Integration Techniques for Environmental Impact Assessment of Industrial Pollutants

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Abstract-**The integrated management of medium (both water and air) based pollutants is vital at current as the management and legalization of individual pollutant is very difficult. Various environmental aspects associated with the different medium during the production processes are major challenges being faced in the environmental management of industrial facilities. It is of vital concern today to find the scientific way of integration of medium-based pollutants. Based on an amount and kind of medium-based pollutants, Integrated Environmental Performance Score (IEPS) is calculated applying Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI). The potential impacts of individual pollutants have been modelled for water based pollutants viz., Chemical Oxygen Demand (COD), Total Phosphorous (TP), and Total Nitrogen (TN) and air pollutants viz., Oxides of Nitrogen (NOx), Oxides of Sulphur (SOx) and Particles Matter (PM10). A kilogram of individual pollutants is taken in modelling to compute the individual impact categories of unit pollutants. The EPS penalty of TN is obtained as highest score of 189.70 i.e. 90.82% shares among six pollutants. The total penalty score for TP, PM10, TN, NOx and SOx, is derived as 13.53 (6.48%), 2.59 (1.24%), 1.30 (0.62%), 1.30 (0.62%) and 0.44 (0.21%), respectively. Hence, it is necessary to integrate effects of pollutants as per the scientific and justified impact caused by individual pollutants derived from the industrial facilities. Therefore, this study recommends for the compliance of EPS penalty of the pollutants based on a result of TRACI. This helps to enforce a scientific and justified polluters' pay principle.**

Keywords- Integrated Environmental Performance Score; TRACI; Medium-based Pollutants; Total Penalty Score; Industrial Facilities

I. INTRODUCTION

Different approaches adopted to control emissions into air, water or soil separately may encourage the shifting of pollution from one environmental medium to another rather than protecting the environment as a whole. Therefore, it is appropriate to provide an integrated approach to prevent and control emissions into the air, water and soil. According to this principle, all licenses are obtained together through an integrated approach and initiatives must, therefore, be taken for the management of environment as a whole [1-2]. The concept of a single environmental authorization or permit called Integrated Environmental Authorization [3] need to be implemented.

For this, the use of Environmental Impact Assessment (EIA) process should be expanded as a mechanism for integrating environmental concerns of decisions making and designing of various industrial categories. It introduces the procedural elements to be followed, such as the provision of environmental impact assessment and consultation with public and environmental authorities within the framework of the development of consent procedures for the activities covered.

Currently, the various environmental aspects associated with the activities of production processes in an integrated way are one of the major challenges being faced in the environmental management of industrial facilities. For simulation of an integrated approach, European Commission (EU) adopted a directive on Integrated Pollution Prevention and Control (IPPC) in 1996 [4]. This Directive was codified in 2008 [5] and reorganized along with the Industrial Emissions Directive (IED), 2010/75/EU2 [6]. IED was adopted in 2010 as the guidelines for management of EU - wide discharge facilities as per the extent of the effect on the environment. In fact, IED is a follow-up of IPPC Guidelines, 1996. Five principles of IED can be summarized as follows: 1) Integrated Approach (IA) 2) Best Available Technique (BAT) 3) Flexibility 4) Environmental Inspection (EI) and 5) Public Participation (PP). IPPC directives apply an integrated environmental approach to the regulation of certain industrial activities i.e. emission to air, water (including discharge to the sewer), land and other range of environmental effects collectively to achieve a high-level protection of the environment as a whole.

An integrated control system as guided by the IPPC Directive puts into practice with medium-based pollutants. This is a synergetic and coordinated approach for protecting the environment as a whole [7]. The IPPC permit contains standards and requirements that should be complied by the facilities. The permit should include sources of emissions, nature and quantities of foreseeable emissions, and measures or other techniques implemented or provided to avoid or prevent pollution [8].

The relative environmental risks of each pollutant need to be analysed with the scientific approach. It is very difficult to measure the ecological and environmental risks of contaminants precisely. The emission charges of proxy indicator per unit of polluting substances, as defined in the regulations, have been enforced already as social cost and environmental conservation levy. However, the regulation does not have provisions to measure the extent of the impact of the pollutants on environment

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and health.

This is time to introduce integrated environmental management system that allows optimal management techniques based on BAT. There have been numerous efforts made so far to set up an integrated medium and Emission Limit Values (ELVs) based on BAT guidelines. Most of the developed nations of the world including EU have already enforced the permit system using the BAT, and medium- specific integrated approach into their operating systems. They have considered the comprehensive economic and environmental assessment of medium-based pollution and facilities.

The major purpose of this study is to analyze the environmental impact of medium in accordance with an operation of an industrial facilities and production activities comprehensively. Currently, there is no proper integrated industrial environment management system due to the lack of proper assessment of integrated medium-based actual impact of emission. This study focuses on integrating the environmental impact of the medium-based pollution as shown in Fig. 1 using TRACI. This can be helpful to categorize the industries as per their actual adverse impact on environment and human health. Hence, it can facilitate to enforce an actual levy to the industrial facilities based on impact extent of pollutants.

Fig. 1 Air and water-based pollutants released from industrial facilities

II. METHODOLOGY AND METHODS

In this study, TRACI is used to compute Integrated Environmental Performance Score (IEPS) of individual pollutant types released from industrial facilities. Both water and air medium-based pollutants emitted commonly from the industrial facilities are taken into consideration in this study. Water pollutants resulted from industrial facilities viz., COD, TP and TN discharged in waste water and air pollutants viz., NOx, SOx and PM10 are utilized to calculate the total impact.

TRACI is intended to assist companies, federal facilities, industrial organizations, and public interest groups in performing broad-based impact assessments on human health, environment, and resource depletion. It helps to compare the environmental and health that prefers ability of two or more products or processes. Moreover, it enables characterization of factors that may have potential impact on twelve impact categories viz., Ozone Depletion (OD), Global Warming (GW), Acidification (AC), Eutrophication (EU), Photochemical Smog (P.smog), Human Health Cancer (HHCA), Human Health Non-Cancer (HHNC), Human Health Criteria (HHC), Ecotoxicity (ET), Fossil Fuel Depletion (FFD), Land use, and Water use. TRACI is selected to reflect current state-of-the-art for each impact category. This is a simple screening tool, which allows the consideration and quantification of the potential impacts [9]. The emission inventory used in TRACI is the Life Cycle Assessment (LCA) inventory, where LCA is a tool to measure the environmental consequence of product or process over its entire life. Generally, it begins with the resource consumption and ends with the residual return to the earth surface [10-11].

Environmental life-cycle assessment is a “cradle to grave” system approach for measuring environmental performance. This approach is based on the assumption that all stages in the life of a product generate environmental impacts, including raw materials acquisition, product manufacturing, transportation, installation, operation and maintenance, and ultimately recycling and waste management [12]. The amount and types of emissions are varied in each production stage and it is controlled by the mixture of raw materials and product processing techniques. Air pollution based industrial emission (PM10, NOx, SOx) in accordance with Clean Air Conservation Act and waste water based discharge (COD, TP and TN) load in accordance with the law on water and aquatic ecosystems conservation is taken as medium-based pollutants for this study. EPS of both types of pollutant is calculated using TRACI.

Six types of different pollutant resulted from both air and water medium viz., NOx, SOx, PM10, COD, TP and TN are taken as major industrial emissions for this study. The EPS of each type of medium-based pollutants derived from industrial facilities are calculated by considering associated environmental impacts of potential importance i.e. GW, AC, EU, HHC, P. Smog, etc. of individual pollutants. The unit amount of emission (i.e. 1 kg for each) of individual pollutants is taken as a

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baseline data to evaluate EPS of a unit amount of individual pollutants of both medium types using TRACI. Where, five applicable categories of the environmental impact of pollutant types are taken into consideration in this study as shown in Table 2 despite TRACI includes twelve environmental impact categories. The emission characterization values are estimated and normalized using Building for Environmental and Economic Sustainability (BESS) 3.0 guideline [12]. Finally, total EPS of a unit amount of individual pollutant types is computed to find the total penalty score.

Five environmental impact categories viz. GW, AC, EU, HHC and P.Smog caused by different pollutants derived from facilities for each stage are calculated using the emission inventory data and impact assessment characterization factors. Equations (1) - (3) are the basic mathematics for computing environmental impact categories as well as total EPS. For each category, environmental impacts and impact assessment characterization factors are taken as described in BEES 3.0 [12]. Normalization value and relative importance weight values for each of the impact categories are summarized in Table 2. Environmental Performance Index (EPI) of various pollutants is calculated as per the effects of individual pollutants using TRACI. Hence, it gives the EPS as per the weight effect of each pollutant.

$$IA_{jk} = \sum_{i=1}^{n} I_{ij} \times IA\ factor \tag{1}$$

$$IA\ Score_{jk} = \frac{IA_{jk} \times IVwt_{k}}{Norm_{k}} \times 100 \tag{2}$$

$$EnvScore_{j} = \sum_{k=1}^{p} IAScore \tag{3}$$

Where,

Env Scorej = environmental performance score for the product alternative j,

P = number of environmental impact categories,

IA Scorejk = characterized, normalized and weighted score for alternative “j” with respect to environmental impact “k”,

IVwtk = impact category importance weight for impact k,

Normk = normalization value for impact k,

I = inventory flow,

n = number of inventory flows in impact category k,

Iij = inventory flow quantity for alternative j with respect to flow I,

IA factori = impact assessment characterization factor for inventory flow i.

III. RESULT AND DISCUSSION

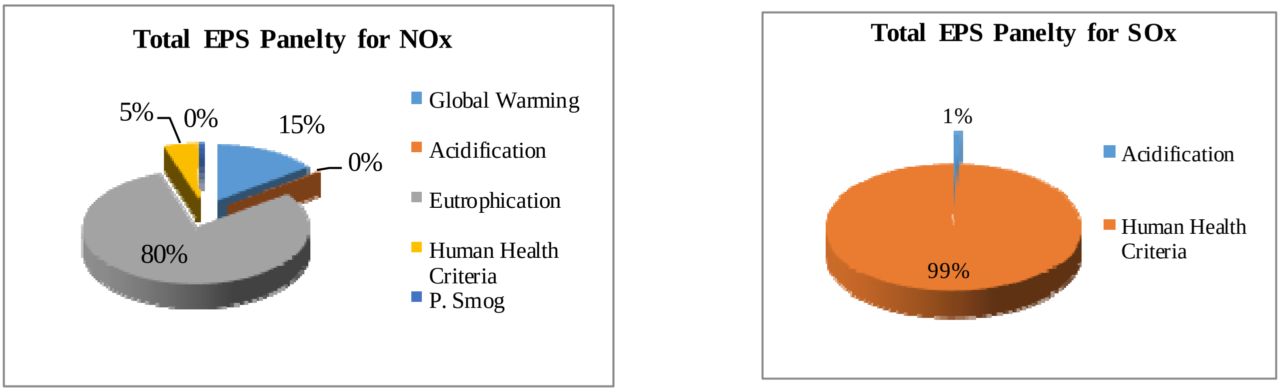
The result of integration of the total EPS of both air pollution and waste water discharge from industrial facilities is presented in this paper. The impact of individual pollutants is analysed and computed using TRACI as shown in Table 1. Therefore, it results the total IEPS penalty as per the impact of individual pollutants on environment and human health. The total IEPS penalty score of NOx, SOx, PM10, COD, TN, TP are 1.30, 0.44, 2.59, 1.30, 189.70 and 13.53, respectively. The percentage share on impact of individual pollutants are obtained as 0.62%, 0.21%, 1.24%, 0.62%, 90.82% and 6.48%, respectively for pollutants NOx, SOx, PM10, COD, TN and TP.

TABLE 1 EPS OF POLLUTANTS CATEGORY FOR UNIT EMISSION AND DISCHARGE FROM INDUSTRIAL FACILITIES

Unit	Air Pollutants			Water Pollutants			Total
	NOx	SOx	PM10	COD	TN	TP	
EPS	1.30	0.44	2.59	1.30	189.70	13.53	208.87
%	0.62	0.21	1.24	0.62	90.82	6.48	100

While considering a unit amount of pollutants, the percentage share of total EPS penalty of TN is obtained excessive i.e. 91% among various other pollutants as depicted in Table 1. From this, it has been cleared that environmental impact of TN is very high in comparison to other water-based pollutants and even among other air based pollutants. The total EPS penalty for TN is obtained 189.70 for a unit kg of TN discharged into the water stream, which stands to be the highest score in comparison to other pollutants. The EPS penalty score of TP is found only 13.53 for its unit kg discharge into the water stream. With the similar volume for two different pollutants discharged as waste water, however, there is a very big difference in penalty score between these two pollutants. The impact score of TN is established 14 times higher than TP impact score. Similarly, while concerning with COD, the EPS penalty score is obtained 1.30 which is around 146 times lower impact than that of TN as depicted in Table 2.

For air based pollutants, the EPS penalty of the unit amount of PM10 is obtained as 2.59. This penalty score is 73 times lower than TN score. While concerning the unit amount of NOx and SOx, EPS penalty score is found to be 1.30 and 0.44, respectively. The penalty score based on modelling results with TRACI can help to set a rule for each industrial facility based on the extent of the impact of each pollutant categories.



(a) (b)

Fig. 2 (a) Percentage share with various impact categories due to associated EPS score of NOx (b) Percentage share with impact categories due to associated EPS score of SOx

So far as the associated impacts of individual pollutants, NOx have 80%, 15% and 5% contribution in EU, GWP and HHC, respectively as shown in Fig. 2(a). Similarly, SOx share 99% and 1% contribution in HHC and AC, respectively as reflected in Fig. 2 (b). PM_{10} causes HHC impact, and Water pollutants (COD, TP, TN) have impact contribution on EU as shown in Table 2.

TABLE 2 COMPARATIVE ANALYSIS OF ENVIRONMENTAL PERFORMANCE SCORE OF SIX DIFFERENT POLLUTANTS TYPES

S. N.	Pollutants Type	Impact Category	Unit input (gm)	Normalization value (Norm_k)	Unit	Weightage value (IV_wt_k)	Emission Characterization value	EPS/Unit Emission
1	NOX	Global Warming	1000	25582.64009	kg CO2 equivalent/year/capita	16	3.10E+00	1.94E-01
		Acidification		7800200	moles H+ equivalents/year/capita	5	4.00E+01	2.56E-03
		Eutrophication		19.2142	kg N equivalents/year/capita	5	4.00E+02	1.04E+00
		Human Health Criteria (HHC)		0.0192	DALYs/year/capita	6	2.00E-06	6.25E-02
		P. Smog		151.50003	Kg NOX equivalents/year/capita	6	1.24E-03	4.91E-03
2	SOX	Acidification	1000	7800200	moles H+ equivalents/year/capita	5	5.08E+01	0.003256
		Human Health Criteria (HHC)		0.0192	DALYs/year/capita	6	1.40 -05	0.4375
3	PM10	Human Health Criteria (HHC)	1000	0.0192	DALYs/year/capita	6	8.03E+01	2.59375
4	COD	Eutrophication	1000	19.2142	kg N equivalents/year/capita	5	5.00E-02	1.301121
5	TP	Eutrophication	1000	19.2142	kg N equivalents/year/capita	5	5.20E-01	13.53166
6	TN	Eutrophication	1000	19.2142	kg N equivalents/year/capita	5	7.29E +00	189.7034

Out of six selected pollutants taken for this study, only three pollutants have the impact on HHC. The percentage share of 84%, 14% and 2%, respectively of air based pollutants viz., NOx, SOx and PM_{10} on HHC impact as depicted in Fig. 3 (a). In concerned with total EU impact for selected pollutants, the percentage share of NOx, COD, TP and TN are 0.51%, 0.63%, 6.58% and 92.28%, respectively as reflected in Fig. 3 (b). The acidification impact is caused by NOx and SOx only out of total six pollutants with the percentage share of 56% and 44%, respectively as shown in Fig. 3 (c). The direct regulation improves the environmental performance [13], however, there are contradictory results about the effectiveness of the mandatory approach to incentivize the environmental adjustments made by companies [14-15].

To achieve sustainable growth through the promotion of greener economy is one of the priorities of the European Strategy 2020 (European Commission, 2010), for which an important and real changes in regulations have been requested [16]. This focuses on economic instruments, such as ‘pollutants’ taxes’, that determine more positive impacts over time compared to command and control approach to innovation and diffusion of environmentally desirable technologies and techniques. The effectiveness of the ‘market-based’ instruments, such as emission trading schemes are more debated and uncertain [17]. Many

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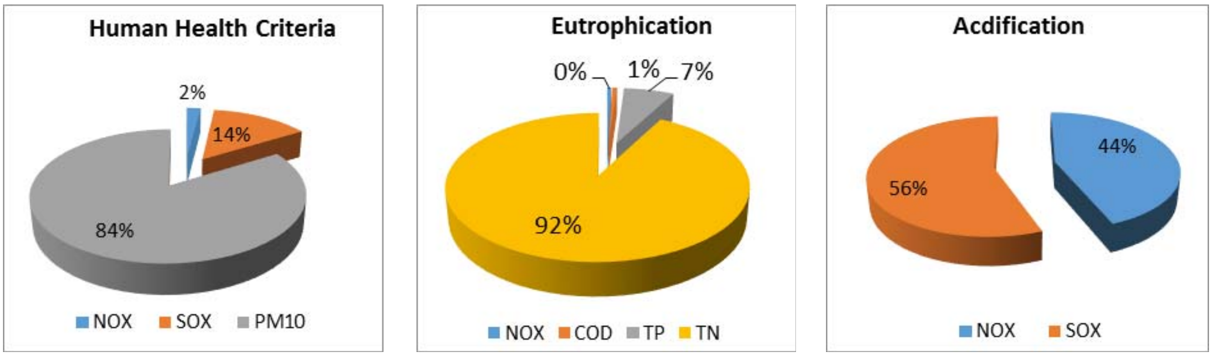
studies investigated the effects of an environmental management system and compliance to the environmental performance of companies with voluntary instruments. This helps to find the positive links between their adoption and improvement [18-19].



(a) (b) (c)

Fig. 3 Percentage shares of individual pollutants based on human health and environmental impact (a) Impact contribution of air pollutants on HHC (b) Eutrophication impact contribution of water based pollutants and NOx (c) Acidification impact of NOx and SOx

IPPC approach also aims to stimulate the introduction of eco–innovation in the production processes through the role of BAT. According to this approach, the companies are stimulated in their production processes, pursuing the level of emissions achievable through these techniques. ELV, equivalent parameters, and technical measures are enforced on the basis of BAT. Unlike the EIA, the EU-IPPC scheme places more emphasis on BAT as an instrument for guaranteeing the effects of emissions on environment treating as a whole. In addition, it allows for better monitoring and reporting of the environmental performance of industrial facilities. BAT allows licensing authorities to introduce a requirement for achieving a high degree of environmental protection with reasonable cost. BAT plays a role in improving industrial sustainability through higher energy efficiency, reduced pollution and related environmental and economic benefits. EU and major countries operate BAT as a proxy for the optimal value for each indicator.

IPPC Bureau covers 31 different industries and manufacturing processes. They have adopted an optimal value for the respective pollution emission stated in BAT reference document (BREFs), irrespectively of industry mix in a particular Chinese region. However, in a case of Japan, it is necessary to manage medium for each individual to carry out medium integration permit system for the enforcement of pollutant management. Therefore, review of the classification system of the source of contamination and establishment of a new classification system which is suitable for domestic industry are vital. Hence, compliance of the IEPS to both medium such as air and water pollution associated with production activities and operation of industrial facilities based on the real impact of the individual pollutants is vital to regulate the industrial pollution. The result of this study can be helpful to revise the current enforcement system with a scientific way of ranking of facilities based on the actual impact of pollutants they released that forced to the environment and human health.

IV. CONCLUSIONS

Excessively increasing industrial facilities generate pollutants which are hazardous to human health and the environment. The protection measure should be taken as per the impact of pollutants released by industries rather than merely quantity of pollutants only. This study recommends in pursuing the computation of a unit amount of pollutants as per the degree of environmental and health impact of individual pollutants for both medium (water and air).

From the assessment of the result derived from TRACI, it is proved that the current practices of enforcement system need to be amended. Hence, it is necessary to revise the current enforcement system with a scientific way of ranking of facilities based on the real impact of pollutants they release, which is forcing to environment and health of people. Hence, the enforcement system of pollutants should be revised as per the total EPS penalty of the industrial category as prescribed by this study to comply the justified “Polluters pay principle”.

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