LCA based environmental index for process industries: model for application in integrated steel plants

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1.0 Introduction

Environmental decision making as well as dissemination of environmental information for public discussion and proper interpretation by all stakeholders (employees, public, neighbours, financers, promoters etc.) - requires concise, relevant, scientifically based and easily interpretable information on various environmental impacts caused by human activities.

A model based on principles of Life Cycle Assessment(LCA) has been developed for evaluation of environmental performance of Integrated Steel Plants. Thus ten key environmental problems(impacts) comprising of global warming, acidification, eutrophication, eco-toxicity(acquatic, terrestrial and marine), abiotic depletion, human toxicity and ozone depletion are determined and environmental performance of the Integrated Steel Plant(ISP) is presented in the framework of :

- Process cycle impacts versus minimum and maximum impacts(best and worst scenarios) for the same level of steel production
- Pressure indicators for signifying impacts of ISP in relation to global impact values
- Performance indicators to specify environmental performance of ISP against maximum and minimum reference values for each of the ten impact categories for use in environmental claims and eco-labeling.
- An overall environmental index to rate and rank ISP's

2.0 Applicability of LCA to develop this model

Manufacturing in an ISP is a multistage process and interwoven with energy and material flows from one stage to another Due to the complex nature of the process the environmental aspects are many. LCA is a technique for assessing the environmental aspects and potential impacts associated with products or processes [1]. LCA techniques help in investigation of the environmental effects on land, air, water, human beings etc during production of steel. Therefore application of principles and techniques of LCA help in determination of environmental impacts. The environmental impacts thus determined are the basis for development of environmental indicators and an overall environmental index for ISP's.

3.0 Process cycle impacts as foundation for development of environmental indicators and index:

LCIA study done for the Indian Steel Industry [2] has established that in the life cycle stages of steel manufacturing - comprising of i) upstream process, ii)steel manufacturing process and iii)down stream process – the manufacturing process is responsible for the maximum environmental impact as given below:

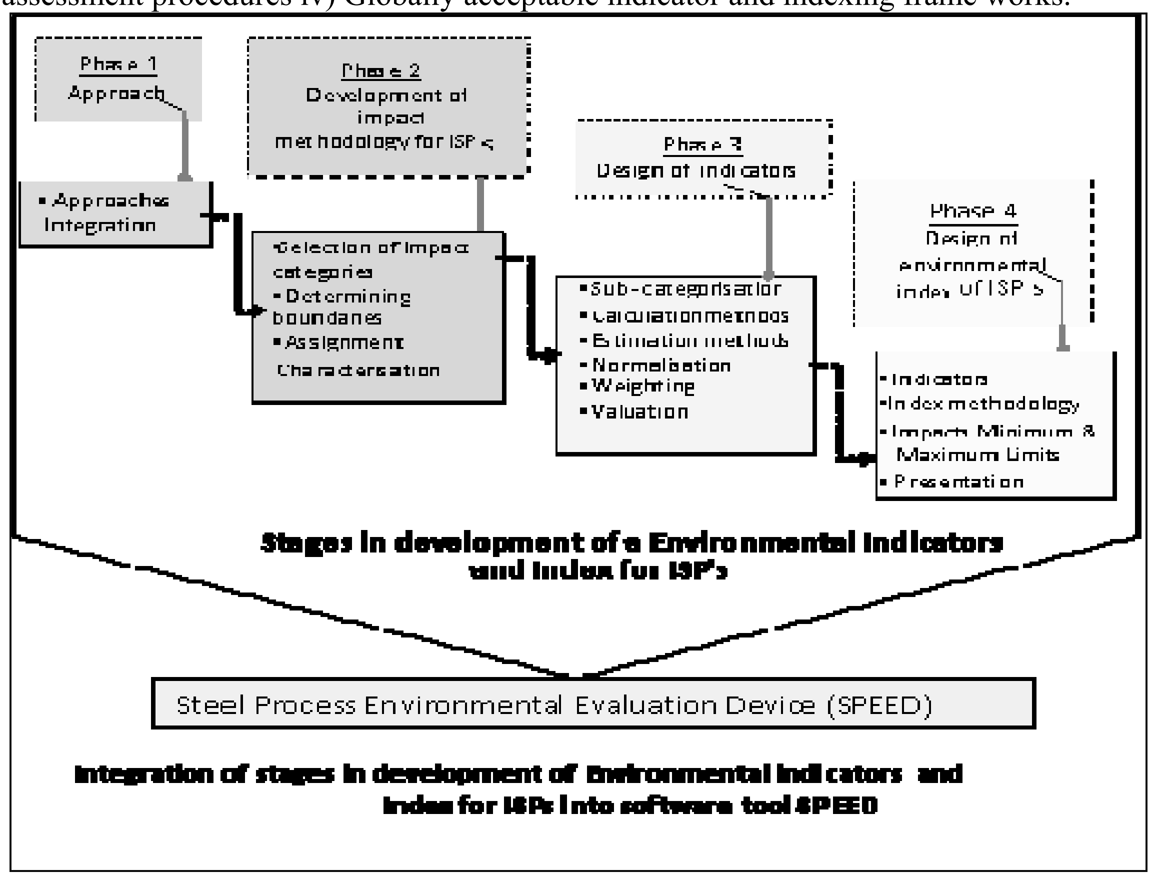
Table -1 Contribution of various life cycle stages of steel making to environmental impacts

Impact category	Upstream %	Steel Manufacturing process %	Total %
Greenhouse effect for 20 years	6.4	93.6	100
Air acidification	23.0	77	100
Water eutrophication	0	100	100

Downstream process need not be considered as manufactured steel products are totally recyclable and hence their impact on the environment is minimal.
Hence process cycle impacts (steel manufacturing process impacts) are the foundation for development of the environmental indicators and index.

4.0 Constitution of the model

The methodology for development of this model is accomplished in four phases.
In the first part extensive literature review is carried out in order to comprehend i) Steel manufacturing processes ii) Practical application of principles of Life Cycle Assessment iii) Selection of appropriate impact approaches and categories iii) Multistage impact assessment procedures iv) Globally acceptable indicator and indexing frame works.



The second and third phase involves designing of an impact model specific to ISP's.
Here about fifteen environmental flows(or environmental pressure variables) and varying number of material flows relevant to integrated steel plants are aggregated using process life cycle impact methods to arrive at ten categories of impacts comprising of Depletion

of abiotic resources, Global Warming, Stratospheric ozone depletion, Human Toxicity, Ecotoxicity-Acquatic, Ecotoxicity-Marine, Ecotoxicity-Terrestrial, Photo-Oxidation Formation, Acidification and Eutrophication.

These impacts are arrived at, through a multi-stage process comprising of identification of environmental flows relevant to ISP's, inventorisation, selection of appropriate impact approaches and category models, classification and characterisation. In the selection of impact categories, indicators for the categories and models to quantify the contributions of different environmental interventions to the impact categories are selected. Classification assigns the inventory data to the impact categories. In characterisation the models use validated characterization factors to make an aggregation of interventions within each impact category and arrive at impact results for each of the category. This process is done for all the ten categories of impacts using four methodological subcategories of quality and quantity of resources, environmental load on air, environmental load on water and the extent of material use.

The final phase engages in devising a method by which the impacts determined in phase two and three are utilised for development of pressure indicators and performance indicators. Pressure indicators are developed using normalization principle by relating the magnitude of the impact results in the different impact categories to global references values. Performance indicators are developed using time dependant rescaling technique. Here minimum possible impacts using best environmental flow reference values in ISP's and maximum impact values using maximum environmental flow values are determined. Then re-scaling techniques are employed to arrive at indicator values from zero to one for each of the impact category. Lower indicator value indicate better performance of the ISP in that impact category and vice-versa. The four phases are integrated to form the basis of the software tool 'Steel Process Environmental Evaluation Device'**(SPEED)**

5.0 Methodology adopted for development of environmental indicators and index:

The summary of different methodologies utilised to develop the model is summarized below:

i) Approach for determining: Mid-point or problem oriented approach which uses mid-point category indicators from the point of intervention for calculating the primary results of an intervention in a specific impact category

ii) Integration: LCA methods and indicator and index development methods are integrated together to develop the overall index model

iii) Selection of impact categories: This is done based on guidelines provided by CML [3] for baseline impact categories. CML has defined three problem oriented categories as category A B and C. Out of these three categories, Category A(Baseline impact categories) is chosen which includes impact category of :

Depletion of abiotic resources(AD), Global Warming(GW), Stratospheric ozone depletion(OD) , Human Toxicity(HT), Ecotoxicity (Acquatic(AET), Marine (MET) Terrestrial(TE), Photo-Oxidation Formation(POCP), Acidification(A) and Eutrophication(E) and Landuse(L)

iv) Assignment of environmental flows: This is done as per flows identified by IISI in their LCI studies and availability of scientifically acceptable characterization values

v) Characterisation models: Are chosen as per guidelines of CML[4] and given at table 2.

Table-2 – Characterisation models chosen

S.No	Environmental Impact category	Method status	Characterisation model	Reference
1	Global warming	Baseline	GWP 100	Houghton et al,1994,96
2	Stratospheric Ozone Depletion	Baseline	ODP_∞	WMO,1992,95,99
3	Human Toxicity	Baseline	HTP_∞	Huijbregts,1999
4	Ecotoxicity	Baseline	$FAETP_\infty$ $MAETP_\infty$ $TETP_\infty$	Huijbregts,1999
5	POCP	Baseline	High NOx POCP	Jenkin and Hayman 1999
6	Acidification	Baseline	Average European Acidification Potential	Huijbregts,1999
7	Eutrophication	Baseline	Generic Eutrophication Potential	Heijungs et al 1992
8	Abiotic depletion	Baseline	Based on ultimate reserves and extraction rates	Guinee & Heijungs

vi) Calculation methods: For Global Warming impact calculation two methods for determining CO_2 emissions from steel processes(which contributes to maximum CO_2 emissions) is adopted as recommended by GHG protocol[5]. One is based on estimation when quantities and qualities of carbon-bearing material are known. The other determines CO_2 emissions based on quantities of iron and steel produced and default values provided by IPCC.

For impacts category given at Table 2(sl no-2 to 7) - two methods of calculating environmental loads is adopted in the methodology. One method is based on actual monitoring values and the other is based on estimated values depending on the type of pollution control equipment adopted by the ISP. However for determination of Abiotic depletion impact,there is only one method of estimation i.e based on actual monitoring values.

v) After evaluation of actual impacts, normalization of the impacts is done using, World 1995 normalisation values specified against each category are utilized.

vi) Weighting: Weighing of environmental concerns has been done using values provided by Statistics Finland used in development of Environmental Friendliness Index.[6]

vii) Indicators and Index : Are developed as per the P-S-R framework of OECD. Threshold or reference values are adopted from IISI's, global LCI studies [7]and European Union's, Best Available Technologies[8] documents. Values of environmental flows from the ISP under evaluation are aggregated into impacts using LCIA methods. They are then compared with minimum impacts and maximum impacts for the same level of steel production by utilising best and worst environmental flow values provided by these documents(after they are aggregated into impacts using similar LCIA methods).

viii) Methodology adopted for indicator and index development is the mathematically proven re-scaling technique.

ix) Values of impacts and indicators, for all the ten categories, are finally tabulated for presentation of impacts, indicators and index.

Table 3 Tabulation of indicators and index

S.No	Impact Category	Minimium Impact	Maximum Impact	Actual Impact	Units	**Pressure indicators**		**Performance indicators**	
						Actual Pressure Indicator	Weighted Pressure Indicator	Actual performance indicators	Valuation
1	Global warming Impact								
2	Acidification								
3	Human Toxicity								
4	Ecotoxicity-Acquatic								
5	Ecotoxicity-Marine								
6	Ecotoxicity-Terrestrial								
7	Photo-oxidation								
8	Eutrophication								
9	Depletion of abiotic resources								
10	Stratospheric ozone depletion								
					Overall performance index				

5.1Valuation of the indicators and the index

The final step involves the valuation of index scores, in other words comparing scores with a predetermined classification of what constitutes good or poor values. Classification of both the indicators and the index is done in five bands as given below:

Table 4 Valuation criteria

Indicator		**Overall Performance Index**	
Range	*Valuation*	*Range*	*Valuation*
0.19<	Very Good	1.9<	Poor
0.20 to 0.39	Good	2.0 to 3.9	Below Average
0.40 to 0.59	Average	4.0 to 5.9	Average
0.60 to 0.79	Below Average	6.0 to 7.9	Good
0.80 to 1.0	Poor	8.0 to 10	Very Good

6.0 Requirement of SPEED as a tool

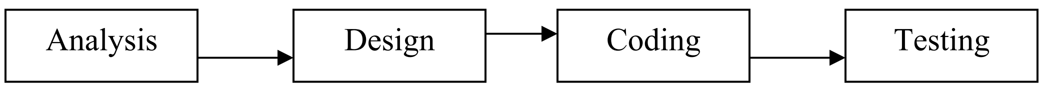
SPEED facilitates multi-stream and multi-stage Integrated Steel Plants in determining process cycle impacts. It further facilitates in systematic application of principles of indicator and index development. It thus acts as a handy tool for ISP's to evaluate their environmental performance. SPEED a software tool is developed primarily to facilitate construction of environmental indicators and index, which is a multilayered process comprising of evaluation of ten categories of process cycle impacts, conversion to indicators and an overall index - in a multi-stream and multi-stage ISP. At the same time SPEED is essential as it makes possible reliable application of principles of indicator and index development(OECD's guiding principles-[9]). It also offers a systematic and convenient means for assessing environmental performance of any multi-streamed and multi-stage ISP.

7.0 Design of SPEED

SPEED is designed to integrate processes and methods and arrive at desired reports of impacts, pressure and performance indicators and an overall environmental index.

Model adopted for software development:

For achieving the defined requirements, Linear Sequential Model[10] is adopted. Linear Sequential Model suggests a systematic, sequential approach to software development that begins at the system level and progresses through analysis, design, coding and testing as shown below



Linear Sequential Model for SPEED

8.0 Critical aspects of the model

The model presented herewith, for environmental performance evaluation of ISP's, is designed to meet three universal criteria prescribed by OECD[9] while constructing any environmental indicators or index . These three criteria are:

- Analytical soundness
- Policy relevance and utility for users(Usability and suitability) and
- Measurability

8.1 Analytical Soundness

For the model to be analytically sound it needs to:

i) Be theoretically well founded in technical and scientific terms.

ii) Be based on international standards and international consensus about its validity and

iii) Lend itself to being linked to economic models, forecasting and information systems

8.1.1 Be theoretically well founded in technical and scientific terms.

Indicator and index development which basically involves four stages of selection, transformation, weighing and valuation, has been done purely on analysis of technical requirements. Environmental variables for determining impacts have been selected only for those flows with scientifically established characterisation values.

Transformation of these variables into impacts has been done using scientific principles of LCIA.

Indicator's have been developed on time dependant and mathematically proven rescaling techniques [13]. Weighting of the indicators has been done using weighed values [6] that are determined using Analytic Hierarchy Process (AHP) which is a widely used technique for multi-attribute decision making.

8.1.2 Be based on international standards and international consensus about its validity

The process of collating data on environmental variables, assigning values and arriving at impacts are done on widely accepted ISO standards of LCA [11].

Environmental flows (pressure variables) selected here are based on consensus arrived at by Worldsteel(formerly IISI) in their LCI inventory study [7]

Environmental impacts, which are the foundation of indicator and index building have been evaluated using LCIA methods. Out of two LCIA approaches i.e Mid-point and end-point approach, the mid-point approach is chosen for determining impacts, since these are recommended by a group of experts on LCA methodology development and implementation[3].

Characterization model chosen in the themes have been selected after assessing their scientific validity, environmental relevance, international acceptability, value choices of assumptions, focal point of environmental mechanism, linearity, time span, fate(exposure,intake,effects), less is better, time and location independence, operational convenience and uncertainty margins. Characterisation values and normalization values are chosen from models developed by i) CML, Institute of Environmental Sciences, Leiden University and SETAC ii)IPCC. They and are widely accepted by International Organisations such as UNEP, IISI etc.

The indicators and index have been developed in the Pressure-State-Response framework, widely accepted and propagated by OECD.

8.1.3 Lend itself to being linked to economic models, forecasting and information systems

The output of the software tool 'SPEED' developed provides information that can be easily linked with economic models such as economic performance of a ISP and can assist in forecasting of environmental performance based on economic conditions of an ISP. For example if an ISP needs to determine on choice of process equipment or pollution control investments, it can enter the environmental pressure variables data estimated from each of the equipment, into SPEED and determine the environmental impacts. From this a trade–off between choice of process equipment or pollution control equipment and investments can be made.

8.2 Policy Relevance and Utility Criteria

Any type of environmental indicators/index that are developed should be relevant to the requirement and also be useful. For this it is necessary that they:

8.2.1 Provide a representative picture of environmental conditions or pressures on the environment

The environmental pressures due to steel production in an ISP are presented in the form of environmental impacts of global warming, acidification, eutrophication, eco-toxicity(acquatic, terrestrial and marine), abiotic depletion , human toxicity and ozone depletion.- which together or individual present environmental conditions.

8.2.2 Be simple, easy to interpret and able to show trends over time

The indicators are presented in dimensionless numbers, on a scale of 0 to 1 and the overall index is also presented on a one to ten scale. They are therefore easy to interpret both by the expert and the non-expert. SPEED is designed for evaluation of indicators and index over a time period of one year and therefore its reports can be used to see trends over time for any ISP that is being evaluated.

8.2.3 Be responsive to changes in the environment and related human activities

Indicators and index are developed using about 20 environmental flow variables relevant to an ISP. As environmental flows are the basis for construction of the indicators and the index - any change in their quantities will correspondingly reflect change in the indicators and the index

8.2.4 Provide a basis for international comparisons

Methodology is developed utilising internationally acceptable methods of LCA, indicator and index development and reference flows. It is a generic model for an ISP following the BF-BOF route of steel production and can be used internationally, irrespective of spatial extensions. It therefore lends itself for international comparisons.

8.2.5 Be either national in scope or applicable to regional environmental issues of national significance.

Ten categories of impacts are evaluated. These impacts deal with local, regional and global environmental issues and can therefore be connected to local, regional or national environmental issues.

8.2.6 Have a threshold or reference value against which to compare it, so that users can assess the significance of the values associated with it.

Threshold or reference values are provided from IISI's, global LCI studies [7]esults, 2002]and European Union's, Best Available Technologies[8] documents. Values of environmental flows from the ISP under evaluation are aggregated into impacts using LCIA methods. They are then compared with minimum impacts and maximum impacts for the same level of steel production by utilising best and worst environmental flow values provided by these documents(after they are aggregated into impacts using similar LCIA methods) Hence ISP's can compare and assess the significance of their impact values with best and worst impact scenarios.

8.3 Measurability

Any development of environmental indicators need to fulfill criterion of :

i) The data required to support the indicator should be readily available or made available at a reasonable cost/benefit ratio.

ii)The data required to support the indicator should be adequately documented of known quality and updated at regular intervals in accordance with reliable procedures.

iii) The data required to support the indicator should be updated at regular intervals in accordance with reliable procedures.

8.3.1 The data required to support the indicator should be readily available or made available at a reasonable cost/benefit ratio.

Environmental flows such as particulate matter, SOx , NOx, volumetric quantities for air emissions, Ammonia, COD and nitrates in effluents, Ozone Depleting Substances etc used in this work are monitored on a regular basis by ISP's- as measurement of these environmental flows is statutory . Information on quantities of coal, iron ore and are accurately measured and monitored by ISP's for reasons of techno-economics and eco-efficiency. Only some parameters, such as organic emissions and heavy metal emissions etc that are used in the model - need to be monitored for arriving at the environmental indicators and index proposed in the model.

8.3.2 The data required to support the indicator should be adequately documented of known quality and updated at regular intervals in accordance with reliable procedures.

More than 80 ISP's are participating in the global initiative on Life Cycle Inventorisation(LCI). LCI process has an elaborate system of data validation and documentation. Hence the data for this model can be acquired following these reliable procedures. Also the impetus for this requirement requires needs to be fulfilled by the user of the model.

8.3.3 ***The data required to support the indicator should be updated at regular intervals in accordance with reliable procedures.***

SPEED provides the means for updating indicator data on a yearly basis.

9.0 Usability of the model

9.1 Environmental impacts and performance

The work provides a platform by which individual ISP's can evaluate their impacts and compare their environmental performance with world wide best practices For the stake holders it provides a convenient means to understand environmental performance of the ISP, rate their environmental performance, rank different ISP's on the basis of their environmental performance.

9.2 Environmental declarations and eco-labelling

The model also provides a technical and scientific platform for environmental labels and — Type III environmental declarations [ISO 14025, 2006]. This is because it fulfills all the requirements of the standard[ISO 14025, 2006] for environmental declarations and eco-labeling vis-à-vis

i) LCA-based information and additional information on the environmental aspects of products

ii) Assists purchasers and users to make informed comparisons between products and

iii) Encourages improvement of environmental performance

An snapshot view of different impacts, indicators and index obtained through use of SPEED is given in the last page of the paper.

10.0 Conclusion

Sustainable development is the prevailing paradigm for balancing society's environmental, social and economic goals. It offers a framework within which the appropriate combination of consumption and preservation can be obtained . In promotion of this concept of sustainable development it is often seen that environmental problems are social problems and that playing economic development goals against environmental goals is inappropriate and ineffective because the two are interconnected and mutually dependent. Therefore environment management becomes the key driving force to achieve sustainable development goals.

Process industries to a large extent can achieve their sustainable development goals by tuning their environmental performance. Many methods have been promulgated by various organizations for process industries to measure their environmental performance in order to manage it and to demonstrate their achievements. However these methods are handicapped as they do not represent actual environmental conditions or pressures on the environment, are not easy to interpret if different units are used, do not have reference to threshold values against which to compare, choice of 'one out of many' indicators is subjective and do not provide a basis for 'one to one' comparison. Moreover no method exists to rate or rank the environmental performance of a industry using these indicators as it is difficult to find a trend in separate indicators.

The method proposed in this paper is based on LCA principles and it categorically divulges environmental performance information of an process industry(ISP in this case) – that can be understood from the scientists to the common man, in the realm of their own perspective.

Therefore the method helps ISP's provides a theoretically well founded scientific and technical basis for assessment of their environmental performance by way of:

- Understanding the degree of environmental stress resulting from their activity
- Understanding which of the environmental pressures are of concern and how important one is in relation to the other
- Comparing their environmental performance with each other
- Benchmarking their own environmental performance against threshold or reference values

In addition to the above, this method provides for all stake holder's of the ISP wherein a simple system for assessment is devised that can easily:

- Judge how the ISP is faring on different aspects of environment
- Understand where the ISP's stands in comparison to international reference values and
- Rate and rank ISPs
- Develop eco-labeling procedures for steel products using type III environment declarations

Similar system can be adopted for other process industries and thereby promote environmental friendliness by them

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Environmental Indicators and Index for Integrated Steel Plants

Year 2003 Organization ABC Steel Plant

Overall Index
0-10 scale
The higher the better

Utility → Environmental declarations / Eco-labels / Rating

<------ Pressures ------> <------ State ------>

Impact Category	Minimum Impact	Maximum Impact	Actual Impact	Unit	Actual Pressure Indicator	Weighted Pressure Indicapr	Actual Perf. Indicator	Valuation
Global Warming Impact(GWI)	6104358480.00	15846774284.00		Kg CO2 equivalent/yr			0.68	Below Average
Stratospheric ozone depletion(OD)	0.00	1684428.00		Kg CFC-11 equivalent/yr			0.99	[redacted]
Acidification(A)	395380.00	15220551.30		Kg SO2 equivalent/yr			0.15	[redacted]
Human Toxicity(HT)	562416140.05	2882526523.22		Kg 1.4 dicholorobenzene equival			0.53	Average
Ecotoxicity-Acquatic(AET)	173258.88	1101297.14		Kg 1.4 dicholorobenzene equival			0.56	Average
Ecotoxicity-Marine(MET)	24229195.15	898523637.04		Kg 1.4 dicholorobenzene equival			0.68	Below Average
Ecotoxicity-Terrestrial(TET)	185888.52	5075230.86		Kg 1.4 dicholorobenzene equival			0.12	[redacted]
Photo-Oxidation Formation(POCP)	110327.51	1067911.91		Kg ethylene equivalent/yr			0.30	Good
Eutrophication(E)	32392.04	180462.38		Kg PO4 equivalent/yr			0.08	[redacted]
Depletion of abiotic resources(AD)	54504305.74	160616710.87		Kg antimony equivalent/yr			0.13	[redacted]
Overall Peformance Index							[redacted]	Average

Exit

Indicator Description

Utility

Impact values

Impact values evaluated based on yearly steel production

- Information on pressures on environment
- Information on best, actual & worst scenarios
- Policy decisions
- Consent clearances
- Investment decisions

Pressure indicators

Impact indicators w.r.t to world reference impacts

- Information on relative significance
- To estimate assimilated impact contributions of ISP

Performance indicators

Performance w.r.t reference values
0-1 scale
The lower the better

- Performance valuation on various environmental aspects.

Snapshot of environmental performance of an Integrated Steel Plant showing process impacts, pressure and performance indicators and their utility