COMPARATIVE ANALYSIS OF LIFE CYCLE INVENTORY DATABASES FOR STRUCTURAL STEEL MEMBERS

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Summary

Due to the acknowledged urgency for sustainable development, the building sector has been introduced with a number of new technologies which aim at ensuring the sustainability of building projects worldwide. Among the key issues related to the optimization of building sustainability is the improvement of the initial stages of a project, namely early decision making and design. Environmental assessment methods such as Life Cycle Assessment (LCA) are useful tools and provide the opportunity to assess the environmental impact of buildings, taking into account all necessary materials and processes of their complete life cycle. A detailed comparison of environmental data used in these studies and found in a range of Life Cycle Inventory (LCI) databases is presented in the current paper, focusing on steel buildings and structural steel members. The data is managed with the SimaPro software and compared on the basis of environmental impact caused for the manufacturing of specific structural steel members. The comparative analysis results lead to conclusions regarding the uncertainty embedded in the use of LCI databases and also the range of application of the databases that were examined.

Keywords: Comparative analysis, Life Cycle Assessment (LCA), Life Cycle Inventory (LCI), Structural steel members

1 Introduction

Life Cycle Assessment (LCA) has been introduced as a newly developed methodology aiming at the quantification of the environmental impact associated with the product, process or ‘system’ examined. This useful decision-making tool can achieve significant efficiency within business sectors such as construction [2], when used pro-actively to assess the environmental impact of different solutions prior to ‘system’ delivery. Its application is based on environmental data either collected especially for the specific LCA study or used with or without slight modifications, as found in Life Cycle Inventory (LCI) databases [1].

For the building sector this translates into requirements of environmental data regarding structural components and construction processes [6]. The quality and accuracy of this data is of critical importance to the validity of the outcome of any LCA study. Although significant progress has been made as far as LCA methodology and LCI database development are concerned [5], no data benchmarking strategy has been widely acknowledged. Especially within scientific fields with increased sustainable potential where LCA studies are expected to be used extensively [8], such as metal structures, an attempt should be made to estimate the divergence which can occur due to LCI data differences.

The current research focuses on providing a comparison of environmental impact results derived from different existing LCI databases for structural steel members commonly used for the construction of steel buildings, namely hot-rolled structural steel sections. Environmental impact is estimated according to the Eco-Indicator and Global Warming Potential (GWP) methods.

2 Comparative analysis parameters

2.1 Functional unit

In order to maintain a uniform point of reference for all data used, the production of 1kg of hot-rolled structural steel members via the electric arc furnace steel-making route (utilizing steel scrap) was defined as the functional unit for the environmental impact comparative study. For the selection of the most appropriate existing LCI databases, extensive research was conducted in order to determine whether or not they contain verified data concerning the environmental impact associated with the production of hot-rolled structural steel members.

2.2 LCI databases

2.2.1 Ecoinvent

The Ecoinvent LCI database is one of the most detailed and complete worldwide, widely used in LCA studies. It contains about 4000 datasets for products, services and processes and was developed in 2003 at the Swiss Centre for Life Cycle Inventories, which is also responsible for updating it [3]. The data geographic coverage is mainly the European region. The datasets used include the production of steel with the electric arc furnace route and the process of hot-rolling. The process of the reheat furnace was not included in the database and was therefore simulated with the corresponding process of the AUTh database.

2.2.2 World Steel LCI

The World Steel Association (Worldsteel or IISI) has already conducted two Life Cycle Inventory Studies at a global scale in order to quantify raw material requirements and environmental emissions associated with 14 steel products, including structural steel sections. The data was collected from sources globally, initially in 1994-95 and has been updated in 1999-00 [7]. It has been calculated for 1kg of steel product at the factory gate, including an 85% recycling rate at the end of the life cycle. It should also be noted that the data refers to the average of both steel-making routes, electric arc furnace and blast furnace as well.

2.2.3 Canadian Raw Materials Database (CRMD)

The CRMD database was developed by the Canadian industrial sector and government and contains a wide range of datasets, including the production of steel billets with the electric arc furnace route. The rest of the necessary processes for the production of hot-rolled members, such as the reheat furnace and hot-rolling are simulated according to the corresponding processes of the AUTh database.

2.2.4 Aristotle University of Thessaloniki (AUTh) LCI database

The AUTh LCI database was developed at the Institute of Metal Structures of the Aristotle University of Thessaloniki in 2009. It contains detailed datasets associated with the production processes for hot-rolled and cold-formed structural steel members. The data was mainly provided by the leading steel member manufacturing company in Greece and was completed with thorough literature research.

3 Eco-Indicator impact assessment

The Eco-Indicator 99 impact assessment methodology provides a thorough presentation of environmental impacts and is used within the current comparative analysis. Figure 1 shows the impact associated with the production of hot-rolled structural steel members with the electric arc furnace steel-making route, according to the LCI databases available.

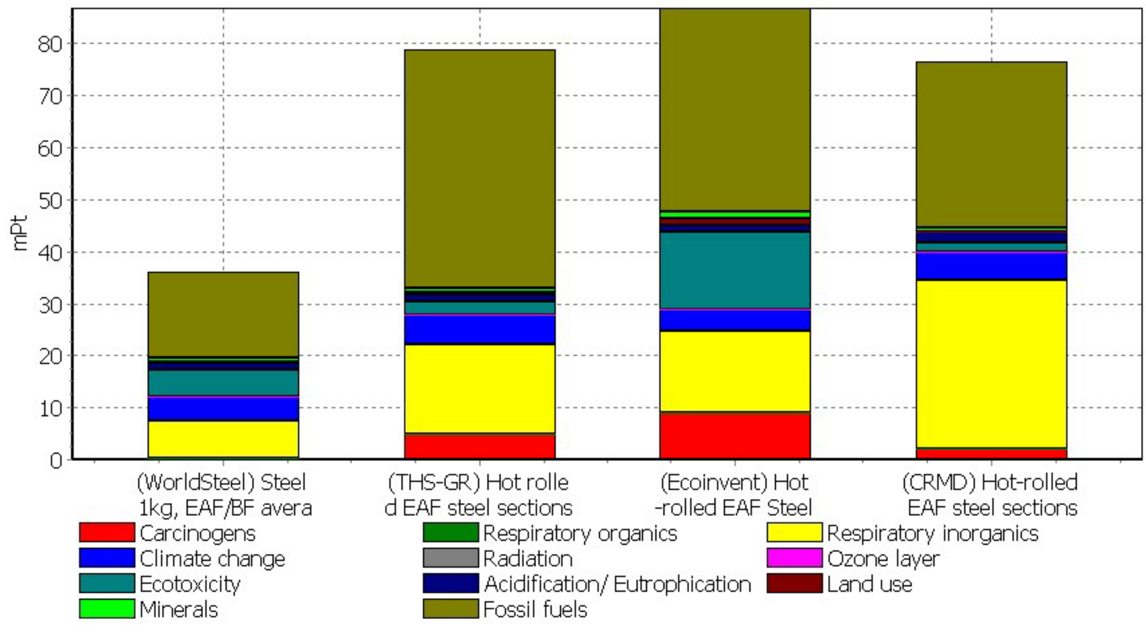

Fig. 1 Environmental impact of the production of 1kg of hot-rolled structural steel members, according to four LCI databases.

As can be observed, the total environmental impact (measured in mPt, where 1kPt relates to the average annual environmental impact of a European inhabitant) is almost the same according to three of the four databases. Worldsteel data entails quite a smaller impact, less than half of the other databases. This observation signifies the noticeable divergence that can characterise Life Cycle Inventory data. Although all data was collected thoroughly and then checked for validity, the total outcome appears capable of varying up to 50%.

The same conclusion can be drawn from Figure 2, where total environmental impacts are presented according to three major impact categories, namely human health, ecosystem quality and resources. It is also evident that ecosystem quality is less affected, compared to human health and resources which are mainly burdened.

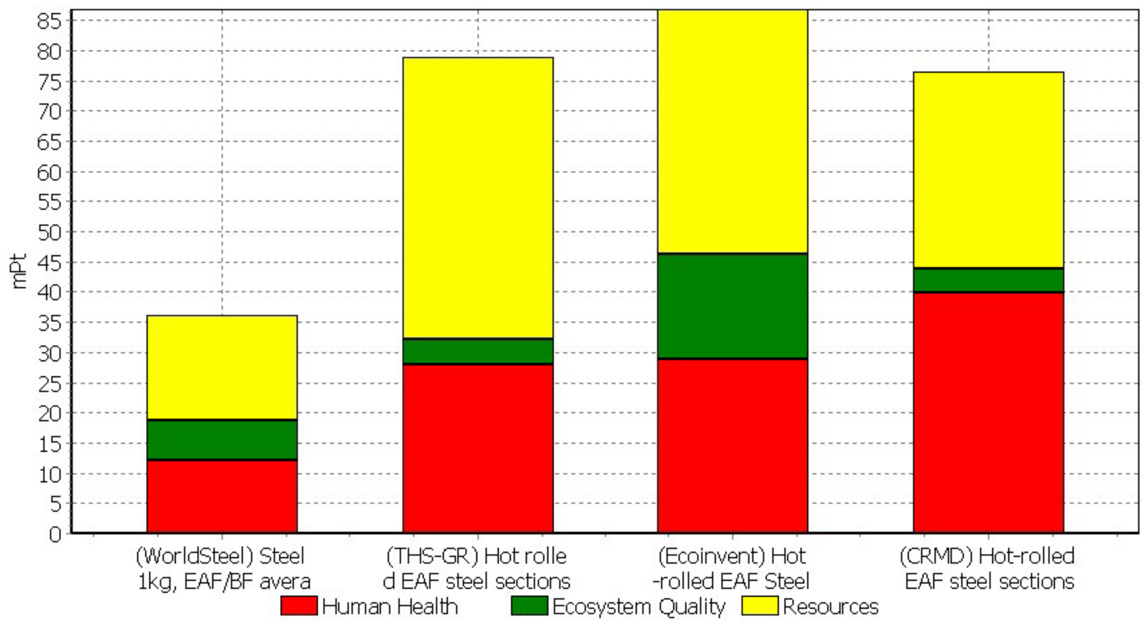

Fig. 2 Environmental impact of the production of 1kg of hot-rolled structural steel members, according to major impact categories.

In Figure 3 it is possible to compare the environmental impacts at a more detailed level, according to the impact indicators used by the Eco-Indicator assessment methodology. Certain impact indicators, such as ‘fossil fuels’ (referring to the additional required energy for extraction, due to low raw material quality) and ‘Respiratory – inorganics’ (referring to effects on the human respiratory system caused by emissions of inorganic substances during winter time) are heavily burdened compared to the rest of the indicators. It is also evident that although all of the results are not identical, for certain indicators some databases give similar results.

In order to determine the production processes that are responsible for the environmental burdens caused, it is necessary to examine each impact indicator separately.

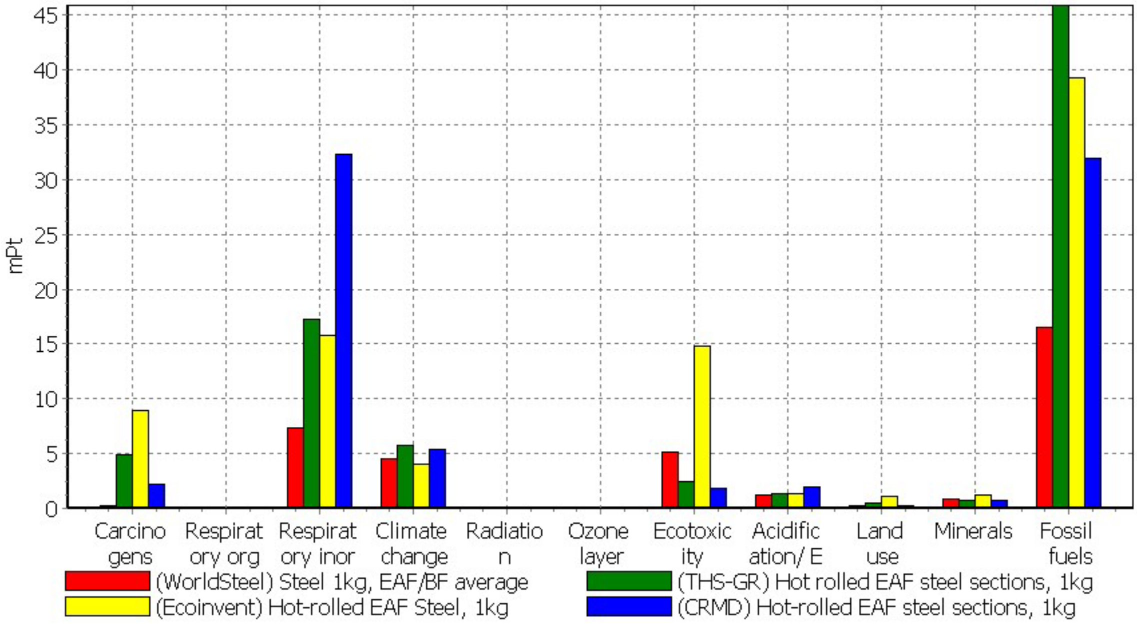

Fig. 3 Environmental impact according to Eco-Indicator impact indicators.

3.1 'Fossil fuels' environmental impact indicator

As can be observed in Figure 3, 'fossil fuels' is the impact indicator which is mainly burdened during the production of hot-rolled structural steel members with the electric arc furnace steel-making route. In Figure 4, the environmental impact of the 'fossil fuels' indicator is presented, according to the substances which are responsible for the impact.

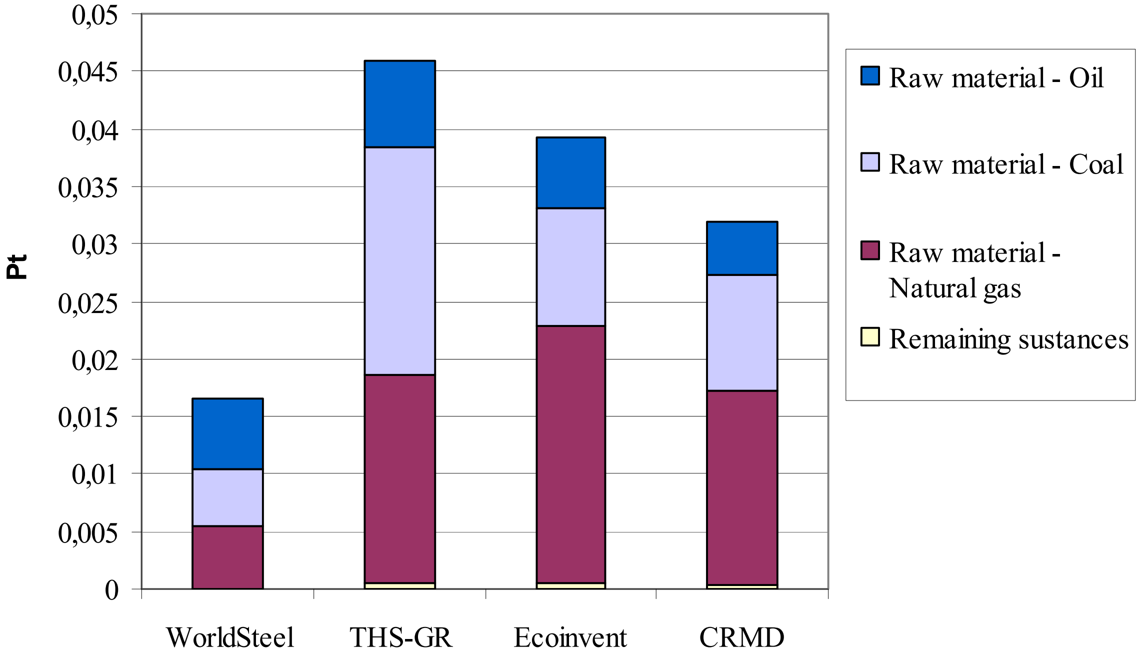

Fig. 4 Substances responsible for 'fossil fuels' environmental impact (1% cut-off).

It is obvious that there are three substances which mainly cause the 'fossil fuels' environmental impact, all of which refer to raw material requirements. The impact caused by oil requirements is very similar according to all four databases. Natural gas related impact is equal to 5,54 mPt (1kPt relates to the average annual environmental impact of a European inhabitant) according to the Worldsteel database and ranging from 16,83 to 22,34 mPt according to the other three. The impact caused by coal requirements - associated directly to the consumption of electric energy- is almost the same according to the Ecoinvent and CRMD databases (10,29 and 10,04 mPt respectively), while Worldsteel data gives a lower result (4,91 mPt, almost half) and AUTh a higher one (19,79 mPt, almost double).

This divergence is caused by differences in data concerning the total electric energy consumption. A detailed examination of the production processes in the AUTh database reveal that the greatest percentage of electric energy is consumed during three processes, the electric arc furnace operation, hot-rolling and the ladle furnace stage. It is therefore evident that in order to achieve better uniformity of results within 'fossil fuels' it is necessary to accurately determine the amount of electric energy consumed at these three production stages.

4 IPCC GWP 2007 impact assessment

The IPCC (Intergovernmental Panel on Climate Change) Global Warming Potential (GWP) impact assessment method can provide an additional comparative viewpoint, based on the calculation of a single index, namely the amount of equivalent carbon dioxide emissions (CO_2) to the air. The results are presented in Figure 5, for each of the four LCI databases and according to a time horizon of 20, 100 and 500 years, respectively.

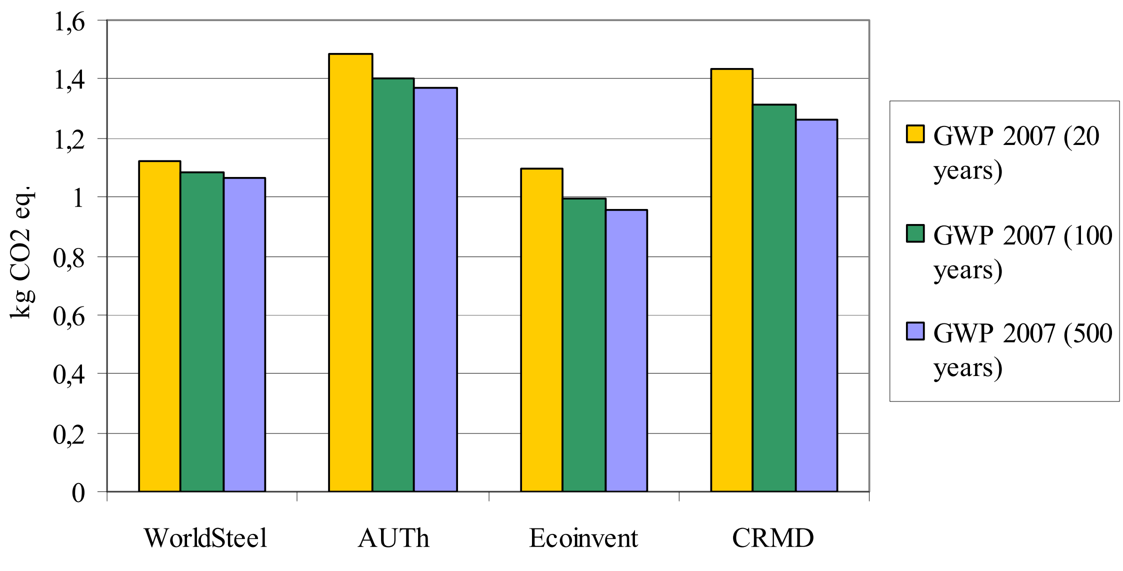

Fig. 5 Global Warming Potential (2007) for 1kg of hot-rolled structural steel members (EAF).

The comparison of total environmental impact for the production of 1kg of hot-rolled structural steel members according to the four LCI databases, based on the IPCC GWP 2007 method provides slightly different results in relation to the Eco-Indicator method. The first observation concerns the impact calculated with the WorldSteel data, which in this case is not the lowest and certainly does not differentiate to such a noticeable degree as with the Eco-Indicator method. The Ecoinvent and Wordsteel databases entail the smallest amounts of equivalent carbon dioxide emissions (0,99 and 1,09 kg, respectively, for a 100-year horizon), while for the same time horizon the AUTh database results in 1,41 kg and the CRMD in 1,31 kg. In general terms, the results are more uniform with the GWP impact assessment method.

5 Conclusions

The calculation of the environmental impact associated with the production of structural steel members requires the collection of environmental data which is often almost impossible to gather within the scope of a single LCA study. It is therefore inevitable that data is used as found -or with minor modifications- in LCI databases. The current research activity compared the environmental impact results for the production of 1kg of hot-rolled structural steel members via the electric arc furnace route, according to four existing LCI databases which contain relevant data.

One of the main issues identified concerns the impact assessment methodologies used in LCA. It was shown that in order to gain a more complete and broad perspective of the actual environmental impact caused, it is preferable to calculate the environmental impact results according to more than one impact assessment methods. As was the case with the current study, the final results' comparison portrayed a slightly different situation for the Eco-Indicator and IPCC Global Warming Potential methods.

As well as providing specific results concerning the actual environmental impact of structural steel members, the research also comes to a more general conclusion regarding the use of LCI data and the uncertainty embedded in it. Regardless of the quality of the data, the final result can vary significantly. As was shown, LCI data from different databases, although referring to the same product, process or system can lead to different results. As each dataset is characterized by specific conditions, technology levels, geographic regions etc. and therefore it can not be expected that results can ever match completely. However, it is advisable to review the source of LCI data used in a Life Cycle Assessment (LCA) study before interpreting its final results.

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