Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI

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Abstract

The most effective way to achieve long-term environmental results is through the use of a consistent set of metrics and decision-making framework. The U.S. EPA has developed TRACI, the Tool for the Reduction and Assessment of Chemical and other environmental Impacts, which allows the characterization of potential effects, including ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human particulate effects, human carcinogenic effects, human non-carcinogenic effects, fossil fuel depletion, and land use effects. To develop TRACI, impact categories were selected, available methodologies were reviewed, and categories were prioritized for further research. Impact categories were characterized at the midpoint level, for various reasons, including a higher level of societal consensus concerning the certainties of modeling at this point in the cause-effect chain. Research in the following impact categories - acidification, smog formation, eutrophication, land use, human cancer, human non-cancer, and human criteria effects - was conducted to construct methodologies for representing potential effects in the US. Probabilistic analyses allowed the determination of an appropriate level of sophistication and spatial resolution necessary for impact modeling for several categories, yet the tool was designed to accommodate current inconsistencies in practice (e.g., site specific information is often not available.). The methodologies underlying TRACI are presented along with a discussion of the application of TRACI methodologies in various decision-making frameworks. TRACI is available for incorporation into other environmental tools, and is currently downloadable at the following website: http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm

Introduction

There continues to be international discussion centered on various issues associated with sophistication, accuracy, and complexity in comprehensive impact assessment including the consideration of temporal and spatial dimensions of potential impacts (Udo de Haes et al, 2002, Bare et al, 2000, Bare et al, 1999, Udo de Haes et al, 1999a, Udo de Haes et al, 1999b). Because completing comprehensive assessments for all potential effects at a high level of simulation sophistication and disaggregation would require impossibly large amounts of time, data, knowledge, and resources, every study must be limited in some aspects of sophistication and/or comprehensiveness. Selecting the appropriate goal and scope of the study and choosing methodologies and data to support each goal and scope is crucial to meeting the expectations of the stakeholders.

For the last seven years, the US EPA has focused on determining and developing the best impact assessment tool for Life Cycle Impact Assessment (LCIA), Pollution Prevention (P2), and Sustainability Metrics for the US. A literature survey was conducted to ascertain the applicability, sophistication, and comprehensiveness of all existing methodologies. When the development of TRACI began, the state of the practice involved nearly all US practitioners utilizing European methodologies when conducting comprehensive impact assessments for US conditions simply because similar simulations had not been conducted within the US. Since no tool existed which would allow the sophistication, comprehensiveness, and applicability to the US which was desired, the US EPA decided to begin development of a tool which could be utilized to conduct impact assessment with the best applicable methodologies within each category. This research effort was called TRACI - the Tool for the Reduction and Assessment of Chemical and other environmental Impacts.

Early in the development of TRACI, the impact categories were selected for analysis and methodology development. An updated literature search revealed several sources that have discussed this issue, including Heijungs, et al., 1992, and Udo de Haes, 1996. Universal impact categories for most studies included: ozone depletion, global warming, human toxicology, ecotoxicology, smog formation, acidification, and eutrophication. While it was recognized by the EPA that the selection of these impact categories is a normative decision depending on what is valued, the EPA decided to include at least this common set as a minimum.

During the development of TRACI, impact categories were selected based on their level of commonality with the existing literature in this area, their consistency with EPA regulations and policies, their current state of development, and their perceived societal value. The traditional pollution categories of ozone depletion, global warming, human toxicology, ecotoxicology, smog formation, acidification, and eutrophication were included within TRACI because EPA programs and regulations recognize the value of minimizing effects from these categories. Human health was subdivided into cancer, non-cancer, and criteria air pollutants (with an initial focus on particulates) to better reflect the focus of EPA regulations and to allow methodology development consistent with the regulations, handbooks, and guidelines (e.g., EPA Risk Assessment Guidelines (RAGs), and Human Exposure Factor Handbook). Smog formation effects were maintained independently and not further aggregated with other human health impacts because environmental effects related to smog formation would have become lost in the process of aggregation. Criteria pollutants were preserved as a separate human health impact category to allow a modeling approach that could take advantage of the extensive epidemiological data associated with the impacts of criteria pollutants. (US EPA, 1999, Levy, et al, 2000, Nishioka, et al 2000, Nishioka, et al, 2002)

Resource depletion was recognized as being important within the realm of potential environmental effects for most studies; however, there was much less consensus on which categories should be included and how the characterization should be conducted. Although many studies choose to focus on energy consumption as an impact category, the source and transmission of energy is highly variable. As an example, the potential effects from coal extraction, transport, and combustion is expected to have very different effects from energy consumption resulting from the manufacture and operation of a solar cell, fuel cell, or nuclear source. In reality, society seems most concerned about the potential impacts of depletion (e.g., fossil fuels) and chemical emissions that result from extraction, transportation, and combustion. TRACI recommends that these depletions and emissions be accounted for independently within each energy source. Similarly the other resource depletion categories have been selected and designed to discriminate between emissions and depletion effects.

TRACI's Design

TRACI is a modular set of LCIA methods intended to provide the most up-to-date scientifically defensible impact assessment methodologies for the US. These methods can be used within other LCA tools, such as LCA modeling tools and LCA-based decision support tools. They have also been made operational within a public domain software tool available from the EPA, which reads inventory data and applies the TRACI methods to provide graphical and tabular results. TRACI is available for incorporation into other environmental tools, and is currently downloadable at the following website: http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm

TRACI's modular design allows the compilation of the most sophisticated impact assessment methodologies that can be utilized in software developed for PCs. Where sophisticated and applicable methodologies didn't exist, research was conducted by the use of various simulations to determine the most appropriate characterization factors to represent the various conditions within the US. As the research, modeling, and databases for LCIA methods continue to improve, each module of TRACI can be improved and updated. Future research is expected to advance methods for resource-related impact categories.

As shown in Figure 1, the TRACI software allows the storage of inventory data, classification of stressors, and characterization for the listed impact categories. Inventory data is stored as either inputs or outputs on specific process levels within the various life cycle stages. Studies can be conducted on products or processes and compared to alternatives.

A framework incorporating the normalization and valuation processes would allow decision makers to determine their values for one situation and to maintain these values for consistency in other environmental situations requiring similar tradeoffs between impact categories. (Hofstetter, 1998, Udo de Haes, et al, 2002) At the time of writing, the current best practice for normalization and valuation is still very much under debate. Examples exist demonstrating their use in European situations with European normalization databases, while a comparable US normalization database is planned for release during 2002. The valuation process was (and is) also in need of advancement. Participants in an international workshop on Midpoints vs. Endpoints held in Brighton, England, in May 2000 (Bare et al, 2000) could not point out any examples of successful, unbiased panel procedures that could be utilized to guide future valuation processes. Based on these issues, and supported by issues related to possible misinterpretation and misuse, it was determined that the state-of-the-art for the valuation process did not yet support inclusion into TRACI.

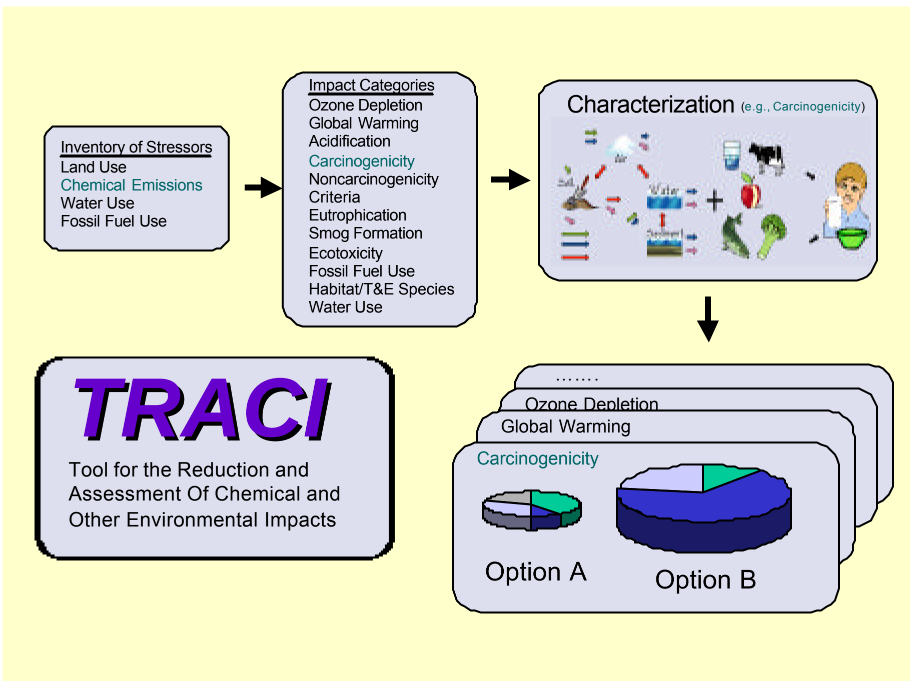

Figure 1 TRACI Framework

TRACI Impact Assessment Methodology Development

A workshop was held in Brussels, Belgium, in 1998 to discuss among international experts Life Cycle Impact Assessment Sophistication in conducting case studies, research, and tool development, but also in the development of ISO 14042. (Bare, et al. 1999) Most researchers agreed that the most sophisticated methodologies should be used as long as they did not require significant additional work in compiling the inventory and did not require significant additional modeling assumptions that were not already incorporated into regulations or societal standards. It was recognized that this level of sophistication would vary across impact categories, with some of the categories having had years of research and standardization (e.g., human toxicity), while other categories were still very much in their infancy, even in determining what is to be valued (land use). EPA decided to incorporate the most sophisticated methodology for each impact category in TRACI, as far as possible, while minimizing new modeling assumptions and using a modular approach which would allow easy updating as new research on impact assessment methodologies became available.

As an example, prior to the development of TRACI many researchers used simple measures of toxicity (Heijungs, et al 1992), or scoring procedures involving persistence, bioaccumulation, and toxicity (Swanson, et al 1997, Pennington, et al 2002) to provide indicators for human toxicity. These methods yielded proxy indicators that did not fully quantify the potential for effects, but simply provided a measure of a related parameter. By incorporating a sophisticated multimedia model followed by human exposure modeling, the current methodology within TRACI provides a more sophisticated and applicable answer that is related to the potential impacts being quantified.

In addition to model sophistication, factors involved in methodology development included: portability and ease of use, consistency with existing guidance, and lastly, but importantly, minimization of assumptions/value choices. Significant emphasis was given to applicability to the US. Applicability to the US is important for many of the categories that have location specific input parameters. In those categories where sophisticated models allowed (e.g., human health cancer and non-cancer) the location related input parameters (e.g., meteorology and geology) were varied according to a sensitivity analysis structure to see the relative contribution to variation. Preliminary research suggested that uncertainties not related to location (e.g., uncertainties in half-life data, toxicity, or cancer potency) exceeded regional sensitivities for the impact factors by several orders of magnitude; for this reason, US average impact factors were developed for the human cancer and non-cancer categories. (Hertwich, et al, 1998, Hertwich, et al, 1999, Hertwich, et al, 2001) For categories such as acidification and smog formation detailed US empirical models, such as those developed by the US National Acid Precipitation Assessment Program (Shannon 1992) and the California Air Resources Board (Carter, 2000), allowed the inclusion of the more sophisticated location specific approaches and location specific characterization factors. In all impact categories, US average values are available when the location of the inventory data is not available.

Consistency with previous modeling assumptions (especially of the EPA) was important for every category. The human health cancer and non-cancer categories were heavily based on the assumptions made for the US EPA Risk Assessment Guidance for Superfund (US EPA, 1989). The EPA’s Exposure Factors Handbook (US EPA, 1989) was utilized to make decisions related to the various input parameters for both of these categories as well. Another example of consistency with EPA modeling assumptions includes the use of the 100 year time frame reference for Global Warming Potentials (GWPs). When there was no EPA precedent, assumptions and value choices were minimized in some cases by the use of midpoints. Although other modelers have extrapolated to endpoints in published LCIA methodologies (EcoIndicators’99 – Goedkoop, et al, 1999), the EPA decided that TRACI should not conduct these calculations because several assumptions and value choices are necessary to extrapolate to the endpoints. There were other advantages to the use of midpoints (such as comprehensiveness) that will be discussed in the next section.

TRACI’s Midpoint Choices

Consistent with EPA’s decision not to aggregate between environmental impact categories, many of the impact assessment methodologies within TRACI are based on "midpoint" characterization approaches. (Bare et al, 2000) The impact assessment models reflect the relative potency of the stressors at a common midpoint within the cause-effect chain; see the example in figure 2 for ozone depletion.

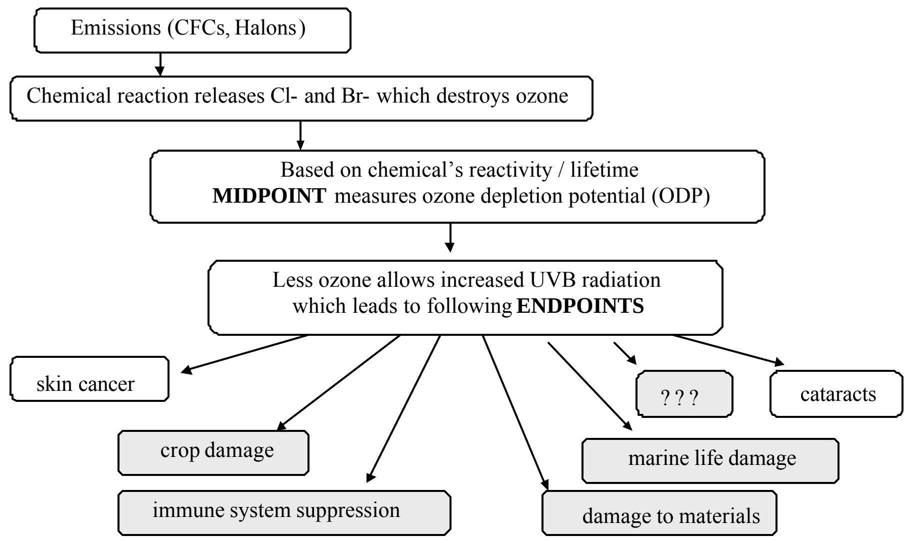

Figure 2 Ozone Depletion Midpoint / Endpoint Modeling

This diagram shows that characterization could take place at the level of midpoints such as ozone depletion potential or endpoints such as skin cancer, crop damage, immune system suppression, damage to materials like plastics, marine life damage, and cataracts. Analysis at a midpoint minimizes the amount of forecasting and effect modeling incorporated into the LCIA, minimizing the complexity of modeling and often enhancing simplicity of communication. Another factor supporting the use of midpoint modeling is the incompleteness of model coverage for endpoint estimation. For example, as shown in figure 2, models and data may exist to allow a prediction of potential endpoint effects such as skin cancer and cataracts, but the inclusion of effects such as crop damage, immune system suppression, damage to materials, and marine life damage is less well supported. These associated endpoints and their expected effects remain important but are not captured in certain endpoint analysis.

How to Use TRACI

TRACI's strengths lie in the scientific research underlying the impact assessment methodologies, its consistency with existing policies and regulations, as well as its versatility. In addition to its modular design, TRACI was developed to allow use within LCA, Sustainability Metrics, and Pollution Prevention. In each case, the level of the analysis is dependent upon the goal and scope of the study and the inventory data collected. As an example, TRACI may be used at a process decision level to compare minor changes which are not expected to have significant impacts outside of the process. Or TRACI can be used on a facility or corporate level to make Environmental Sustainability Goals - benchmarking progress from one year to the next with one or more of the impact categories under consideration.

TRACI could be used in a screening level LCA to determine where to collect higher quality data. Screening level inventory data would be gathered along the entire life cycle chain and imported into TRACI within specific process data formats. These data formats would allow useful graphical and tabular analysis to determine the most significant processes and stressors. Then in an iterative fashion, refinements to the original estimates and improvements to the data quality of these most significant processes and stressors could be made for most efficient use of case study funds. Finally, TRACI could be used in the highest quality, most comprehensive LCA to focus future modifications on processes and stressors which would reduce the environmental impact most effectively.

TRACI could be used to set Environmental Sustainability Goals. In this case, the facility (or corporation) would estimate (or measure) the emissions of all potential contributors to each impact category at the facility (or facilities) during the base line year and then use TRACI to calculate the potential indices for each category. A normalization database could be used with these indices to determine which impact category had the most significant index when compare to the US national annual emissions within each impact category. Then the facility or corporation would be better informed about their relative potential impacts (and possible future liabilities) within each impact category. They could use this information to set corporate goals for future performance. An example of the above use would be in a case when a corporation determined that eutrophication was the impact category of most significance when compared to the US national annual emissions normalization database. The corporation could then decide to set an Environmental Sustainability Goal "to reduce the potential eutrophication impacts by 15% per year over a 4 year time frame within a specific facility (or facilities)." After setting this goal, the facility (or corporation) could estimate (or measure) the emissions of all potential contributors to eutrophication at the facility (or facilities) during the subsequent years following the base line year and use TRACI to calculate the potential eutrophication index. The environmental decision makers could then look at the TRACI tables and graphs to determine which processes and emissions contribute most significantly to potential eutrophication impacts. They could then use TRACI in a “What If?” mode to simulate various scenarios which would represent process changes which could be employed to reduce these emissions most effectively to meet the goal.

Conclusions

TRACI is a highly versatile impact assessment tool which includes the most state-of-the art, scientifically defensible impact assessment methodologies for the following categories: ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human particulate effects, human carcinogenic effects, human non-carcinogenic effects, fossil fuel depletion, and land use effects. Methodologies have been developed specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined. TRACI can be used in LCA, to set corporate environmental goals, to plan a path to meet those goals, and then to measure environmental progress.

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Disclaimer

Use of TRACI (the Tool for the Reduction and Assessment of Chemical and other environmental Impacts), including but not limited to the impact assessment modeling, does not confer legal rights or impose legal obligations upon any member of the public. Furthermore, it does not release users from any potential liability, either administrative or judicial for any damage to human health or the environment.

Neither EPA nor anyone involved in the development of TRACI makes any warranty, expressed or implied, as to any matter whatsoever, including the accuracy of the database, the appropriateness of actions taken by third parties as a result of using the model, or the merchantability or fitness of the model for a particular purpose. EPA does not endorse any products or services.

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