Uncertainty in Life-Cycle Assessment Induced by Life-Cycle Inventory Data: The Case of Structural Steel

IORDANIS ZYGOMALAS and CHARALAMBOS BANIOTOPOULOS

ABSTRACT

Life-cycle assessment (LCA) is currently widely used to quantify environmental impacts and thus support decision making within business sectors such as steel construction, which utilizes vast amounts of materials to deliver large-scale projects globally. Because the validity of LCA results greatly depends on the quality and appropriateness of the life cycle inventory (LCI) data referring to the environmental inputs and outputs associated with the examined subject, it is necessary to estimate the degree of uncertainty embedded in these data, which will inevitably be incorporated into the final LCA results. The purpose of this research is to examine the extent and the characteristics of uncertainty due to LCI data, based on findings for the case of commonly used structural steel components. Impact assessment results are calculated according to four relevant LCI databases and two assessment methods. The results are compared based on a detailed analysis of the impact caused for the production of the steel members. Major conclusions include the observation that data quality characteristics do not ensure the accuracy of the final LCA results because datasets referring to the same steel member type were found to lead to noticeable divergence. An overall lack of uniformity was observed within each of the mainly burdened impact indicators, while the influence of system boundaries was also examined. Issues concerning the collection of primary LCI data were raised, and it was also shown that different impact assessment methods provide different perspectives, which result in a more complete and factual approach.

Keywords: life-cycle assessment (LCA), life-cycle inventory (LCI), uncertainty, structural steel, steel structures.

INTRODUCTION

Life-cycle assessment (LCA) has been introduced as a methodology to quantify the environmental impact associated with any given product. Based on the concept of the life cycle, it takes a very wide range of environmental information into account and has understandably come to be regarded as one of the most detailed and complete environmental impact assessment methods available.

However, during the course of its increasing application within almost every business sector, a few issues concerning its efficiency have arisen, perhaps the most critical of which being uncertainty—both the uncertainty embedded in the final results and, subsequently, the validity of the environmental impact calculated.

Because the application of LCA depends on the life-cycle inventory (LCI) data used to model a product's life cycle, the final result is directly affected by the quality and accuracy of this environmental information. It is, however, acknowledged that obtaining and maintaining LCI datasets require a huge and constant effort (Simoes da Silva et al., 2007); it is, therefore, impossible to develop new data for each LCA conducted. The degree of influence of environmental data to the final results has become a subject of argument and, in some cases, has given reason to question the outcome of LCA. However, each sector—and even each LCA study carried out—is characterized by particular conditions and properties; as a result, in order to investigate uncertainty due to LCI data, it is necessary to examine its characteristics within a given scope.

One of the business sectors that not only utilizes vast amounts of materials and energy, but is also involved in adopting a strategy to incorporate sustainability into its product's design, is steel construction (Bragança, Mateus and Koukkari, 2007). The design and construction of steel projects such as high-rise buildings or heavy-traffic bridges require the application of sustainable development principles, and as a result, industry decision makers are increasingly using relevant decision-support tools such as LCA. It is within this particular sector that the current research analyzes uncertainty due to LCI data. Because structural steel members are associated with the greatest percentage of environmental impact caused by the construction of steel projects (Zygomalas, Efthymiou and Baniotopoulos, 2009), they are chosen as the reference point for this analysis. Prior to the description of the methodology and results of the

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current research a brief presentation of the LCA methodology is given.

As a result of the global movement for sustainable development, sustainability has become the main agenda for the majority of practices in construction (Zygomalas et al., 2009). In order to incorporate the basic principles of sustainability into design and construction, it is first necessary to quantify all aspects of construction as far as their effects on the environment are concerned. By calculating the environmental impact caused by each construction process, the most environmentally damaging processes are identified, and it is then possible to work toward lowering this impact and, ultimately, optimizing the environmental performance of a project for the duration of its life and beyond its completion.

In order to document each and every construction process required for the delivery of a project, the concept of the life cycle has been introduced. For construction projects, the four main life cycle stages that can be identified are (1) raw material acquisition, (2) construction, (3) use/operation/maintenance and (4) end scenario/waste management (see Figure 1).

The calculation of the environmental impact across the whole life cycle of a project constitutes a new scientific field with new methods and new goals (Zygomalas et al., 2009). The methodology that has been developed for this purpose is life-cycle assessment (LCA). The application of LCA is to be conducted according to the relevant ISO (International Organization for Standardization) standards [ISO 14040 and ISO 14044 (ISO 2006a, 2006b, respectively)] and consists of four phases, as shown in Figure 2.

The first phase requires the definition of a series of theoretical parameters (such as the goal of the LCA, its scope, and so on), while at the second stage, environmental data (or LCI data) are documented for each process or material of the project's life cycle. These data are translated into environmental impact values at the third stage; finally, the results obtained are interpreted at the fourth and final stage of the LCA.

METHODOLOGY AND CALCULATION

Overview

In order to examine uncertainty due to LCI data, a reference product is chosen for the analysis along with an appropriate functional unit referring to a specific quantity of the chosen product. After a thorough literature review, a number of LCI databases available containing relevant environmental data are identified, and the environmental impact for the defined product and quantity are calculated according to each LCI database. The impact assessment methods used are Eco-Indicator 99, IPCC Global Warming Potential (GWP) and TRACI. These methodologies are not only widely used on a global level, but also because they were developed for differing geographic regions. Eco-Indicator was developed mainly for Europe, GWP for global use and TRACI for the United States. The results obtained are compared in order to reach useful conclusions regarding uncertainty caused by LCI data, not only within the steel construction sector, but also as more general observations regarding LCA application.

Reference Product and Functional Unit

The most commonly used structural steel members are hot-rolled sections such as wide-flange beams (European equivalent: IPE and HEA) and cold-formed hollow sections such as SHS (square hollow sections) and RHS (rectangular hollow sections). For the purpose of the current study, the production of hot-rolled structural steel sections is chosen from raw material acquisition to storage at the factory before shipment for use (cradle-to-gate). As far as the manufacturing process for these structural members is concerned, there are two main routes: the blast oxygen furnace (BOF) route, which produces primary steel utilizing raw materials, and the electric arc furnace (EAF) route, which produces steel of

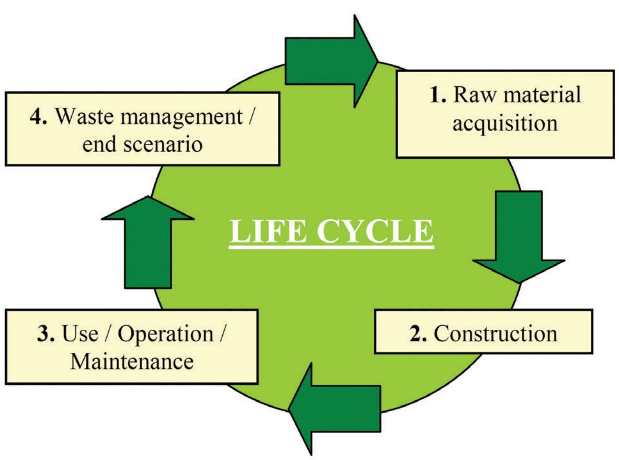

Fig. 1. The life cycle of a construction project.

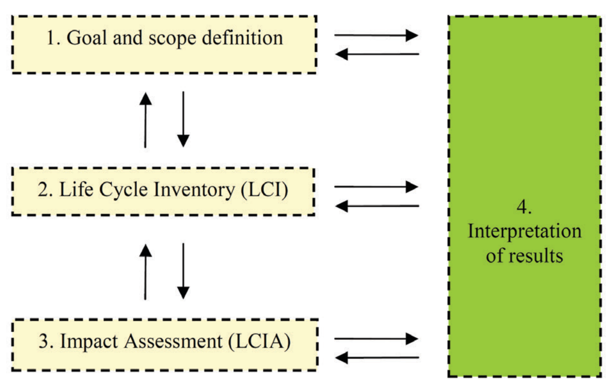

Fig. 2. Phases of life-cycle assessment (LCA).

equal properties by recycling iron and steel scrap. Although the blast furnace route is still being widely used globally (Worldsteel, 2009), it is the EAF that presents significant sustainable potential and is therefore regarded as more appropriate for the current analysis. It should be noted that the steelmaking route can differ significantly globally, with some European countries mainly utilizing the BOF route, while other countries such as the United States utilize only the EAF for the manufacturing of hot-rolled steel sections. The functional unit was subsequently defined as 2.2 lb (or 1 kg) of hot-rolled structural steel members manufactured via the EAF route.

Selection of Available LCI Databases

The next step is to examine existing literature and determine the LCI databases available that contain verified data concerning hot-rolled structural steel members. As a result, the following LCI databases were selected.

AUTh

In 2009, the Institute of Metal Structures of the Aristotle University of Thessaloniki in Greece conducted a study to quantify environmental inputs and outputs concerning commonly used structural steel members, such as hot-rolled and cold-formed sections (Zygomalas et al., 2012). A number of detailed datasets are included in the database, based on the information provided by the leading steel member manufacturing company in Greece and completed, where necessary, by literature research.

The dataset for hot-rolled structural steel sections refers to the production of 2.2 lb (1 kg) of finished products via the EAF steelmaking route and their storage at the factory before shipment for use (cradle-to-gate). The main production stages documented and included in the development of this dataset are presented in Figure 3. Each production process was documented as described in the ISO 14040 and 14044 standards (ISO 2006a, 2006b), according to environmental inputs and outputs.

Ecoinvent

The Ecoinvent LCI database was initially developed in the late 1990s and contains more than 4000 datasets referring to products, services and processes; it was developed in Switzerland by the Swiss Centre for Life Cycle Inventories, which is also responsible for data updates (Classen et al., 2009). It refers to a mix of European technology, and the collection method used was a sampling procedure based on literature. A number of research centers in Switzerland and Germany were involved with the development and constant update of the database, while the data are intended for use mainly within the European region (IPPC, 2001).

The Ecoinvent database includes a dataset referring to the manufacturing of steel with the EAF route, based on data from the year 2000 and according to the relevant ISO standards concerning LCA and LCI. The dataset also includes the transports of scrap metal and other input materials to the EAF and casting. Because this dataset refers to the manufacturing of steel up to the casting stage, it is necessary to add the rest of the processes required for the production of the hot-rolled structural steel members. These processes are the reheat furnace operation, the hot-rolling process and the transport of the finished products to storage rooms before they are sent out for use. The hot-rolling and transport processes are included in the Ecoinvent database and were therefore used in this case, while the reheat furnace process was used as found in the AUTh database.

Canadian Raw Materials Database (CRMD)

The CRMD was developed in collaboration with the Canadian business sector and government and aimed at providing life-cycle inventory data concerning several different products. Among these products are steel billets manufactured with the EAF route, as used for hot-rolling to produce the structural steel sections commonly used in steel construction projects. The functional unit used was 2.2 lb (1 kg) of finished product, and the data were provided by steel

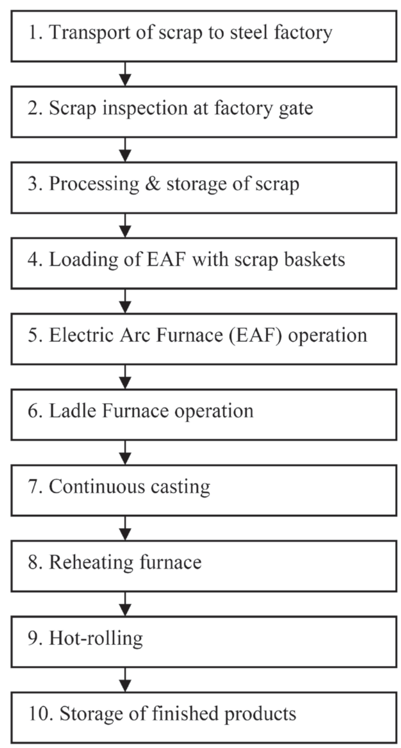

Fig. 3. Main processes for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF) taken into account for the development of the AUTh LCI database.

factories in Europe and North America because no steel sections are currently being manufactured in Canada. The primary data refer to the years 1994–1995, while secondary data were used as found in literature through 1990. These dates do present an issue concerning the current validity of the dataset; however, there is no recent update available.

In order for the data to be used in the current study, the data were completed with the remaining necessary processes for the production of the structural steel members, namely, the reheat furnace operation, hot-rolling and transport to storage rooms. These processes were used as found in the AUTh database.

Worldsteel

The World Steel Association (Worldsteel, previously IISI) conducted an LCI study at a global scale, aiming at the quantification of raw materials, energy and environmental emissions associated with the production of the main finished products of the steel industry, including structural steel sections. A significant number of steel factories from different countries have provided the data, which cover all production stages from raw material acquisition to delivery of the finished products at the factory gate before sent for use (cradle-to-gate). The study was initially conducted in 1994–1995, and it was updated in 1999–2000 and then again in 2010. The data for the current analysis are used as published in the February 2010 update.

The Worldsteel datasets provide cradle-to-gate (from raw material extraction to the steel factory gate) data on all the major raw materials, energy usage, air and water emissions, and wastes for the steel products included in the study. Forty-three major data categories (flows) are included in the available datasets out of the 450 that were quantified. Environmental inputs and outputs were calculated for the production of 2.2 lb (1 kg) of steel products at the factory gate according to ISO 14040 standard (Worldsteel, 2005). In the case of structural steel sections, the data were provided by a number of steel factories from all over the world (with, however, very limited coverage of U.S. steel mills), some using the EAF steelmaking route, while others the blast furnace route. The data are, therefore, calculated as an average of both steelmaking routes.

It should also be noted that the data include an environmental credit corresponding to an 80% recycling rate, while in the United States, the current corresponding rate is about 98%. The rest of the selected databases do not incorporate any waste scenarios; therefore, their impact assessment results are expected to appear relatively increased. Because of the fundamental differences in system boundaries—namely, the inclusion of the blast furnace steelmaking route and the recycling scenario—it is not possible to directly compare the results based on this dataset to the ones calculated according to data from the other selected databases. However, the dataset is included in the current research as a way to determine the influence of system boundary differentiation within LCI data on the results obtained.

RESULTS AND DISCUSSION

Eco-Indicator Impact Assessment

The Eco-Indicator 99 impact assessment method provides a detailed and complete presentation of the environmental impact associated with the system under examination and is, therefore, used within the scope of the current analysis. It is a damage-oriented approach, which is based on weighting results and calculating environmental impact according to a set of indicators. The methodology is mainly intended for LCA referring to the European region, and the unit used is the Eco-Indicator point (Pt), which was chosen in such a way that the value of 1 Pt is representative of one-thousandth of the annual environmental load of one average European inhabitant (The Netherlands Ministry of Housing, Spatial Planning and the Environment, 2000).

The impact assessment results for the production of 2.2 lb (1 kg) of hot-rolled structural steel members via the EAF steelmaking route are calculated according to the Eco-Indicator methodology (V2.06/Europe EI 99 E/E), for each of the four selected LCI databases, and are presented in Figure 4.

The first observation from the results is that the total environmental impact values are very close according to three of the four databases, ranging from 76.5 to 86.8 mPt (millipoint = 1/1000 Pt). As expected, the Worldsteel data lead to a relatively decreased value, which can be justified due to the inclusion of the 80% recycling rate. This differentiation, in combination with the fact that these data refer to both steelmaking routes and not only the EAF, does not allow for the direct comparison of the results from the four databases. However, it is clear that the degree of final result divergence (which can be obtained due to differences in data boundaries and corresponding technology) can be more than significant.

Furthermore, it should not be neglected that these results refer to 2.2 lb (1 kg) of structural steel members. Even the small value differences observed among the remaining three LCI databases can lead to noticeable value variation—considering that, within an LCA study concerning a steel structure, hundreds or thousands of tons of structural steel members are used.

The point at which even the three databases that lead to similar impact results vary is the burden of each environmental indicator. The respiratory inorganics and fossil fuels indicators, for example, although prominent within each database impact result, are burdened to varying degrees. Other indicators, such as ecotoxicity, are barely visible within all databases except Ecoinvent, where it accounts for a significant impact load. The same can be observed in Figure 5, where impact assessment results are presented according to impact category, a more general environmental assessment model based on the grouping of the indicators.

Resources and human health accept the largest percentage of environmental impact according to all four LCI databases, yet at a varying degree. According to the three databases that do not include recycling scenarios, the resources category impact varies from 32.6 to 46.7 mPt, whereas the human health category varies from 27.9 to 39.9 mPt. Ecosystem quality is burdened significantly less, with values ranging from 4.1 to 17.4 mPt, according to the same three databases.

These values, calculated for each impact category, present noticeable divergence and can thus provide substantially different assessment conclusions. That is, although, as a total, most databases lead to similar impact values, the same is not the case for each individual category impact. These value differences can be interpreted as a general lack of data uniformity between the selected LCI databases. In order to investigate this in depth, it is necessary to calculate environmental impact results to a higher level of data detail. Within the Eco-Indicator methodology, this can be achieved with the impact indicators used. In Figure 6, the impact results for 2.2 lb (1 kg) of hot-rolled structural steel members are presented according to each impact indicator.

The first observation is that not all impact indicators are burdened and only a few are affected to a significant degree. Fossil fuels [which refers to the additional required energy for extraction due to low raw material quality (as high volumes of raw materials are extracted continuously, the quality of the remaining raw materials decreases and requires additional energy for further extraction)] are responsible for the greatest environmental impact according to all databases but one, followed by respiratory inorganics (which refers to effects on the human respiratory system caused by emissions of inorganic substances during the winter time).

As far as impact values within each indicator are concerned, there is an obvious lack of result uniformity. Within fossil fuels, the most heavily affected impact indicator, the impact value ranges significantly among the selected databases. The same can be observed for the respiratory inorganics indicator, with only the Ecoinvent and the AUTh databases providing similar values of 15.8 and 17.2 mPt, respectively. The ecotoxicity indicator (which refers to effects on the quality of the ecosystem due to the emission of ecotoxic substances to the air, water and soil) also presents an uneven value distribution because the Ecoinvent databases leads to a significantly increased impact value, compared to the other three, which lead to relatively negligible ones. Impact indicators that do present a relatively

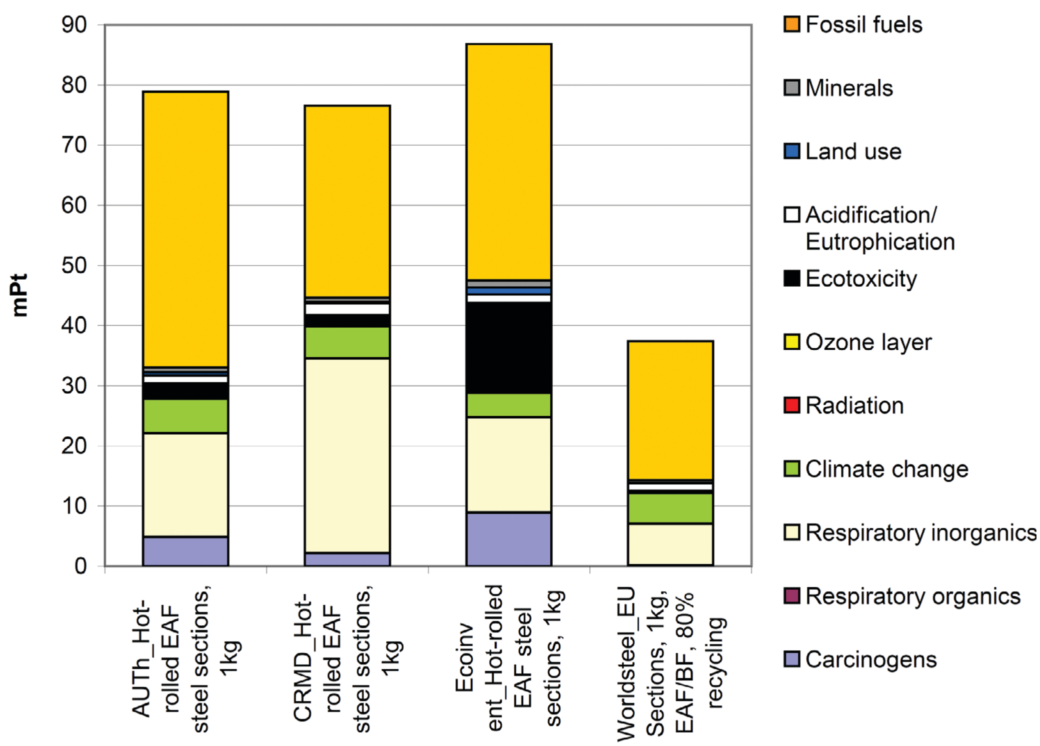

Fig. 4. Eco-Indicator 99 environmental impact results for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases.

even value distribution, such as climate change and acidification/eutrophication, are associated with very low impacts and are, therefore, limited in terms of gravity and influence of the final result.

These observations lead to the conclusion that there is an overall lack of uniformity regarding the environmental impacts caused by the production of structural steel members. Although each database is based on data provided by manufacturers, there is significant divergence of results for environmental impact caused. Although this can partly be attributed to a number of reasons such as differences in geographic coverage, data collection time period and technology level, different processes or data sampling methodologies, and different electrical grids of the age of the data, it should not be neglected that the production process for hot-rolled structural steel members via the EAF steelmaking route consists of the same stages and, therefore, does not present major variations or utilizes fundamentally different machinery or manufacturing processes. Thus, it can be expected that similar LCA studies on the same steel product or project, but based on data from different LCI databases, can lead to varying final impact results. In order to provide an indicative estimate of this result variation, impact result divergence was calculated as a percentage of the average value for each of the mainly burdened indicators and the total impact. These percentages are presented in Table 1 for each of the four selected LCI databases.

As can be observed, there are very few cases in which divergence percentages can be considered within acceptable limits. The divergence percentage reaches almost 80% within the respiratory inorganics indicator and 205.2% within ecotoxicity. These value differences are directly associated with the quality and accuracy of LCI data, and although expected, they are certainly a clear indication of the extent of uncertainty embedded in LCI data, which is inevitably transferred to final LCA results.

In order to examine the source of this uncertainty, it is necessary to examine the processes responsible for the environmental impacts caused for each indicator. For this purpose, the situation within the mainly burdened impact indicators is analyzed further.

Fossil Fuels

The fossil fuels impact indicator accepts the greatest environmental impact caused for the production of the structural steel members, as was shown in Figure 6. In Figure 7, this impact is presented for each of the four selected LCI databases, according to the processes that cause it. As can be observed, the impact is almost completely caused by three processes. These processes all refer to energy-related raw materials consumed during the production of the steel members, namely, oil, coal and natural gas.

The impact caused by the consumption of oil does not vary significantly across the three databases that do not include recycling scenarios, ranging from 4.6 to 7.6 mPt. For natural gas, the impact caused is again relatively lower according to the Worldsteel database; however, due to the inclusion of recycling within the data, this difference cannot be regarded indicative of uncertainty. According to the rest of the databases, the natural gas–related impact attains

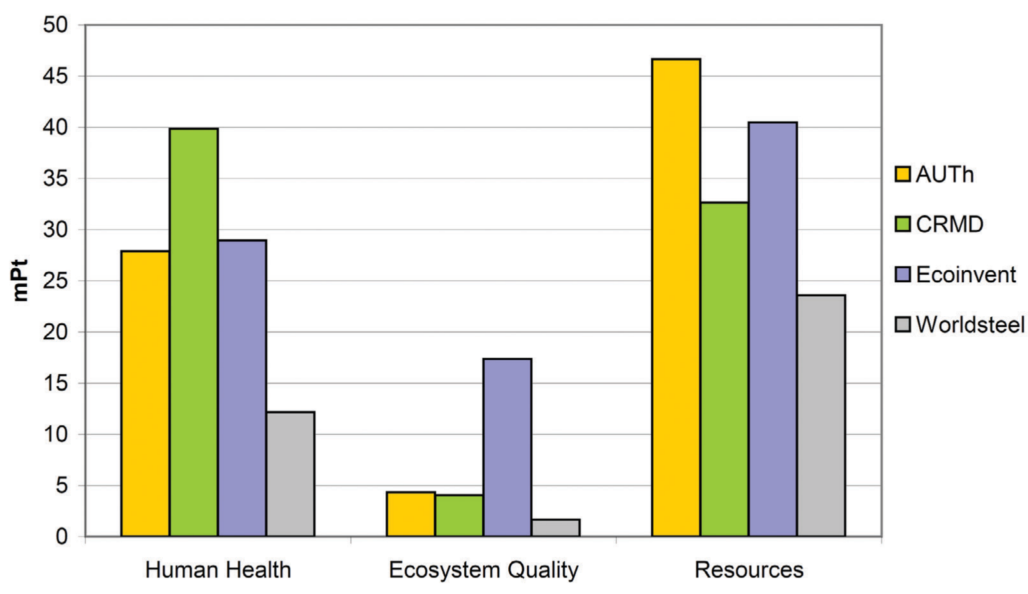

Fig. 5. Eco-Indicator 99 environmental impact results for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases, per impact category.

Table 1. Impact Result Divergence for Each LCI Database, According to Mainly Influenced Indicators					
Impact Indicator	Average Impact, (Pt)	AUTh Divergence, %	CRMD Divergence, %	Ecoinvent Divergence, %	Worldsteel Divergence, %
Total impact	0.068	16.0	12.6	27.7	46.5
Fossil fuels	0.033	38.6	3.7	18.5	34.0
Respiratory inorganics	0.018	4.6	78.7	12.6	61.6
Ecotoxicity	0.005	49.6	62.9	205.2	92.6
Carninogens	0.004	20.9	46.3	122.1	96.7
Climate change	0.005	13.6	5.8	19.6	0.2

values from 16.8 to 22.3 mPt, a quite noticeable value range. With coal, the consumption of which is directly associated to the consumption of electrical energy, the situation is even more complex. Only two of the four databases present similar results at 10.3 and 10 mPt, while the remaining two lead to greater values of 14.7 and 19.8 mPt.

These differences in values of the impact caused derive from calculations based on the environmental data contained in each database and can thus be interpreted as corresponding variations of LCI data. It is, therefore, clear that even fundamental environmental information such as the amount of energy required for the production of the steel members presents variations depending on the database in which it is found. Further analysis of the production processes included in the AUTh database reveals that the greatest amount of electrical energy is consumed during the operation of the EAF, the hot-rolling process and the ladle furnace stage. Accordingly, natural gas energy and oil are mainly consumed at the EAF, hot-rolling and reheat furnace stages. In order to minimize uncertainty embedded in LCI data within steel related LCA and in regard to fossil fuels, it is necessary to examine these processes thoroughly and determine the exact energy requirements. It should be noted that this observation also applies to the other mainly burdened impact indicators, such as respiratory inorganics.

Respiratory Inorganics

The respiratory inorganics indicator is the second most burdened indicator for the production of hot-rolled structural

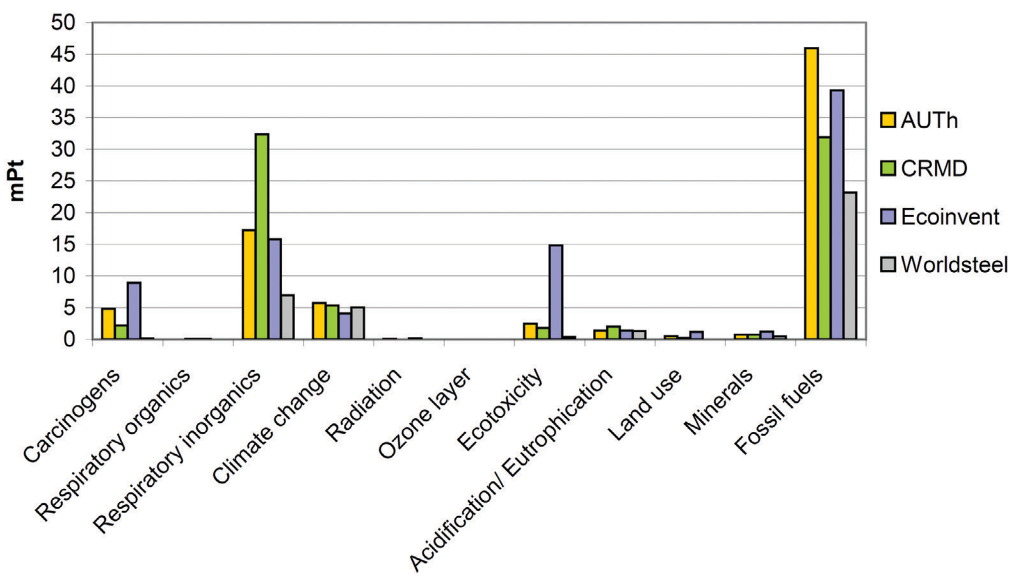

Fig. 6. Impact results for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases, per impact indicator.

steel members via the EAF steelmaking route. Figure 8 shows the corresponding impacts caused according to the four selected databases, including the main substance emissions that cause them.

The first observation is the increased total impact calculated according to one of the four databases. Although the Ecoinvent and AUTh databases lead to similar results, these values are close to half of the impact according to CRMD. In such cases, it is not possible to determine which result should be used, and the 50% difference is quite significant. The impact caused by the emission of sulfur oxides to the air ranges from 1 to 3.8 mPt according to two databases, while it is negligible according to the other two. Furthermore, the emission of sulfur dioxide to the air also presents noticeable variation, from 1 to 4.2 mPt. This substance emission is a result of the consumption of electrical energy and is, therefore, directly affected by the amount taken into account during the calculation of the LCI data. Thus, this type of energy is again identified as critical to the validity of the steel-related LCI data.

The value of the impact caused by the emission of particulates to the air also presents significant divergence (from 1.3 to 22.5 mPt), although it is very similar according to two databases (9.8 and 10 mPt). Further analysis of the AUTh database production processes reveals that the greatest percentage of particulates emitted to the air is caused by the consumption of electrical energy for the production of the structural steel members. The environmental impact caused by the emission of nitrogen oxides to the air is the only value that does not present significant divergence among the four databases, ranging from 3 to 4.8 mPt. As an overall observation, there is a lack of uniformity with regard to the impacts calculated. This can be attributed to data differentiation and can lead to similar result divergence within steel-related LCA.

IPCC Global Warming Potential (GWP) Impact Assessment

In order to acquire an additional perspective on the environmental impact of the production of hot-rolled structural steel members, its assessment was calculated according to another widely used methodology, the IPCC Global Warming Potential (GWP) 2007. This methodology was developed by the Intergovernmental Panel on Climate Change (IPCC, 2007), a global organization aiming at providing a clear, scientific view on the current state of climate change and its potential consequences. It is based on the calculation of a single index that refers to the quantity of carbon dioxide equivalent emissions to the air in kilograms of carbon dioxide (kg CO_2 eq). For the purpose of the current study, the GWP index was calculated for the production of 2.2 lb (1 kg) of hot-rolled structural steel members, according to the four selected LCI databases, and for a 20-, 100- and 500-year time horizon. The results are presented in Figure 9.

The examination of the impact results according to the IPCC GWP 2007 methodology presents a slightly different assessment, compared to Eco-Indicator. The first observation is that the impact according to the Worldsteel database is not the lowest of the four, even though it is the only dataset that includes a recycling scenario. All four impact values present a more even distribution, ranging, for example, from

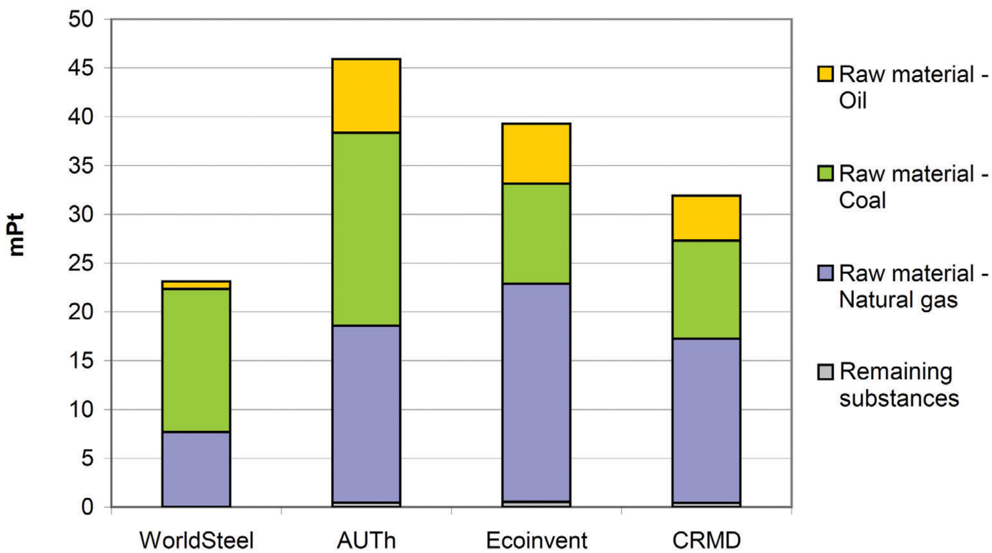

Fig. 7. Fossil fuels indicator impact for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases.

0.996 to 1.405 kg CO_2 eq. for the 100-year time horizon. The range of values for the 20- and 500-year time horizons remain similar. In general terms, a more uniform depiction of the environmental impact caused by the production of 2.2 lb (1 kg) of structural steel members is presented.

It is, therefore, highlighted that within the scope of LCI and LCA studies, impact assessment results can be calculated with more than one assessment methodology, each based on certain assumptions and criteria. Several impact assessment methods focus on a particular aspect or category of environmental impacts, such as the IPCC GWP 2007, which examines global warming and climate change. Although other methodologies, such as the Eco-Indicator, aim at providing a more complete approach to the assessment of environmental impacts, it should be noted that they are based on specific assumptions regarding impact assessment as well. It is advisable, then, to calculate environmental impacts according to more than one methodology in order to gain a wider, more complete and more factual perspective. Particularly in the case of comparative studies, the calculation of

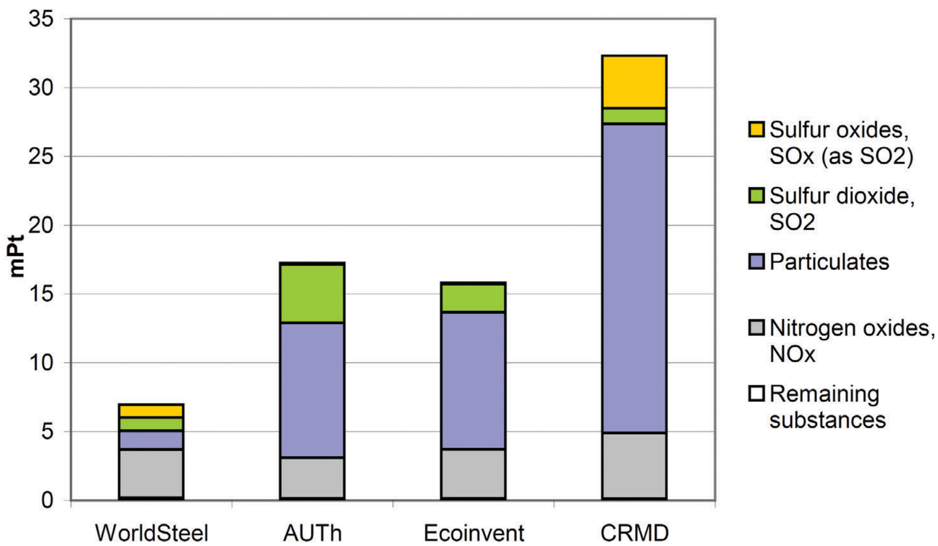

Fig. 8. Respiratory inorganics indicator impact for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases.

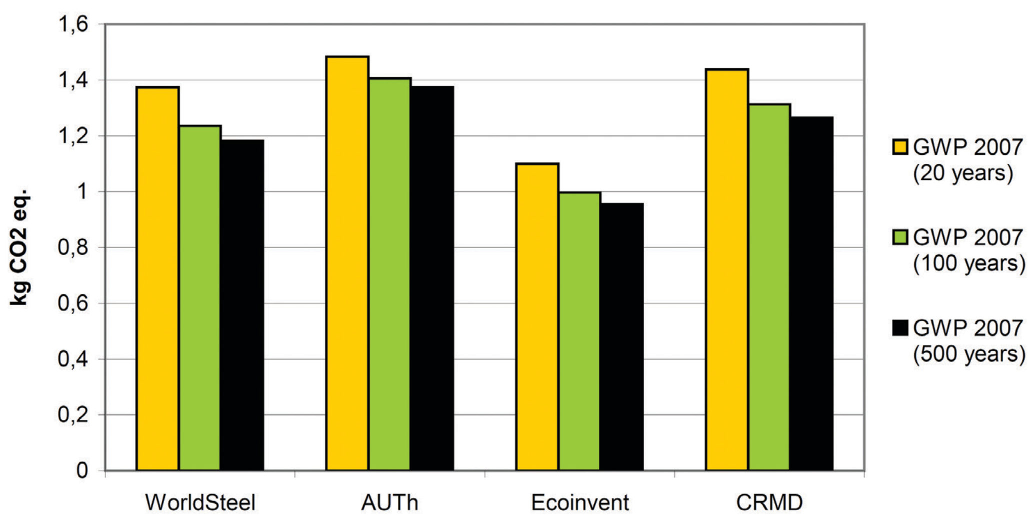

Fig. 9. IPCC GWP 2007 impact assessment for the production of 2.2 lb (1 kg) of hot-rolled structural steel members (EAF), according to four LCI databases.

Table 2. Environmental Impact Assessment Results for 2.2 lb (1 kg) of Hot-Rolled Structural Steel Sections According to Each LCI Database and the TRACI Methodology

Impact Category	Unit	AUTh	CRMD	Ecoinvent	Worldsteel
Ozone depletion	kg CFC_{-11} eq.	9.0872E-08	4.89151E-08	1.0269E-07	0
Global warming	kg CO_2 eq.	1.406224548	1.312803155	0.988808454	1.23522998
Smog	kg O_3 eq.	0.043009061	0.06858607	0.050892542	0.051060138
Acidification	mol H+ eq.	0.290464931	0.357480433	0.189167198	0.178937872
Eutrophication	kg N eq.	0.016775008	0.004248367	0.004377911	0.000110648
Carcinogenics	CTUh	3.66154E-07	2.49415E-07	3.46166E-06	1.38632E-09
Noncarcinogenics	CTUh	3.19333E-07	1.10754E-07	2.92674E-06	7.29306E-08
Respiratory effects	kg PM_{10} eq.	0.001953061	0.000805941	0.00162357	0.000206099
Ecotoxicity	CTUe	4.76130729	2.801574071	35.14301133	0.007596337

impact assessment results according to more than one methodology is necessary, as was shown by the current analysis of the production of structural steel members.

TRACI Impact Assessment

TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) is another widely used impact assessment methodology that was developed by the U.S. Environmental Protection Agency specifically for the United States with the use of input parameters that are consistent with U.S. locations. Environmental impact assessment results for the four selected LCI databases are presented in Table 2.

As can be observed, the results obtained according to the TRACI methodology present noticeable differences in most impact categories. In ecotoxicity, for example, the Ecoinvent database leads to a very high result compared to the rest of the databases, while the same can be observed for the AUTh database in the eutrophication impact category. On the other hand, only the smog and acidification impact categories present an accepted range of values.

The Effect of the Market on LCI Data

At this point, a significant issue concerning the source of LCI data arises. For the collection of primary LCI data, it is businesses involved with the product, system or service under study that are asked to provide detailed information concerning the environmental impact of the production processes they are currently applying. It is necessary, however, to consider the conditions under which today's businesses operate before putting the data they provide to use as the basis of decision-making methodologies and tools. It is true that within every major business sector where large-scale projects and clients are involved—with the steel industry being no exception—there is extreme competitiveness among the participants for not only maintaining a strategic market position but also for broadening it. Every business that is interested in its future survival and prosperity is trying to adapt to the changing market conditions in order to gain more clients.

These changing market conditions have lately been greatly influenced by the global movement for sustainable development, with European and global organizations oriented toward achieving it through legislation adaptation and the promotion of more environmentally friendly policies. It is therefore quite common, within large-scale projects such as steel constructions, to investigate material and component suppliers from the point of view of their product's environmental impact. As a result, it is not unreasonable to require verification of the environmental data supplied by any business whose turnover and subsequent net profit are coming to depend on these data. The only efficient verification process of data provided by businesses is thorough examination. The degree, however, to which data can be verified, remains questionable. As an alternative, data and measurements conducted by independent organizations and according to specific guidelines would certainly provide a more dependable reference, corresponding to the actual environmental impact caused.

CONCLUSIONS

At the outset of each LCA study, one of the critical tasks that have to be carried out is finding the appropriate LCI data. Even in cases that facilitate the collection of primary data directly from manufacturers, the verification of the obtained data is required, while the use of secondary data as found in existing LCI databases is inevitable. As was shown with the analysis of structural steel members, there are a number of available LCI databases that contain data concerning the same products, processes or systems. The selection of the most appropriate data usually depends on a number of data quality factors, including geographic coverage, technology level and collection time period. It should not, however, be based solely on the examination of these factors and in no case should it be taken for granted that the validity of the final LCA result is ensured by the fact that a specific existing dataset matches the data quality requirements of the study. Because it is not possible to determine the most appropriate data based only on the examination of the data's quality characteristics, the extent of uncertainty embedded should be taken into account before the interpretation of relevant LCA results.

LCI datasets referring to the same product or system, even with very minor differences in terms of data quality, can lead to noticeable divergence of the final LCA result. Impact assessment results for the production of structural steel members showed significant value variation among different LCI databases when calculated for each of the mainly burdened impact indicators. An overall lack of environmental impact result uniformity was observed, in spite of the fact that all selected LCI databases are based on data provided by manufacturers. This could be attributed to data quality differentiations—such as differences in geographic coverage, data collection time period, technology level, data sampling methodologies or the age of the data—yet only partly, because the production process for hot-rolled structural steel members via the EAF steelmaking route does not present major variations or utilize fundamentally different machinery. Additional reasons include different manufacturing processes and different electrical grids.

It was estimated that, within certain indicators, the relevant impact calculated presented divergence of up to almost 80%, and even 205% at one instance, with regard to the average value among the selected databases. This variation is directly associated with the quality and accuracy of the data; although expected to a certain level, it is a clear indication of the extent of uncertainty embedded in LCA and, inevitably, transferred to the final LCA results. Thus, it should be expected that LCA studies that differ only in the source of LCI data can lead to varying impact assessment results. Furthermore, issues such as electrical grid differences, different production processes or methodology differences also increase the level of uncertainty embedded in LCI data.

The detailed analysis of the calculated impacts of the production of hot-rolled structural steel members for the most heavily burdened impact indicator—which was found to be fossil fuels—showed that even fundamental environmental information such as the amount of consumed electrical energy presents variations depending on the database in which it is found. As was shown, it is the amount of electrical energy that causes the largest percentage of environmental burden, and as a result, it can be assumed that the largest percentage of the divergence of impact assessment results between the examined databases can be attributed to the differences in electrical grid mixes documented in each database.

The influence of system boundaries was also shown by the calculation of impact assessment results based on a dataset that includes a recycling rate, as opposed to the rest of the selected datasets that do not include end-of-life scenarios. As expected, a significant difference between the corresponding calculated impacts was observed, the extent of which highlights the importance of examining the characteristics of LCI data thoroughly, before incorporating it into an LCA study.

An issue concerning the collection of data was also raised. Primary LCI data are provided by businesses that operate within sectors, such as the steel industry, where market conditions have and are constantly becoming even more competitive. In order to consolidate their current market position and also attempt to broaden their standing, these businesses are now called to become competitive in terms of sustainability of the services or products offered. Large-scale clients and projects require materials and products with low environmental impact, in line with the orientation of European and global organizations toward legislation adaptation and the promotion of more environmentally friendly policies. As a result, it is advisable to thoroughly examine the data provided by any business whose turnover and subsequent net profit are coming to depend on such data to a continuously increasing degree. Alternatively, LCI data collected by independent third-party organizations and according to widely acknowledged guidelines [such as Product Category Rules (PCRs) and Environmental Product Declarations (EPDs)] would certainly provide a more dependable reference, corresponding to actual environmental impacts caused.

It was also highlighted that within the scope of LCI and LCA studies, it is necessary to calculate impact assessment results according to more than one assessment methodologies. Although the use of a methodology capable of providing results across a wide range of impact categories provides a multilevel depiction of the environmental impact caused, it should not be neglected that even this type of methodology is based on specific assumptions regarding impact assessment. In order to gain a wider, more complete and more factual perspective, it is suggested that impact assessment results be calculated with methods that focus on particular aspects or categories of environmental impacts as well.

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