IMPACT ASSESSMENT OF ENVIRONMENTAL POLLUTANTS ON THE TAJ MAHAL – A FUZZY SET THEORETIC APPROACH

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ABSTRACT

The Taj Mahal, a mausoleum constructed in white marble by the mughal emperor Shahjahan in the beloved memory of his wife, has been accredited as being one of the Seven Wonders of the World, by millions of people worldwide. However, it is a well known fact that for quite some time now, various polluting factors such as those relating to water, the atmosphere, land etc. which have seen an exponential rise due to inexorable regional development, are collectively responsible for the corrosion and wearing of the marble that forms the Taj Mahal. This degradation is taking place to such an extent that its effect may soon become irreversible. What intensifies the gravity of the situation is the fact that the damage is mostly qualitative, and so is practically immeasurable. This paper utilizes a fuzzy-logic approach for *quantitatively* assessing the impact of various environmental hazards, by exploiting linguistic variables for assessing pertinent factors affecting the hazards. Towards this end, we identify and measure the contribution of specified state variables towards the considered hazards in order to compute an overall index for a generic pollutant.

Keywords: Systemic state change variables, Fuzzy logic, Taj Mahal

1. INTRODUCTION

Environmental Impact Assessment (EIA), may be understood as evaluation of the influence on the environment, of the various activities carried out at any place as a part of any project/process. The influence may be only temporary, i.e. it may disappear after a while, or it may be long lasting with no definite end-point as can be the transformations brought to the environment, that may be repairable by carrying out some specific managerial procedure or may be irreversible. Environmental impacts are changes seen in the natural environment, such as variations in habitats and ecosystems, changes in basic natural resources such as soil, air, water etc. [16]

The most damaging of all forms of pollution on the marble of Taj have been air and water pollution [6] . Effluents are released from over 1700 factories that exist in and around Agra, in the form of gases such as CO, CO_2, SO_2, chlorofluoro carbons, nitrogen oxides, particulate matter etc. Out of these, SO_2 in particular causes yellowing and intensive damage to marble [15]. Another extremely damaging phenomena is that of acid rain which takes place due to formation of acidic compounds in precipitation by the reactions between effluents containing compounds of ammonia, carbon, nitrogen sulphur etc. with atmospheric water. Acid rain reacts with the calcium carbonate of the marble and forms water soluble compounds leading to slow corrosion and decay of the monument's marble [9]. The only way of checking this soon-to-be-irreversible damage, is to somehow curb the uninhibited and large quantities of pollutants being dumped into the environs of Taj.

Over the years, many methods have been adopted to reduce the pollution in the vicinity of Taj which were mostly ineffectual. However, a partial victory was achieved when the supreme court of India delivered a ruling in December 2008 which demarcated an area called the 'Taj Trapezium', a 10,400 square kilometers wide area around the Taj within which certain laws and regulations with the aim of controlling pollution had to be strictly followed such as: use of only LPG as fuel in houses instead of wood and biomass used traditionally by the majority, prioritized supply of unleaded petrol and low sulphur diesel to retail outlets throughout Agra, ban on the use of coal/coke by industries within the trapezium with a mandate to switch over to natural gas or else be relocated outside the trapezium [17].

Though the above mentioned policies are helpful to some extent, there are some fundamental difficulties with the enforcement of these laws which makes it difficult to take complete advantage of the mandates provided by the court. One of the critical problems is the lack of existence of any solid scientific/mathematical index which can actually provide a quantitative measure of the extent of impact a given hazard is having on the environment, and thus use such an index to further regulate and control the emissions from various industries, factories, vehicular traffic etc. In this paper we have attempted to design such a basic index based on the laws of fuzzy logic and fuzzy sets.

Fuzzy set theory, proposed by Zadeh [10], is an established and growing research discipline. The use of fuzzy set theory as a methodology for modeling and analyzing decision systems is of particular interest to researchers due to fuzzy set theory's ability to quantitatively and qualitatively model specific problems which involve vagueness and imprecision. Karwowski and Evans [18] identify three key reasons why fuzzy set theory is relevant to production management research. First, imprecision and vagueness are inherent to the decision maker's mental model of the problem under study. Thus, the decision maker's experience and judgment may be used to complement established theories to foster a better understanding of the problem. Second, in the production management environment, the information required to formulate a model's objective, decision variables, constraints and parameters may be vague or not precisely measurable. Third, imprecision and vagueness as a result of personal bias and subjective opinion may further dampen the quality and quantity of available information. Hence, fuzzy set theory can be used to bridge modeling gaps in descriptive and prescriptive decision models.

In applications such as systems monitoring, domain attributes often emerge from an elusive vagueness, a readjustment to context or an effect of human imprecision. The use of the soft boundaries of fuzzy sets, namely the graded memberships, allows subjective knowledge to be incorporated in describing these attributes and their relationships [7]. Fuzzy techniques have proven to be very successful for creating, for example, robust controllers and user-friendly classifiers to address such problems [14] [12] [5]. Even when precise knowledge is available, fuzziness may be a concomitant of complexity involved in the reasoning process [7]. Among the interesting features of fuzzy approaches is the potential of fuzzy rules in attaching meaningful labels to the fuzzy sets [11] thereby allowing a human comprehensible representation of the system under consideration.

The first section of the paper lays down the basic concepts and justifies the use of a fuzzy set theoretic approach. Section 2 highlights the detrimental effects of various pollutants on Taj Mahal. In section 3, the principles regarding the impact assessment approach are stated, followed by section 4 in which the factors affecting impact types are identified on the basis of observations presented in section 2. Section 5 presents the implementation details for the presented framework. Section 6 provides a summary conclusion of the key contributions of the paper.

2. DETRIMENTAL EFFECTS OF POLLUTANTS ON THE TAJ

Water

One of the most damaging forms of pollution to the Taj, is actually indirectly linked to the atmosphere. This is known as 'acid rain' and simply refers to precipitation in any form that has an abnormally low pH i.e. elevated levels of hydrogen ions. Acid rain affects stone in general and especially marble, largely by two processes which are called dissolution and alteration. When acid rain containing various acids such as sulphurous, sulphuric, and nitric etc. react with the calcite in marble and limestone, the calcite dissolves, leaving a roughened surface due to removal of the material. Over time, such slow erosion of the marble, as in the case of the Taj, leads to deformations in the original design and carvings of the building. Even those parts of the monument that are protected from direct contact from rain have blackened crusts that have peeled off in some places, revealing crumbling stone underneath. This black crust is constituted mainly of gypsum which is formed by the reaction between calcite and acid rain. Gypsum can form anywhere on marble or stone surfaces which have exposure to SO_2 gas and it remains only on such surfaces that are not directly washed by the rain. Though Gypsum itself is white, but its crystals form networks that trap particles of dirt and pollutants, so the crust looks black. In the long run, this black outer layer strips off, leaving the fresh stone underneath exposed to the same eroding phenomena once more. This process continues cyclically ultimately leaving the monument irreversibly deformed [9].

Regional development

An ironic fact is that the very marker used to gauge economic growth of a region, that is the extent of growth of industries, has actually accelerated the pace of deterioration of the Taj. There has been an exponential rise in the number of large scale factories and production units in and around Agra. At the same time, there has been such rapid mushrooming of indigenous manufacturing units, foundries, furnaces, brick kilns, tanneries etc. that their total number can only be roughly estimated and no stringent check on their effluent production and disposal is possible. These have collectively added a sizable and completely uncontrollable amount of hazardous waste to the environment which has had a rapid detrimental effect on the Taj [16].

Ecosystem

The lack of control over the population of stray animals has led to a large increase in the amount of excreta produced by them as well as a substantial rise in the quantities of CO_2 exhaled into the atmosphere by them. Both these factors are damaging to the natural ecological balance which must be maintained. The very fact that the Taj attracts thousands of tourists every year has itself led to an escalation in the garbage thrown around the premises and has led to undue mutilation of its splendor which could otherwise have been preserved with a little effort [16].

Atmosphere

In India itself, more that 100 million tons of waste effluents are added to the atmosphere every year. Since the setting up of industrial units was under no strict restriction, waste gases of every possible nature are being released into the atmosphere over the past several years. These include the following: CO from automobile exhaust and photochemical reactions in the atmosphere; CO_2 due to burning of hydrocarbon based fuels including wood and biomass, at the same time extensive deforestation has led to a further rise in the CO_2 content which may have otherwise remained in check. SO_2 and NO_2 are two of the most damaging gases to marble, and are produced by industries, electric generation plants and smelting plants. These gases are particularly significant in the case of the Taj due to the presence of a petroleum refinery at Mathura, about 45 kilometers from Agra. This refinery is believed to release approximately 25-30 tons of SO_2 into the atmosphere daily. These gases travel with the wind to Agra and cause extreme corrosion and decay of the marble constituting the

Taj due to chemical reactions such as acid rain. In the winters, various effluent gases often react in the presence of sunlight with each other to form a 'photochemical smog' whose haze sometimes completely obliterates the Taj from view [8].

Soil

The presence of SO_2 , NO_2 and other such gases in the air, that cause acid rain, leads to an abnormal rise in the levels of elements such as sulphur in the soil which in turn inhibits the growth of vegetation around the Taj. This factor, coupled with extensive deforestation, has led to denudation of the soil around the Taj. Another derivative of this erosion of soil is that since the soil is now loose, there is an increase in the frequency of sandstorms, and these storms in turn further add to the wearing away of the already crumbling marble [16].

Resources & Habitats

The ever increasing pressures placed on the environment by the swiftly growing human population is reflected in the rapid deterioration observed in the condition of the Taj. As the population of Agra and its surrounding districts is becoming urbanized, we start observing the inputs of new hazards, previously not there, such as the addition of chlorofluoro carbons (CFCs) which are released into the atmosphere from refrigerators, air conditioners, foam shaving cream spray cans and cleaning solvents all of which start being used as the pattern of living shifts from rural to urban. Similarly, other inevitable consequences of modernization such as the indiscriminate use and improper disposal of non-biodegradable products like plastic bags, use of ammonia based paints, oils and greases, cadmium from paint and plastic production, polychlorinated biphenyls (PCB's) from electrical transformers, and the banned DDT and dioxin ("agent orange") from pesticides are just a few examples of how humans themselves are day by day adding to the already heavy toll being borne by the Taj [16].

3. CONTRIBUTING FACTORS

When viewed from a systemic viewpoint, a system can be observed to transit through various states, where the 'state' of the system is essentially a set of parametric values of the system's sub-components that define it completely at a specified point in time. We view the contribution of any factor towards a impact type to be dependent upon the following three variables: First, its relative importance (or weightage) vis-à-vis other factors, i.e., the extent of change that it can bring about in the system. Therefore, if the relative importance of a factor is high it has the potential of causing a significant change in the system's performance, even though it might presently not be manifest. Second, a factor's present manifestation level in the system, i.e., an assessment of the state in which it presently exists. Accordingly, if the current level of manifestation is low, it will require a commensurately large change in its present state in order for it to be deemed effective. Third, the state change efficiency for a factor, i.e., a measure of the efficiency with which its manifestation level in the system can improve. A factor possessing a high state change efficiency can transit from a low to a high manifestation level with a commensurately low effort level expended in the process. The above three variables are now expanded for exposition purposes.

Relative Importance (Or Weightage) of a Factor

The importance or weightage of a factor, W_i ($\Im_{IMP\_i}$), determines its relative significance level vis-à-vis other factors affecting a specific impact type.

Manifestation Level of a Factor

The manifestation level of a factor, $C_i(\Im_{IMP\_i})$, establishes its current state level with respect to the desired level that would epitomize the target level exhibited with respect to a specific impact type.

State Change Efficiency for a Factor

The state change efficiency for a factor, η_i ($\Im_{IMP\_i}$), signifies the ease with which state changes can be effected when transiting from the present to the desired state. The schematic shown in Figure 1.1 captures the essence of the conceptual approach described above when quantifying the factor contribution $\Psi_i(\Im_{IMP\_i})$ for a specific factor $\Im_{IMP\_i}$ towards a given impact type IMP.

4. FACTORS AFFECTING IMPACT TYPES

On the basis of identifications in Section 2, the factors affecting the impact types or pollutants can be summarized as follows:

Impact types	Factors affecting impact types
Water	1. Discharge from industries 2. Runoff of soil containing pesticides 3. Improper drainage system 4. Grit collection 5. Presence of suspended particulate matter
Regional Development	1. Development of slums around the Taj 2. Development of industries
Ecosystem	1. Exhalation of carbon dioxide by various biotic organisms 2. Excreta by biotic factors
Atmosphere	1. Effluents from industries 2. Vehicular emissions 3. Emissions from DG sets, and household gas/coal based stoves 4. Formation of toxic gases within pipelines and rising main sewers 5. High temperature
Soil	1. Use of pesticides in the foliage surrounding the Taj 2. Presence of sulfur dioxide in soil 3. Frequent occurrence of sandstorms
Resources	1. Frequent use of $CaCO_3$ for whitewashing forming $CaSO_4$ 2. Emissions from air conditioning systems
Habitats	1. Throwing of non-biodegradable polythene pouches and bags 2. Use of ammonia based oils, greases and paints 3. Rapid population growth resulting in worsening of situation

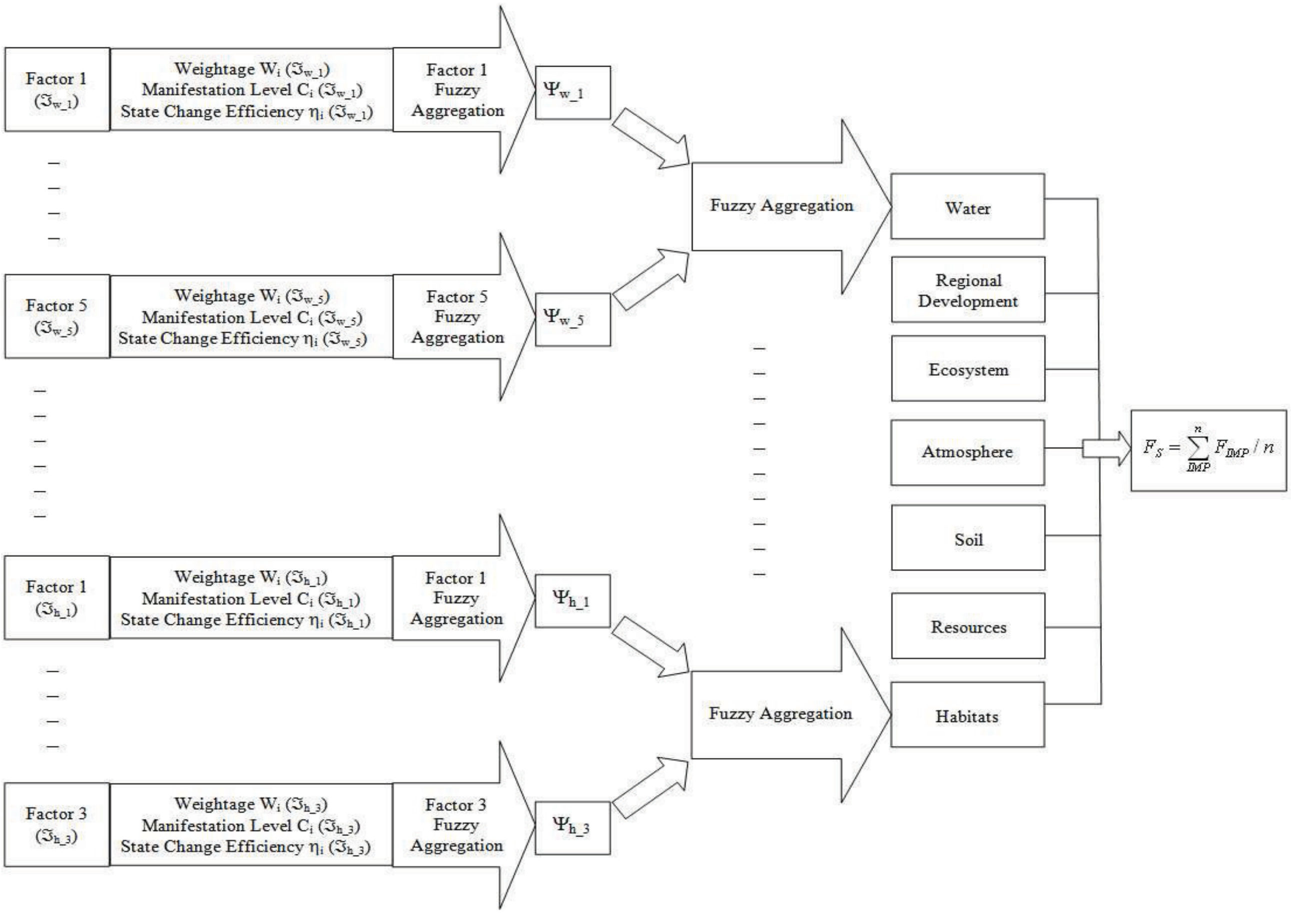

Figure 1.1 Flow diagram of the impact assessment approach

5. IMPLEMENTATION DETAILS

The initial step in the implementation of the suggested approach is to develop a fuzzy expert system for the problem domain of study. Fuzzy expert systems (FES) emulate the reasoning process of a human expert within the required knowledge domain and are built with the purpose of exploiting the experience and problem-solving capabilities of experts available to others [4]. In the present context, the fuzzy rules to be embedded into the FES's knowledge base would comprise of several logical rules that exhaustively capture relationships between $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$, $\eta_i(\Im_{IMP\_i})$ and $\Psi_i(\Im_{IMP\_i})$ for each factor of each impact type on the basis of the observations made by the domain experts.

The next step entails actual observations of $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$ and $\eta_i(\Im_{IMP\_i})$ within the test environment system wherein the impact measurement is desired. The observed conditions (($W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$ and $\eta_i(\Im_{IMP\_i})$) are then compared with the predefined fuzzy rules relating $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$ and $\eta_i(\Im_{IMP\_i})$ already captured within the existing knowledge base of the previously developed FES. Thus, a numeric estimate of contribution of the factor $\Im_{IMP\_i}$ towards the specific impact type IMP is then computed as $\Psi_i(\Im_{IMP\_i})$ by the inference engine based on the synthesis of the input values.

The membership curves for the fuzzy sets corresponding to the above linguistic labels are assumed identical for each of $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$, $\eta_i(\Im_{IMP\_i})$ and $\Psi_i(\Im_{IMP\_i})$ as shown in Fig. 1.2.

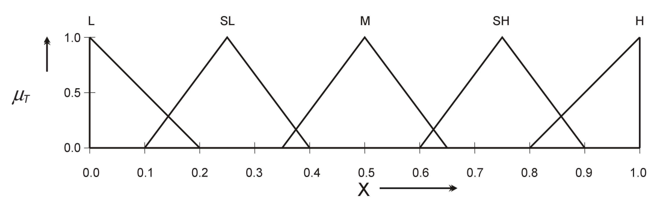

Figure 1.2 The Membership Curves for $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$, $\eta_i(\Im_{IMP\_i})$ and $\Psi_i(\Im_{IMP\_i})$

The membership functions for each of the above variables $W_i(\Im_{IMP\_i})$, $C_i(\Im_{IMP\_i})$, $\eta_i(\Im_{IMP\_i})$ and $\Psi_i(\Im_{IMP\_i})$ are defined on identical universe(s) of discourse (X) constrained to lie within a unit interval [0,1]. The form in which the general schema is expressed is as follows:

$$\Psi_i(\Im_{IMP\_i}) = W_i(\Im_{IMP\_i}) \circ C_i(\Im_{IMP\_i}) \circ \eta_i(\Im_{IMP\_i}) \qquad ...(1)$$

The outcome is in the form of a modified membership function which is subsequently defuzzified using a standard centroidal defuzzification method. In this method, each membership function is simply multiplied by its corresponding weight. The scaled down membership functions are aggregated to give a final crisp estimate of the factor contribution (d) as follows:

$$d = \frac{\int_{-\infty}^{\infty} \sum_{n} \alpha_n x \mu_{n-IMP\_i}(x)dx}{\int_{-\infty}^{\infty} \sum_{n} \alpha_n \mu_{n-IMP\_i}(x)dx} \quad ...(2)$$

where the summation is over all of the consequent membership functions, $\{\mu_{n\text{-}IMP\_i}(x)\}$, and their corresponding weights $\{\alpha_n\}$. In a likewise manner, the individual contributions of other factors are also obtained. The resulting numerical values for the contributions of individual factors then decide the magnitude of the considered impact type for the environment system using the standard fuzzification-defuzzification procedure. The process is repeated for obtaining values for all other impact types. These values are finally averaged to achieve the value of overall impact index for the test environment system. The process may be summarized as follows:

$$F_{IMP} = \bigcap_i \Psi_i(\Im_{IMP\_i})$$

$$F_{IMP} = \Psi_1(\Im_{IMP\_1}) \bigcap .. \bigcap \Psi_i(\Im_{IMP\_i})$$

$$F_{IMP} = \bigcap_i W_i(\Im_{IMP\_i}) \circ C_i(\Im_{IMP\_i}) \circ \eta_i(\Im_{IMP\_i})$$

$$F_{IMP} = W_1(\Im_{IMP\_1}) \circ C_1(\Im_{IMP\_1}) \circ \eta_1(\Im_{IMP\_1}) \bigcap .. \bigcap W_i(\Im_{IMP\_i}) \circ C_i(\Im_{IMP\_i}) \circ \eta_i(\Im_{IMP\_i})$$

Figure 1.3 Schematic portrayal of the development procedure described above.

The defuzzified value of F_W, the force of impact type *water* is then computed using the standard centre of mass formula [3] [13]:

$$F_W = \frac{\int_{-\infty}^{\infty} \sum_{n} \alpha_n x \mu_M(x)dx}{\int_{-\infty}^{\infty} \sum_{n} \alpha_n \mu_M(x)dx} \quad ...(3)$$

giving:

$$F_W = \frac{0 \times .35 + .173 \times .4 + .525 \times .5 + .173 \times .6 + 0 \times .65}{0 + .173 + .525 + .173 + 0}$$

$$= 0.50$$

Accordingly, the values for the remaining impact types are computed in a similar manner to be the following:

$F_R = 0.88,$
$F_E = 0.69,$
$F_A = 0.44,$
$F_S = 0.73,$
$F_O = 0.52,$
$F_H = 0.26$

Finally, the estimate for the *overall pollutant index* is computed as an average of the respective values of the above impact types:

$$F_S = \sum_{IMP}^{n} F_{IMP} / n \quad ...(4)$$

$$F_S = (F_W + F_R + F_E + F_A + F_S + F_O + F_H) / 7$$
$$= (0.88 + 0.69 + 0.44 + 0.73 + 0.50 + 0.52 + 0.61) / 7$$
$$= 0.624$$

6. CONCLUSION

In this paper, the problem that we have attempted is faced at the most basic level of any effort towards environmental conservation. The real life example of the corrosive degradation of the Taj Mahal which we have used in our work, is reflected the world over wherever indiscriminate industrial growth and an explosion in the human population are silently wiping out innumerable natural and historical legacies, from the great barrier reef, Australia to the fast disappearing Amazon rain forests or even the marble statues on street corners in Rome or some of the Seven Wonders of the World like the Taj or the great pyramids of Egypt, none is spared from the relentless and uninhibited steps taken by man in the name of 'progress'. Most of the factors leading to their destruction are qualitative in nature, and this makes it extremely difficult and unreliable to try and pin-point, without following some well-defined and documented scientific methodology, the exact nature, and extent of danger each hazard poses.

We have in this study, designed a 'fuzzy expert system' which on being fed inputs based on the details of the hazard being examined, can intelligently combine an extensive database of existing knowledge, with a logical mathematical formulation and give as the output, a numerical value that can be used as a *quantitative prediction index* to judge the overall impact the hazard under study would actually have on some defined ecological system.

Our model is simple to implement and can easily be incorporated into the most rudimentary ecological conservation movements without the need of any complex groundwork. The model can be further researched and refined to be able to take into account dynamic situations which are closer to real life problems, and can even be modified by the incorporation of evolutionary and swarm intelligence algorithms to be able to optimize the weightage to be assigned to different input factors by carrying out a real-time analysis of constantly changing input parameters.

We hope that our work will serve to act as a reminder that unless we collectively take immediate steps to start reclaiming the natural and historic wonders that belong to all of us, their degradation will soon have crossed the point of no return, and that this is the responsibility not only of environmentalists and ecologists, but requires an amalgamation of the expertise of scientists and engineers from varied disciplines to achieve this common goal.

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