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SUSTAINABILITY METRICS FOR COAL POWER GENERATION IN AUSTRALIA

J. C. DINIZ DA COSTA[1]* and R. J. PAGAN[2]

[1]*Division of Chemical Engineering, School of Engineering, The University of Queensland, Brisbane, Australia*
[2]*UNEP Cleaner Production Centre, School of Geographical Sciences and Planning, The University of Queensland, Brisbane, Australia*

The basis of this work was to investigate the relative environmental impacts of various power generators knowing that all plants are located in totally different environments and that different receptors will experience different impacts. Based on IChemE sustainability metrics paradigm, we calculated potential environmental indicators (P_{EI}) that represent the environmental burden of masses of potential pollutants discharged into different receiving media. However, a P_{EI} may not be of significance, as it may not be expressed at all in different conditions, so to try and include some receiver significance we developed a methodology to take into account some specific environmental indicators (S_{EI}) that refer to the environmental attributes of a specific site. In this context, we acquired site specific environmental data related to the airsheds and water catchment areas in different locations for a limited number of environmental indicators such as human health (carcinogenic) effects, atmospheric acidification, photochemical (ozone) smog and eutrophication. The S_{EI} results from this particular analysis show that atmospheric acidification has highest impact value while health risks due to fly ash emissions are considered not to be as significant. This is due to the fact that many coal power plants in Australia are located in low population density air sheds. The contribution of coal power plants to photochemical (ozone) smog and eutrophication were not significant. In this study, we have considered emission related data trends to reflect technology performance (e.g., P_{EI} indicators) while a real sustainability metric can be associated only with the specific environmental conditions of the relevant sites (e.g., S_{EI} indicators).

Keywords: sustainability metrics; environmental impacts; human health; atmospheric acidification; photochemical (ozone) smog and eutrophication.

INTRODUCTION

Indicators have been used for long time to determine the performance of various sectors of our society such as industrial (i.e., productivity), economics (i.e., inflation, rate of interest or gross national product), or social (number of doctors, number of schools, literacy). In terms of environment, biologists have been using indicators to gauge ecosystem health for many years. Indicators are typically numerical measures that provide key information about a physical, social, economic (Veleva and Ellenbecker, 2001), health or environmental system. Indicator development has led to the introduction of sustainability indicators, which incorporate different dimensions such as quality of life, biodiversity for example (Bell and Morse, 1999). There are numerous suggested indicators lists and matrices, but a remaining problem is how these diverse indicators should be integrated into a single answer (Morse *et al.*, 2001). In addition, there are different dimensions to these problems depending upon the ability of the environment to buffer, control and treat any environmental impact. Hence, it is suggested that all environmental data be normalized after which step the data can be standardized and/or aggregated towards specific indicators (Olsthoorn *et al.*, 2001).

The literature contains several methodologies about generic and tailor-made indicators and an excellent overview is given elsewhere (Warhurst, 2002). One example of a generic 'off the shelf' methodology is 'Sustainability Metrics' proposed by the Institution of Chemical Engineers UK (IChemE, 2002), which is applicable to process industry. Similarly, the US Environmental Protection Agency TRACI methodology assesses environmental stressors (Bare *et al.*, 2003) for chemical and environmental impacts. An advantage of sustainable metrics is that environmental impacts can be aggregated and the environmental performance of different plant sites can be effectively compared, facilitating benchmarking. However, generic methodology

*Correspondence to: Dr J. C. Diniz da Costa, Division of Chemical Engineering, School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia.
E-mail: joeDaC@cheque.uq.edu.au

can be criticized for not being site specific, as environmental impacts are often largely related to the site impacted upon. In other words, a specific environmental indicator as a source of information has more meaning then generic environmental indicators.

The methodology proposed in this study is derived from the Sustainability Metrics (IChemE, 2002) methodology instead of a full Life Cycle Assessment (LCA) model. From this we calculated potential environmental indicators (PEIs) that are simply masses of potential pollutants discharged into different receiving media. However, as previously stated, a potential impact may not be of significance, so we try to build in some receiver significance. Hence, environmental data were acquired to identify environmental characteristics of the air sheds and water catchments in different locations to determine a normalized 'dose' of the pollutants.

To test the proposed methodology, this work also addresses the results associated with emissions of four hypothetical coal power generators in four different regional ecosystems (e.g., air sheds and catchment areas) in Australia. The sustainability metrics of the operation of these hypothetical coal power plants are assessed in terms of potential (P_{EI}) and specific (S_{EI}) environmental indicators. Therefore, this approach formalizes the assessment of relative sustainability metrics of environmental impacts of power generators knowing that plants are located in totally different environments and that different receptors will hence experience different impacts.

SUSTAINABILITY METRICS

Potential Environmental Indicators (P_{EI})

The EB_i, is the ith environmental burden caused by a substance upon the receiving environment (IChemE, 2002) determined by

$$EB_i = \sum_{i=1}^{i=n} (W_N)(PF_{i,N}) \tag{1}$$

where W_N is the weight of substance N emitted, including accidental and unintentional emissions, and $PF_{i,N}$ is the potency factor of substance N for the ith environmental burden. The Institution of Chemical Engineers has published a large potency factor list for different substances (IChemE, 2002). The above equation implies that an environmental burden can be assessed by simply summing a set of pollutants multiplied by their potency factors. Obviously no value judgments about relative harm are implied.

In this study, P_{EI} is derived from the EB method proposed by the IChemE and normalized by dividing the total mass load emitted per year by the total area impacted upon by the emission. The P_{EI} indicates a potential for environmental impact rather than an actual environmental impact. For a selected environmental indicator such as human health impact, there are several components in the fly ash for example which may contribute to the P_{EI} which is determined as follows:

$$P_{EI} = \frac{\sum_{i=1}^{i=n} (EB_1 + EB_2 + \cdots + EB_n)}{A_{imp} \cdot t} \tag{2}$$

where P_{EI} is the potential environmental harm indicator for the main coal power emission substances, A_{imp} is the surface area where an impact occurs and t is time.

The P_{EI} can be viewed as a technology indicator. The coal power plants which are intrinsically more efficient in tandem with a high degree of emission control obviously will show lower P_{EI} values. Technological indicators are easy to measure, and of course many of them have to be measured for process control, economic analysis and compliance with environmental regulations. The P_{EI} is by no means a measure of environmental impact as it assumes that all environments are similar. However, in the context of this work, P_{EI} is viewed as a relative measure of potential environmental impacts.

Specific Environmental Indicators (S_{EI})

S_{EI} indicators are developed to determine whether the emissions upon a receiving environment can cause an impact or not. If the environment has the ability to treat and buffer the emissions, than impacts are not considered significant. One simple example is if there is no rain or if soils are alkaline, then emissions relating to acidification impacts on soil and water do not breach the carrying capacity of the local ecosystem. The approach to determine the S_{EI} is derived from P_{EI} as formulated above. The S_{EI} is the sum of the specific environmental burden (SEB) for the air shed and/or catchment area associated with the specific environmental conditions of each coal power station, as follows:

$$S_{EI} = \frac{\sum_{i=1}^{i=n} (SEB_1 + SEB_2 + \cdots + SEB_n)}{A_{imp} \cdot t} \tag{3}$$

where SEB relates to a single substance and/or compound as a function of the environmental burden (EB) times an specific environmental dose value (K) as follows:

$$S_{EB_i} = (EB_i)(K_i) \tag{4}$$

When dealing with environmental doses, a single substance may have different impacts upon the gas, solid, liquid phases, including both organic and inorganic systems. Hence, K dose values can be derived from a function (f) of several environmental parameters (α).

$$f = \alpha_1, \alpha_2, \ldots, \alpha_n \tag{5}$$

To approach this problem, we propose to employ a simple linear relationship of single or multiple dimensionless average environmental parameters (α).

$$f = \frac{\alpha_1 + \alpha_2 + \cdots + \alpha_n}{n} \tag{6}$$

A second issue relates to whether to use absolute values or normalized values. For instance, the pH range in soils may vary from 4 to 9 while the receiving population may vary from a few thousand to millions of people depending of the location of the coal power plant. As environmental parameters have values differing by several orders of magnitude, then absolute environmental values for comparison purposes will be meaningless. Hence, normalized values can provide a valuable scale as shown in equation (7), where the environmental dose value '*Ki*' represents a function of environmental parameters (α) scaled over the highest function value '*i*, *high*'.

$$K_{\mathrm{i}} = \frac{f_{\mathrm{i}}}{f_{\mathrm{i,high}}} = \frac{(\alpha_1 + \alpha_2 + \cdots + \alpha_{\mathrm{n}}/n)_i}{(\alpha_1 + \alpha_2 + \cdots + \alpha_{\mathrm{n}}/n)_{i,high}} \tag{7}$$

This approach makes the case for a *relative* assessment in order to allow ease of comparison between the S_{EI} of different power stations at different sites. This approach can be criticized for several reasons. For instance, the relationships between emissions and environment are very complex and cannot be simply described by an average parametric linear relationship. Some of the parameters used may have a higher impact factor than others and so forth. However, the aim of this approach is to provide a yard stick that can measure the *relative relationships* between coal power generation plants and their surrounding environment. The sole purpose of this relationship is to compare the environmental performance of plants against each other and benchmark. By adopting this simplified view point, the development of S_{EI} and dimensionless parameters are described by two cases. In case 1, the value dose K is always less than one unit value, thus the potential environmental indicator has a higher value than the specific environmental indicator. On the other hand, case 2 shows that the value dose K is at its maximum of one unit value, reflecting that the potential and specific environmental indicators are of the same value.

Case 1

$$S_{\mathrm{EIi}} < P_{\mathrm{EIi}} \tag{8}$$

if

$$K_{\mathrm{i}} = \frac{f_{\mathrm{i}}}{f_{\mathrm{i,high}}} < 1 \tag{9}$$

Case 2

$$S_{\mathrm{EIi}} = P_{\mathrm{EIi}} \tag{10}$$

if

$$K_{\mathrm{i}} = \frac{f_{\mathrm{i}}}{f_{\mathrm{i,high}}} = 1 \tag{11}$$

ENVIRONMENTAL INDICATORS

Atmospheric Acidification

Atmospheric acidification is related to the release of SO_2 and NO_2 gases (IChemE, 2002). These emissions are derived from anthropogenic activities (industrial and transportation) and natural systems. For instance, one-quarter of the sulfur in the atmosphere is natural, the rest is caused by human activity (Ayers and Gillet, 1996). Nature releases sulfur through decomposing marine algae and erupting volcanoes. Industry releases sulphur dioxide when fossil fuels are burnt and sulphide ores smelted. Sulphur oxides form sulphuric acid once released in the air resulting in acid rain (Spiro and Stigliani, 2003). NO_x are generated by lightning and microbes, and by burning of fossil fuel and biomass. In the atmosphere the oxides are often transformed into nitric acid (Ayers and Gillet, 1996). Eventually, the acids precipitate from the atmosphere, and dry deposition is washed off surfaces, reaching the natural system (soils and watercourses) (Kinross, 2002). Acid rain (pH $<$ 5.6) has been associated with a number of environmental problems including the acidification of lakes and loss of aquatic life, leaching of trace minerals from forest soils, acidification of drinking water, metal corrosion and damage to limestone buildings, monuments and automobile paintwork (AEC, 1989).

The first order parameter is rainfall which is directly related to acidification. The second order parameter is the soil pH which gives an indication of whether the soil can buffer or augment the pH in receiving natural water systems. The rainfall parameter is determined by the frequency of rain per year in the air shed. As rain frequency increases per year, so may acidification. Hence, the dimensionless rainfall parameter in equation (14) increases if the frequency of precipitation increases. If there is no precipitation, then the rainfall parameter equals zero.

Case 1 (no rain)

$$\alpha_{\mathrm{rain}} = 0 \tag{12}$$

Case 2 (if rain)

$$\alpha_{\mathrm{rain}} = \frac{rf_{\mathrm{rain}}}{365\ \mathrm{days}} \tag{13}$$

where rf_{rain} is the number of rainfall days in one year period.

The soil parameter indicator is determined by the ability of the local soil to buffer acidification. If soils are alkaline, (pH $>$7), then acidification of soils and water is not significant. However, if soils are slightly acidic, then acidification is relevant. Hence, the following relationship applies.

Case 1 (if soil pH > 7)

$$\alpha_{\mathrm{soil}} = 0 \tag{14}$$

Case 2 (if soil pH < 7)

$$\alpha_{\mathrm{soil}} = \left(1 - \frac{\mathrm{pH}_{\mathrm{soil}}}{\mathrm{pH7}}\right) \tag{15}$$

Hence, the atmospheric acidification parameter is determined as follows:

$$f_{\mathrm{atm,acid}} = \frac{\alpha_{\mathrm{rain}} + \alpha_{\mathrm{soil}}}{2} \tag{16}$$

Human Health (Carcinogenic) Effects

Unlike global warming, there are no internationally accepted potency factors for human health (IChemE, 2002). Hence, IChemE uses values derived from the reciprocal of occupational exposure limits (OEL) set by the United Kingdom Health and Safety Executive. Many of the substances listed by IChemE include trace elements (Ar, Cd, Ni, Si) and their compounds that are also listed as a risk to health, and are generally found in particulate matter (PM). The TRACI methodology also incorporates SO_2 and NO_x emissions that may lead to the formation of so-called secondary particulates sulfate and nitrate (Bare *et al.*, 2003). Epidemiological studies carried out on a large population basis (500 000 people) have shown that the small particles can cause respiratory problems (Pope *et al.*, 2002). In addition, an increase of 1% the in death rate and a 2–4% increase in hospitalization rates for the elderly was attributed to a small increase of fine particulate matter (PM_{10}) emissions (Samet *et al.*, 2000). More recently, there are large concerns with $PM_{2.5}$ or even smaller particle sizes (between 1–2 microns). These particles are believed to be even more hazardous as they can penetrate deeply into the alveoli and are not easily coughed up (ICAC, 2002). A note of caution must be observed when discussing epidemiological studies, which many times do not take into consideration other causes related to lifestyle, job stress, and so on. Nevertheless, these studies provide important information for causal relationships in health problems.

PM emissions are mainly attributed to fly ash, which is a residue of pulverised fuel (PF) coal power stations, although most flue gas systems achieve approximately 99% entrapment of particulate matter (Wibberley *et al.*, 2001). The particles that are released are generally in the range of less than 1 μm to 10 μm (PM_{10}). The smaller particles (less than 1 μm) can travel large distances as they have extremely low settling velocity and need to be removed by processes such as rain, snow or fog. However particles larger than 1 μm generally fall within 20 km of their source, which may have significant environmental impacts if urban areas are within 20 km from power plants. Hence, the following relation applies where $P_{20\,km}$ is the population within a 20 km radius

$$\alpha_{pop} = P_{20\,km} \qquad (17)$$

Photochemical (Ozone) Smog

Petrochemical derived substances can react with gases from combustion processes (NO_2, SO_2 and CO) (IChemE, 2002) producing ozone photo-chemically and leading to smog. Photochemical smog is the atmospheric haze that is found near many large cities and is due to the action of sunlight on the hydrocarbons and the nitrogen oxides emitted by factories and car exhausts (Sciencenet, 2003). The formation of photochemical smog requires sunlight, hydrocarbons and NO_2, and temperatures above 18°C (van Loon and Duffy, 1999; Sciencenet, 2003; Spiro and Stigliani, 2003). Nitrogen dioxide (NO_2) plays an important role in the sense that it absorbs sunlight in the blue region (400 nm) resulting in smoggy air (Spiro and Stigliani, 2003). The photo excited NO_2 disassociates into nitrogen oxide (NO) and oxygen (O). The latter reacts with a molecule of oxygen (O_2) resulting in the formation of ozone (O_3).

Photochemical smog is therefore largely related to the amount of NO_x concentration in an air shed, the local climatic (i.e., temperatures) conditions, industrial and transportation activities. In this study, we are assuming that the former is the most important effect and the only one to be directly related to air emissions from coal power generations as a concentration parameter as shown in equation (18). Nevertheless, the other indirect factors should also be parameterized in future studies.

$$\alpha_{ozone} = \frac{V_{emission}}{V_{shed}} \qquad (18)$$

where $V_{emission}$ is the total volume of NO_x emissions per year and V_{shed} is the volume of the air shed in which the coal power station is located.

Eutrophication

Eutrophication is defined as the potential for over-fertilization of water and soil, which can result in growth of biomass (IChemE, 2002). Nitrogen and phosphorous are major contributors to the eutrophication process, and in particular NO_x emissions from coal power generators are of environmental concern. Over-fertilization disrupts the natural cycle, leading to a higher population of phytoplankton, and producing algal blooms (Spiro and Stigliani, 2003). This situation can lead to depletion of oxygen in water, once the algae dies off, resulting in killing of fish and other life forms in water bodies.

In this case we assume that NO_x concentrations dispersed over an air shed is constant. Hence, the eutrophication indicator will be a function of the total water surface *A* (water) available in an air shed and/or catchment area.

$$\alpha_{eutrophication} = A(\text{water}) \qquad (19)$$

RESULTS AND DISCUSSION

Table 1 lists generic data from the Australian National Pollutant Inventory (NPI, 2003) for four hypothetical coal power generators in four different regional ecosystems (e.g., air sheds and catchment areas) in Australia. The sustainability metrics of the operation of these hypothetical coal power plants are therefore assessed in terms of potential (P_{EI}) and specific (S_{EI}) environmental indicators. Relevant environmental data was acquired as follows:

- population data—Australian Bureau of Statistics (CDATA, 2001);
- airsheds in catchment areas—Geoscience Australia (GeoscienceAustralia, 2000) and Australian Bureau of Statistics (CDATA, 2001);

Table 1. Generic data about coal power generation plants in Australia.

Coal power plant	#1	#2	#3	#4
Power (MW)	1400	900	500	200
Efficiency (HHV)	35%	32%	39%	30%
NO_x (kg/MWh)	4.22	2.89	3.02	3.48
SO_x (kg/MWh)	2.69	4.05	2.53	4.64
PM_{10} (kg/MWh)	0.68	0.13	0.15	0.03
Air shed area (km^2)	20 825	17 139	63 946	6811
Soil pH	5.8	5.7	6.4	7.3
Rain frequency (days/year)	92	95	53	66
Population <20 km	5749	274 955	1075	812
Water area (km^2)	125.3	3.5	14.2	244.7

- soil pH in catchment areas—National Land and Water Resources (NLWRA, 2001);
- water catchment areas—Geoscience Australia (GeoscienceAustralia, 2001);
- rainfall data—climate impact and natural resources systems (SILO, 2003).

Note that this work considers the given emission items as mid-point rather than end-point activities. All data acquired gives an indication of average values over a spatial (e.g., catchment area or airshed) and temporal scale (e.g., one year). In addition, we do not attempt to examine solid and liquid discharges of coal power generators to waterways or onto land. The potency factors for NO_x and SO_x are those indicated by the IChemE while the PM_{10} values for human health indicators were derived from the average concentration of trace elements (Sb, Ni, As, Cd, Co and Cr) in Australian fly ash coals.

A summary of the P_{EI} index is shown in Table 2 and Figure 1. It is obvious that atmospheric acidification is potentially larger than the other environmental impacts. This is mainly associated with the fact that Australian coal-fired plants operate without desulphurization units, as Australian coals generally have a low sulphur content. With regards to technology performance, plant #1 resulted in the worst P_{EI} which is directly attributed to a higher SO_x, NO_x and fly ash emission. Eutrophication, photochemical (ozone) smog and atmospheric acidification play a minor relative role and these impacts are not considered significant. In terms of technological performance, the local P_{EI} index indicates the following:

- Human health: high emission of PM_{10} and smaller particle fractions increase human health carcinogenic risks. Hence fly ash containment by means of high quality coal washing and bag filters may reduce the human health P_{EI}.
- Eutrophication: mainly related to NO_x emissions. The introduction of low NO_x burners will reduce eutrophication P_{EI}.
- Atmospheric acidification: Australian coals have low sulphur contents and power generation plants generally do not have SO_x removal systems. In this case, scrubber would reduce atmospheric acidification P_{EI}.
- Photochemical smog and human health have relatively small P_{EI} values.

Table 2. Overall P_{EI} and S_{EI} results.

P_{EI}	Atmospheric acidification	Human health	Photochemical (ozone) smog	Eutrophication	Total P_{EI}
#1	3.16	1.204	0.14	0.61	5.11
#2	2.65	0.148	0.12	0.33	3.25
#3	0.30	0.095	0.01	0.05	0.46
#4	1.73	0.008	0.08	0.22	2.04
S_{EI}	Atmospheric acidification	Human health	Photochemical (ozone) smog	Eutrophication	Total S_{EI}
#1	2.92	0.0252	0.14	0.31	3.40
#2	2.65	0.1480	0.09	0.005	2.89
#3	0.16	0.0004	0.001	0.003	0.16
#4	0.69	0.0000	0.04	0.22	0.95

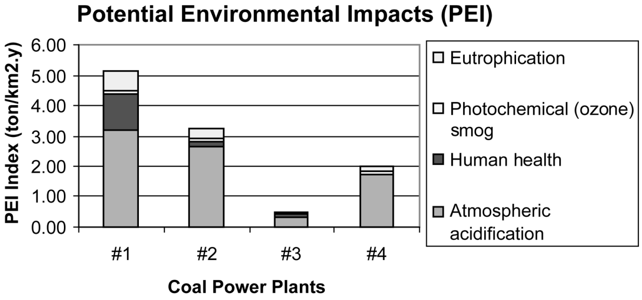

Figure 1. PEI index of coal power plants.

The S_{EI} index offers a different view of sustainability performance indicators, as it integrates the technological index (P_{EI}) with specific environmental parameters. The local S_{EI} indicators shown in Table 2 and Figure 2 reveal the following:

- Human health: power generation plants built and operating close to large population centres will be exposed to a relatively large and significant environmental impact on health issues as observed for plant #2. Hence, site planning will be fundamental for any new plant proposal.
- Atmospheric acidification: the highest S_{EI} is mainly related to the sulphur concentration in coal. Those plants in catchment areas with a high water surface area, acidic soils and relatively high rainfall frequency are likely to have most impact on local environments.
- Eutrophication: a relative low impact but a serious environmental problem in Australia.
- Photochemical smog and human health (carcinogenic): these are relatively very small S_{EI} values and no significant impacts are expected to occur.

Model Application

As environmental conditions and population are dynamic parameters, it is also possible to use the model to verify the incremental variation of the P_{EI} and S_{EI} values on a daily or seasonal basis. This may provide a better sustainability metrics outcome although environmental data may not be available. Environmental data acquisition for the calculation of S_{EI} values provides legitimacy for applying sustainable metrics calculations to a specific site. On the other hand, setting up the boundaries for each site can be a problem, particularly related to air sheds. For instance,

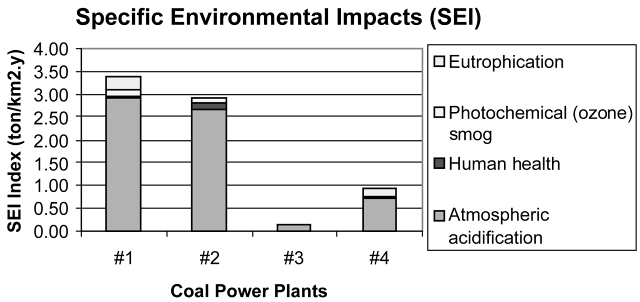

Figure 2. SEI index of coal power plants.

a plant may be in a location that may feed two air sheds depending of the wind direction.

The environmental functions developed in this work were based on average environmental parameters. These functions can be further derived to accommodate a departure from environmental mid-point values such as decay and accumulation dynamic functions. The rate of sustainability metrics may reflect transient trends which cannot be observed when average environmental parameters are employed. Obviously there are heuristic issues to be dealt with in such studies. Future work may apply transient environmental functions linked to wind direction, frequency and deposition rates to provide a more accurate distribution of sustainability metric indicators. Remote sensing may provide on line data for more precise outputs.

In this work, three out of the four hypothetical plants were the major emission sources within the catchment area and/or air shed, while just one plant was close to a major urban and industrial centre. This situation reflects the coal power generation industry in Australia, as many plants are close to coal mines in areas sparsely populated where the major economy is agricultural. As the coal power generators are the major sole emitters in these catchment areas and/or air sheds, sustainability metrics outcomes can be easily compared against ecosystem health indicators. Hence, the trend in changes in ecosystem health will indicate whether coal power emissions are breaching the ability of the environment to buffer and treat those emissions.

In addition, we have limited the substances emitted to NO_x, SO_x and PM_{10} as these are the major pollutants from coal power generation plants (excepting carbon dioxide). There may be hundreds of substances emitted in low concentrations such as volatile organic compounds and N_2O as shown in the Australian national pollutant inventory (NPI, 2003) which were not considered here for the sake of simplicity. Nevertheless the above methodology also allows any substance to be accounted for and incorporated into sustainability metrics. Further, the above methodology is not limited to coal power generation only, but it can be applicable to any chemical and process industry, mining and agricultural activities.

The boundaries of this work were limited to the coal power plants—within their catchments. Coal extraction and transportation, and resource depletion are site and mine dependant and must also be considered in a sustainability metrics study. Furthermore, the receiving environments are likely to be more sensitive to the impact of total mass load of pollutants rather than emission concentration. This brings to light the issue of scale of environmental damage which in turn requires another level of complex modeling to simulate the potential impacts. We recognize these points as valid and important. In our simplified approach, we assume the same emission concentration over the entire air shed (i.e., a perfect mixture). Hence, further work is warranted to take into consideration resource depletion, scale and other relevant issues.

CONCLUSIONS

The methodology proposed in this study clearly shows a distinction between potential environmental indicators (P_{EI}s) and specific environmental indicators (S_{EI}). S_{EI} was based on the development of specific parameters associated with the specific regional environmental conditions of each coal power plant. Environmental condition data were obtained from geographical information systems. It was found that efficient plants such as plant #3 resulted in the best overall performance. On the other hand, less efficient plants such as plant #4 showed a high level of environmental impact on a regional scale, atmospheric acidification resulted in relatively high values, while other indicators such as human health carcinogenic effects, photochemical ozone smog and eutrophication were considered to be less significant.

Although technology improvements pay off in sustainability metrics terms, the environmental conditions of a plant siting provide further limitations. For instance plant #2 has a low PM_{10} emissions resulting in reduced human health P_{EI}. However, as plant #2 is close to a large urban and industrial centre, its human health S_{EI} is relatively high. The opposite is observed for plant #1. Similar trends are also observed for other parameters. There appears to be some validity in trying the approach to see if potential impacts are mitigated or enlarged by specific receptors and if the quantitative results obtained are reproducible. The emphasis here is that technology change and raw material change result in different potential impacts and therefore impact directly on sustainability issues. Thus by improving technological performance, if all other things stayed the same (ceteris paribus) then there would be a sustainability gain.

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