF T**	**THEN N**	**IF C**	**IF T**	**THEN N**
Low	Low	Low	Medium	Low	Medium	High	Low	High
Low	Medium	Low	Medium	Medium	Medium	High	Medium	High
Low	High	Medium	Medium	High	High	High	High	High



(a) (b)

FIGURE 3. The dependence of the odorant concentration at the ground level on the distance *x* (m) for various chimney height values (stable atmosphere, olive pomace oil mill location at *x*=0, wind speed *u*=2m/s): (a) North-South, (b) East-West .

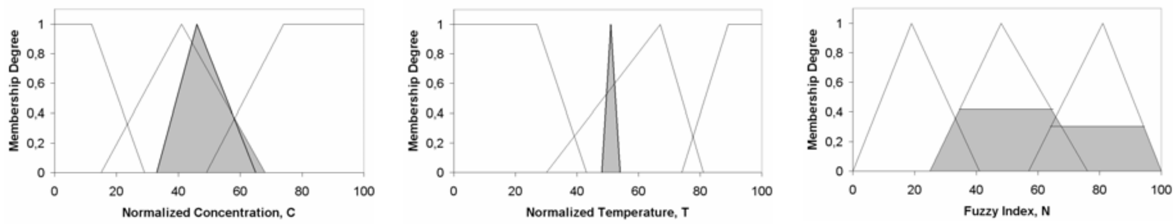


FIGURE 4. Estimation of the fuzzy index N as a final output (THEN-part of the end-rule used in the corresponding chain of IF-THEN fuzzy rules), as a response to two fuzzy inputs, pollutant concentration and ambient temperature, presented as shadowed triangles in the universe of discourse partitioned in Low, Medium, and High partially overlapping scales.

In conclusion, the functionality of the methodological framework, developed/presented herein under the form of an algorithmic procedure including 8 activity stages and 4 decision nodes, for estimating a conditional index as a quantifier for environmental impact assessment was proved by means of a simple numerical case example based on data extracted from a study concerning odor pollution of air round an olive pomace oil mill. The suggested procedure is a significant improvement of the ASTM E544-99 (2004) ‘Standard Practice for Referencing Suprathreshold Odor Intensity’, since it takes into account uncertainty, by means of fuzzy reasoning.

ACKNOWLEDGMENTS

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APPENDIX

Given the function of optimal subsidy $I_{opt}=g(K, F, S, i, r, f, t)$, where K is the fraction of environmental benefit/improvement/gains (assessed in monetary units) deducted per time period by the State from its welfare budget, F is the gains during the first time period, S is the amount of investment for installing the unit intended for prevention of odor pollution of air, i is the interest rate used for money equivalence over time, r is the return on the best alternative investment (called ‘the second best’ in comparison with the first best for the State, which is the amount of subsidy $I_{opt}S$), f is the rate of F increase per period ($f > i$), t is the number of time periods (dimensionless) considered for depreciation, we have proved that $\partial I_{opt} / \partial i > 0$, as follows:

$$I_{opt} = \frac{KF(1+i)^{t-1}}{S(1+r)^t}\frac{\left(\frac{1+f}{1+i}\right)^t - 1}{\frac{1+f}{1+i} - 1} \Rightarrow I_{opt} = \frac{KF}{S(1+r)^t}\frac{(1+f)^t - (1+i)^t}{(1+f)-(1+i)}$$

$$I_{opt} = \frac{KF}{S(1+r)^t}\left[(1+f)^{t-1} + (1+f)^{t-2}(1+i) + \ldots + (1+i)^{t-1}\right] \Rightarrow I_{opt} = \frac{KF}{S(1+r)^t}\sum_{j=t-1}^{0}(1+f)^j(1+i)^{(t-1)-j}$$

$$\frac{\partial I_{opt}}{\partial i} = \frac{KF}{S(1+r)^t}\sum_{j=t-2}^{0}\left[(t-2)+(1-j)\right](1+f)^j(1+i)^{(t-2)-j} > 0$$