Environmental Impact Assessment Review 30 (2010) 192–199

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

The applicability of non-local LCI data for LCA

Margarita Ossés de Eicker [a], Roland Hischier [a,b,*], Luiz Alexandre Kulay [c], Martin Lehmann [a], Rainer Zah [a], Hans Hurni [d]

[a] Empa, Swiss Federal Laboratories for Materials Testing and Research, Technology and Society Laboratory, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland
[b] Ecoinvent Centre, c/o Empa, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland
[c] Centro Universitário Senac. Av. Engenheiro Eusébio Stevaux 823, Santo Amaro 04696-000, Sao Paulo, Brazil
[d] University of Berne, Institute of Geography, Hallerstrasse 10, 3012 Berne, Switzerland

ARTICLE INFO

Article history:
Received 10 October 2008
Received in revised form 12 August 2009
Accepted 14 August 2009
Available online 5 September 2009

Keywords:
LCIA
LCI
Industry
Fertilizer
Brazil
Latin America
Ecoinvent
Database

ABSTRACT

This study evaluated how applicable European Life Cycle Inventory (LCI) data are to assessing the environmental impacts of the life cycle of Brazilian triple superphosphate (TSP). The LCI data used for the comparison were local Brazilian LCI data, European LCI data in its original version from the ecoinvent database and a modified version of the European LCI data, which had been adapted to better account for the Brazilian situation. We compared the three established datasets at the level of the inventory as well as for their environmental impacts, i.e. at the level of Life Cycle Environmental Assessment (LCIA). The analysis showed that the European LCIs (both the original and the modified ones) considered a broader spectrum of background processes and environmental flows (inputs and outputs). Nevertheless, TSP production had in all three cases similar values for the consumption of the main raw materials. The LCIA results obtained for the datasets showed important differences as well. Therefore we concluded that the European data in general lead to much higher environmental impacts than the Brazilian data. The differences between the LCIA results obtained with the Brazilian and the European data can be basically explained by the methodological differences underlying the data. The small differences at the LCI level for selected inputs and outputs between the Brazilian and the European LCIs from ecoinvent indicate that the latter can be regarded as applicable for characterizing the Brazilian TSP.

1. Introduction

1.1. The use of non-local data for life cycle assessment in Latin America

The Life Cycle Assessment (LCA) methodology can be useful to acquire a comprehensive knowledge of the environmental impacts generated by industrial products during their whole life cycle. However, in Latin America the necessary local Life Cycle Inventory (LCI)[1] data from industry is extremely scarce, despite initiatives to support LCA issues in the region and the ongoing efforts in developing local LCI data (Skone, 2001; Coltro et al., 2003, 2006; Kulay, 2004; Curran, 2006; Galdiano, 2006; Sonnemann and De Leeuw, 2006; Suppen et al., 2006; Hischier et al., 2007). Due to this scarcity of local data Latin American LCA experts often have to apply non-local databases in their studies. However, such LCA studies based on non-local LCI data may show inaccurate results, basically due to the potential differences in the environmental performance of the industry in the countries that generated the data and the industry in Latin America (see e.g. Brent et al., 2002), or the second paper from the authors which discusses the suitability of such non-local databases for the environmental assessment of industry in Latin America (Ossés de Eicker et al. under review).

In order to account for these potential differences and apply LCI data in the form most suitable to the local situation, an LCI database applied should have the following characteristics:

- all processes must be addressed individually, as single step processes (the so-called unit processes) of the life cycle of the product, instead of a cumulative LCI where all steps are aggregated into one single dataset;
- all datasets should be clearly documented and include all details, in order to have a maximum of transparency in the database;
- the database should provide different alternatives for the same product, related to technological variations.

All these features would make it possible for an analyst to build the life cycle of a specific product under study by combining LCI data from

* Corresponding author. Empa, Swiss Federal Laboratories for Materials Testing and Research, Technology and Society Laboratory, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland. Tel.: +41 71 2747847.
E-mail addresses: Margarita.Osses@empa.ch (M. Ossés de Eicker), Roland.Hischier@empa.ch (R. Hischier), luiz.akulay@sp.senac.br (L.A. Kulay), Martin.Lehmann@empa.ch (M. Lehmann), Rainer.Zah@empa.ch (R. Zah), Hans.Hurni@cde.unibe.ch (H. Hurni).

[1] A Life Cycle Inventory is the collection of all inputs and outputs associated to a given product (a material product or an activity). Inputs considered are consumption of natural resources, materials, energy and transport; outputs are the main products and by-products generated, as well as the emissions and wastes produced.

0195-9255/$ – see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.eiar.2009.08.007

various single step processes in the most appropriate way. At the same time, the analyst should use a tool allowing him to edit input and/or output values in the LCI in order to better reflect the product under study. Finally, it is advantageous for the database to provide uncertainty values for the LCI data (inputs and outputs) which also can be adjusted in order to reflect the application of the original data to a different situation.[2]

1.2. The suitability of the LCI database ecoinvent

The LCI database ecoinvent (Frischknecht et al., 2005; Frischknecht and Rebitzer, 2005), in combination with either LCA software tool offers all such features. Due to the high and comprehensive transparency in the documentation of this database, as well as the applied principle of unit processes, an original LCI dataset from the ecoinvent database can be used to generate a Latin-American version of the respective dataset adapted for such operations using suitable LCA software tools. Some of these tools also allow one to modify the uncertainty assessment of such an adapted LCI dataset in order to take into account even more adequately the differences between the newly produced "local" (i.e. Latin American) process and the original process in the database ecoinvent.

However, the applicability of such non-local LCI databases as ecoinvent to a local, Latin-American situation should be evaluated by comparing the non-local data with accurate local LCI values. For the case of Latin America no broad trials have been done so far in this direction. One possible reason for the lack of such trials could be the scarcity of LCI data in Latin America. In addition, in order to determine the applicability of such non-local LCI databases to complete LCA studies, the Life Cycle Impact Assessment (LCIA) results obtained with the non-local data should be compared against LCIA results obtained with locally available data. Again, this type of comparison has not been done in Latin America so far. Since the validation of data contributes a lot to improving the reliability of LCA (Björklund, 2002), this study intends to contribute to the fulfillment of both aforementioned gaps.

1.3. Case study triple superphosphate

Triple Superphosphate (TSP), a phosphated synthetic fertilizer, is used here as a first example for the application of European LCI data to developing an LCA study on a Brazilian product, because of the similarities of the production technologies involved and the fact that LCI data are available both in the European LCI database ecoinvent as well as on the level of a Brazilian study (Kulay, 2004; Da Silva and Kulay, 2005). In addition, TSP is a synthetic fertilizer that is extensively used world-wide and thus, this comparison has global relevance (Weidema and Meeusen, 2000; Kulay, 2004).

In Europe TSP is traditionally produced on the basis of a phosphate concentrate obtained from phosphate rock, which is acidulated with phosphoric acid during the production process. The dataset used in this study from the ecoinvent database represents a mixture of the two different production technologies used in Europe, both occurring under controlled conditions of pressure and temperature in batch reactors:

- Two-step-process: in this process a powder is produced in the first step by rock grinding, resulting in the main energy consumption. The powder is then granulated with steam in a second step. The acidulation is achieved with phosphoric acid with a concentration of 48% P_2O_5. In Europe, more than 75% of TSP is produced with such a two-step-process.
- Slurry process: this technology uses a very soft rock, which does not require grinding. The acidulation in the slurry process is performed by phosphoric acid with 42% P_2O_5. This process generally consumes 20% less energy than the two-step technology. However, due to the need for a very soft rock in this process as well as due to the wasted rock which does not react in the process this technology is only of minor importance (Kongshaug, 1998).

In Brazil TSP production is carried out with the run-of-mill technology, which uses semi-batch reactors. In contrast to what occurs in the European process, in the Brazilian process a solid waste called phosphogypsum is generated. Another difference is that in the Brazilian process part of the phosphate concentrate is also used to produce phosphoric acid by digestion with sulfuric acid. For both uses phosphate concentrate obtained from rock needs to be dried with steam prior to its use. Fig. 1 presents as an example the flow sheet of the Brazilian process.

Comparing the technologies in Europe and Brazil, it may be seen that both cases use a similar phosphorous raw material and have a similar energy consumption. Thus, the Brazilian and European production of TSP could be considered to be similar in terms of technology.

2. Goal and scope

This study evaluates the applicability of European LCI data to assessing the environmental impacts of the Brazilian production by using TSP as a case study objective through the whole life cycle.

3. Methods

The LCI data used for this comparison were local Brazilian LCI data (Kulay, 2004; Da Silva and Kulay, 2005) – sometimes called "Brazilian TSP", i.e. European LCI data from the ecoinvent database in its original version (Frischknecht et al., 2005) – sometimes called "original European TSP" and a modified version of the European LCI data, which was adapted to better account for the Brazilian situation – called "modified European TSP". In a second step these datasets were then compared at the LCI level. In a third step, the Life Cycle Impact Assessment (LCIA) results obtained with the three established datasets were compared. Based on the results of these comparisons the applicability of non-local LCI data for LCA of Brazilian TSP is discussed. A schematic of the procedure adopted in this study is shown in Fig. 2.

3.1. Step 1: Preparation of LCI data

The LCI data covered in this case study was: phosphate rock mining, production of phosphatic rock concentrate, sulphuric acid production, phosphoric acid production, TSP production, natural gas production, electricity generation and transport operations. With regard to the elementary flows considered (i.e. inputs or outputs), the following types were evaluated in the LCIs — as is usual in an LCA study: consumption of natural resources, materials, energy, and transport services. Outputs considered were emissions to air, water and soil, solid wastes and products and by-products themselves. The inventories were derived from literature studies and specifications from manufacturers. The functional unit used in this study was 1 kg of phosphate fertilizer expressed in P_2O_5 content.

[2] In LCA literature also different definitions and understandings about uncertainty can be found (Ciroth et al., 2004). In this study the concept stated by Ciroth et al. (2004) is adopted and uncertainty is considered as a term describing the fact that measured values frequently do not match the true values, but differ from them in a probabilistic manner. This understanding is in concordance with other sources (Ellison et al. 2000; Rabinovich, 2000) and with the definition of the International Standardization Organization ISO (1993) which defines uncertainty as "a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand".

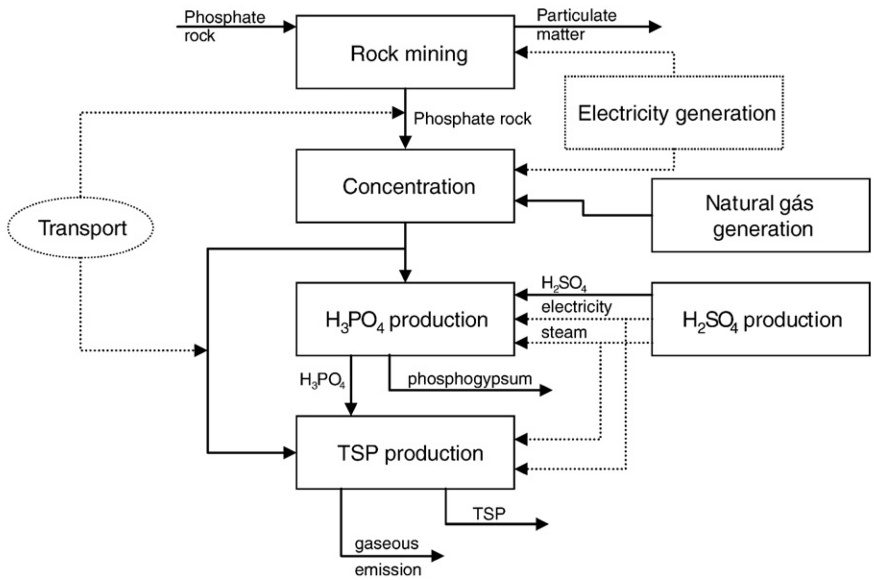

Fig. 1. Brazilian's production of TSP with average technology.

For this study the following three datasets were prepared:

- "Brazilian TSP": an original Brazilian dataset, the local data, referring to the production of TSP from phosphoric acid and phosphate rock in Brazil, taken from Kulay (2004) and Da Silva and Kulay (2005).
- "Original European TSP": the original European, i.e. the non-local, LCI data referring to the same fertilizer produced from the same intermediates, extracted from the ecoinvent database (Frischknecht et al., 2005; Frischknecht and Rebitzer, 2005).
- "Modified European TSP": and as a third set of LCI data, the European LCI data was modified mainly in the background processes in order to be more appropriate for use in Brasil. To this end, changes were made in the electricity mix (i.e. a Brazilian electricity mix was applied), transportation distances and oil production.

The modified dataset was also re-assessed concerning its uncertainty values in order to account for the application to the Brazilian situation by adjusting the scores for the indicators on geographical and technological correlation. Last but not least, the uncertainties in the Brazilian dataset were also assessed with the procedure applied in the ecoinvent database (for more on this see: Frischknecht et al., 2005).

3.2. Step 2: Comparison at LCI level

A comparison was then carried out at the LCI level among the three datasets. Then the LCI data were compared that refer to the single stages of the life cycle of TSP, as well as the cumulated LCI referring to the whole life cycle.

3.3. Step 3: Comparison at LCIA level

Additionally, a comparison was also carried out at the LCIA level among the three datasets. For the environmental impact assessment the so-called CML method (Guineé, 2001), the Eco-indicator'99 (Goedkoop, 2000) and the Cumulative Energy Demand (CED) were

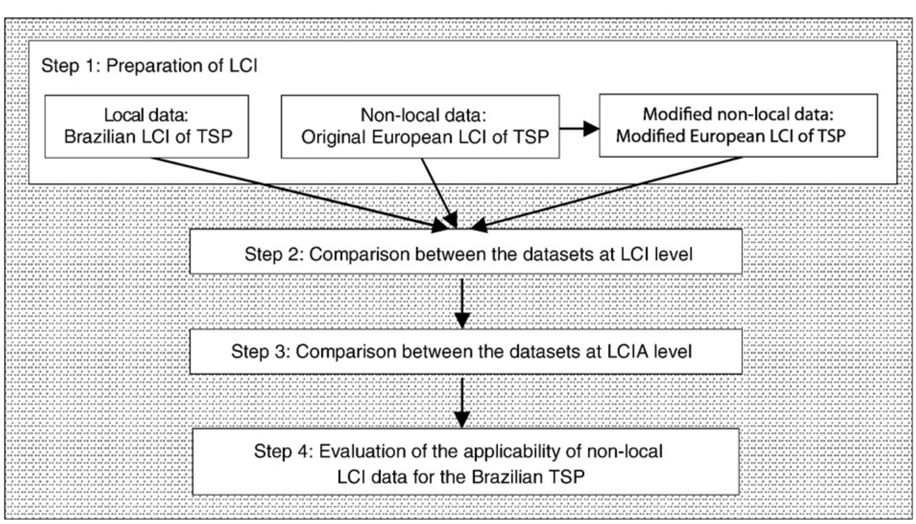

Fig. 2. Schematized representation of the procedure followed.

applied according to their implementation in the ecoinvent database (Frischknecht et al., 2007).[3] While CML and CED are so-called mid-point indicators, the Eco-indicator'99 is an example of an end-point indicator.[4] Using both types of indicators it is possible to address the impacts of substitution in LCIA from different angles. These two kinds of indicators have complementary merits and limitations, which is why some practitioners recommend using them in parallel (Bare et al., 2000).

4. Results

4.1. Differences among the datasets at the LCI level

Although all three datasets represent the LCI of the production of 1 kg of TSP, the Brazilian and the two European (both the original and the modified datasets) TSP datasets differ in the scopes of the product systems applied. While infrastructure and transportation are considered in all steps of the European data, this is only in some of the Brazilian production steps the case. In addition, in the Brazilian data only the subsystems transport, electricity and natural gas are represented from cradle-to-gate. But while transportation of phosphate rock and beneficiated rock is taken into account, the transportation of all other raw materials and auxiliaries is not taken into account. Finally, the composition and fate of the solid wastes generated in several steps of the Brazilian process are unknown, as information was not available at the time the study was conducted. Thus, no integration of the waste treatment steps was possible in the Brazilian data. In addition, we observed that the two ecoinvent datasets address in a much more comprehensive manner the backstage processes of the life cycle of TSP — i.e. their various backstage processes are much more detailed compared to the processes used in the Brazilian TSP dataset.

A further difference among the datasets was found in the number of elementary flows considered. As shown in Fig. 3, the European data from ecoinvent generally takes into account a much broader spectrum of emissions to air, water and soil, as well as of raw materials.

In a further step, the values of those inputs and outputs were compared to obtain what all three datasets have in common. In most cases it could be concluded that the differences between these numbers are lower than the uncertainty of these respective inputs or outputs. For the main raw materials (including phosphoric acid) and for electricity, these differences were below 15%. The values for consumption of phosphoric acid for the production of TSP differed only 8% between the local (Brazilian) and the modified European datasets. The largest differences were observed for transportation, which can easily be explained by the completely different situations in Europe and Brazil (as regards distances and means of transport). Also large differences were found for emissions to air, with the local (Brazilian) dataset showing mostly lower values than the two datasets based on ecoinvent. This might be due to different methodological approaches, especially due to the inclusion of less background processes in the Brazilian dataset.

4.2. Differences among the datasets at the LCIA level

The differences among the LCIA results obtained for the three datasets are shown in Fig. 4. The original European TSP, the modified European TSP and the local Brazilian TSP are presented for the three LCIA methods CML, CED and Eco-Indicator'99. Thus the assessment covers the whole life cycle of TSP.

Fig. 4 indicates that the original and the modified European TSP had rather similar results, while the local Brazilian TSP showed larger differences when compared to the two other datasets. In general, the local Brazilian TSP had much lower environmental impacts than the European TSP for most of the impact categories. These differences between the LCIA local Brazilian and the two European LCI datasets can be explained by the smaller number of inputs considered in the Brazilian data, as well as by the much smaller scope with regard to the background processes taken into account.

In a second step, the relative contributions of the main individual process steps to the overall LCIA result of TSP were examined. The results are shown in Fig. 5.

Fig. 5 clearly shows that the partial contribution of the individual process steps to the overall LCIA of TSP is very similar for the original European and the modified European LCIs, while it was completely different for the Brazilian LCI. However, a common feature of these three datasets was identified: in all three cases, phosphoric acid was clearly dominant. In the Brazilian data, the dominance is even stronger, which might be because all other process steps were underestimated, as only few background processes were considered. The results obtained with CED and the Eco-indicator'99 were very similar to those presented for the CML method in Fig. 4 and indicated the dominance of phosphoric acid as well. This dominance of phosphoric acid on the LCIA of TSP together with the fact that the consumption of phosphoric acid was very similar in the Brazilian and the European datasets (see chapter 4.1) confirms further the applicability of these European data to the Brazilian TSP. The LCIA results obtained for phosphoric acid were similar to those observed for the complete TSP, as shown in Fig. 6.

With regard to the LCIA results of the other production steps, in the sulphuric acid production step the differences in the LCIA results were even larger than for phosphoric acid, as the Brazilian production chain presented completely irrelevant results in comparison to those of the European chain. Again, background processes taken into account in the ecoinvent databases, but not in the Brazilian source can explain this difference.

The smallest differences among the three datasets examined were found for the extraction and beneficiation of phosphate rock. These steps have fewer background processes, a fact which explains why Brazilian data addresses these stages comparatively well. For gas and electricity consumption the impact differences were also relatively small. The reason was that these processes were addressed in the Brazilian study based on information from international databases. These databases take into account their background processes in an approach similar to the ecoinvent database. Nevertheless, there were differences in environmental impacts due to the different methodological approaches utilized in the databases.

5. Discussion

The Brazilian and the modified European LCIs varied a lot in their respective scopes: ecoinvent applies in general a much broader scope regarding inputs and outputs of each LCI; this can be seen e.g., by the inclusion of more background processes and by the fact that infrastructure is given more importance. These methodological

[3] The cumulative energy demand (CED) in the ecoinvent database “states the entire demand, valued as primary energy, which arises in connection with the production, use and disposal of an economic good (product or service) or which may be attributed respectively to it in a causal relation.”

[4] Midpoints are considered to be points in the cause–effect chain (environmental mechanism) of a particular impact category, between stressor and endpoints. For midpoints, characterization factors can therefore be calculated to reflect the relative importance of an emission or extraction in a Life Cycle Inventory (e.g. global warming potentials defined in terms of radioactive forcing and atmospheric half-life differences). Midpoints are located anywhere between the stressors and the endpoint (UNEP, 2003). According to Udo de Haes and Lindeijer (2002), endpoints are those elements of an environmental mechanism that are in themselves of value to society. ISO 14042 (ISO, 2000) mentions forests and coral reefs as examples, UNEP (2003) mentions as well human health, damage to plant or animal species and depletion of natural resources like fossil fuels and mineral ores.

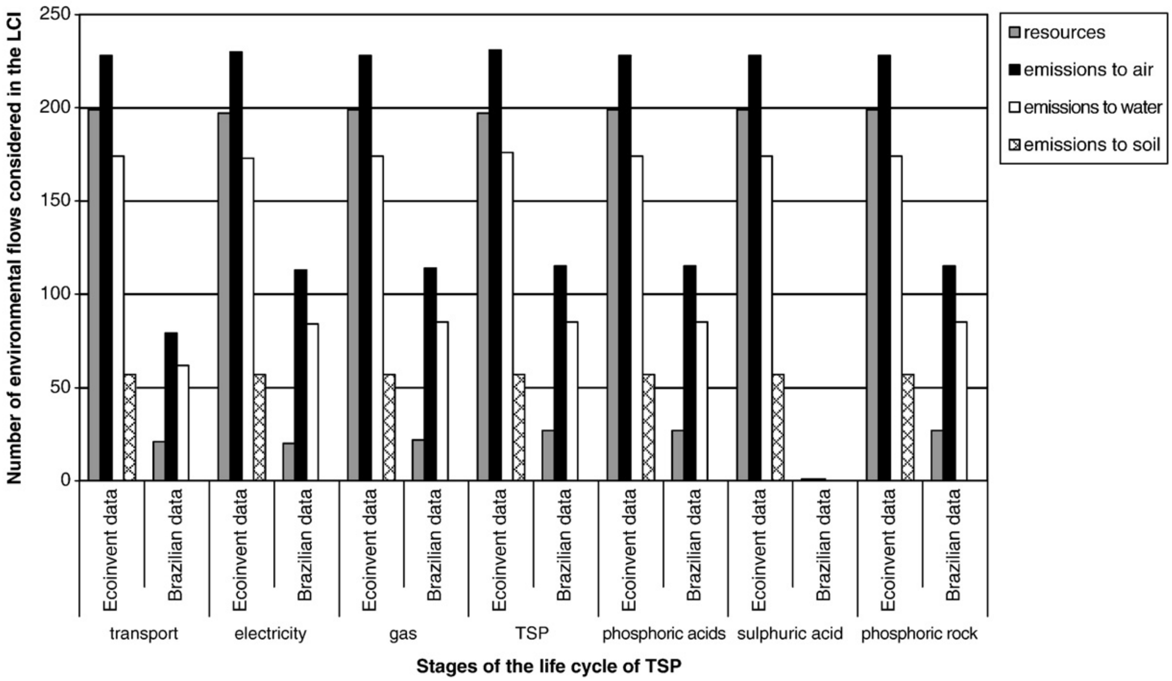

Fig. 3. Amount of environmental flows considered in the European LCI data and in the Brazilian data.

differences underlying the data explain the differences between the LCIA results obtained with the Brazilian and the European data.

On the other hand, there were few differences between the impact values of the same input or output for the same process step. The fact that the consumption of phosphoric acid for the production of TSP only slightly differed between the local Brazilian and the modified European data is of great relevance. This is in agreement with Coulon et al. (1997), who indicated that in general, energy consumption and other environmental loads associated with process efficiency are expected to be highly comparable among different sites. Still, larger differences are expected in the amount of emissions, as well as the amount and destination of solid wastes, as these environmental loads reflect the differences in the processes and the various regulations the producers must comply with (Coulon et al., 1997). This was confirmed in the present study.

The quality of the LCIA results of the Brazilian data could be strongly compromised by limitations such as the lack of harmonization in the inputs and outputs considered in the LCIs, the combination

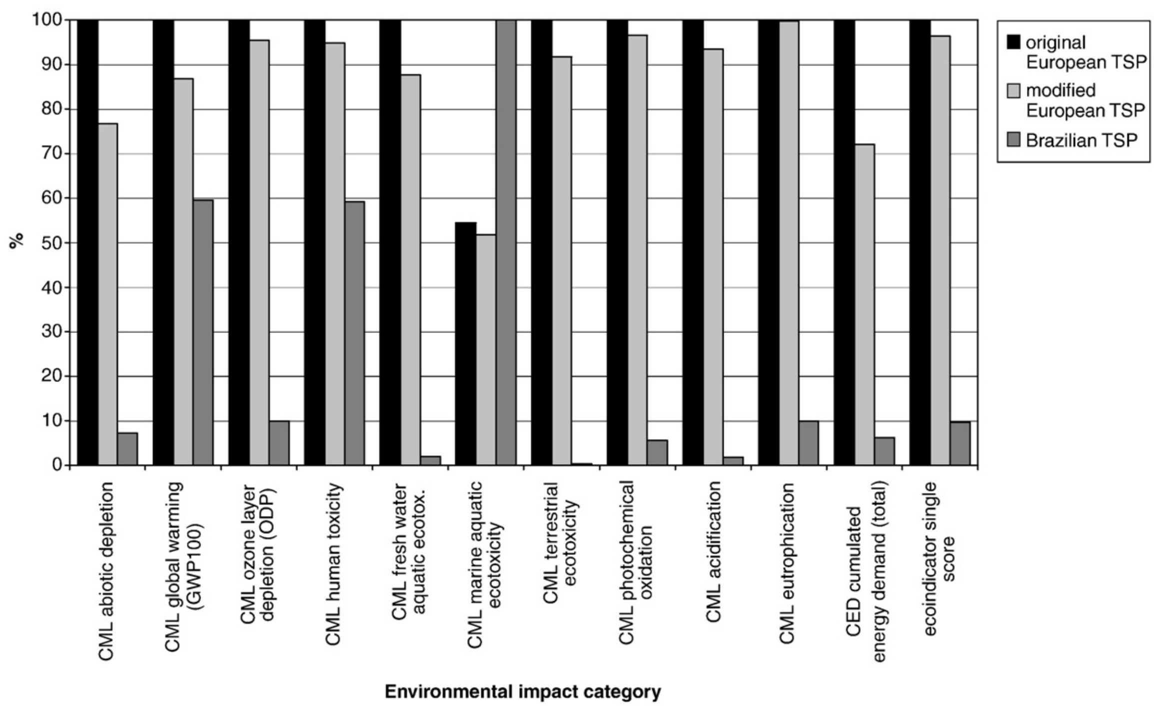

Fig. 4. Comparison of the environmental impacts of the original European, the modified European and the Brazilian TSP using CML, CED and Eco-Indicator'99.

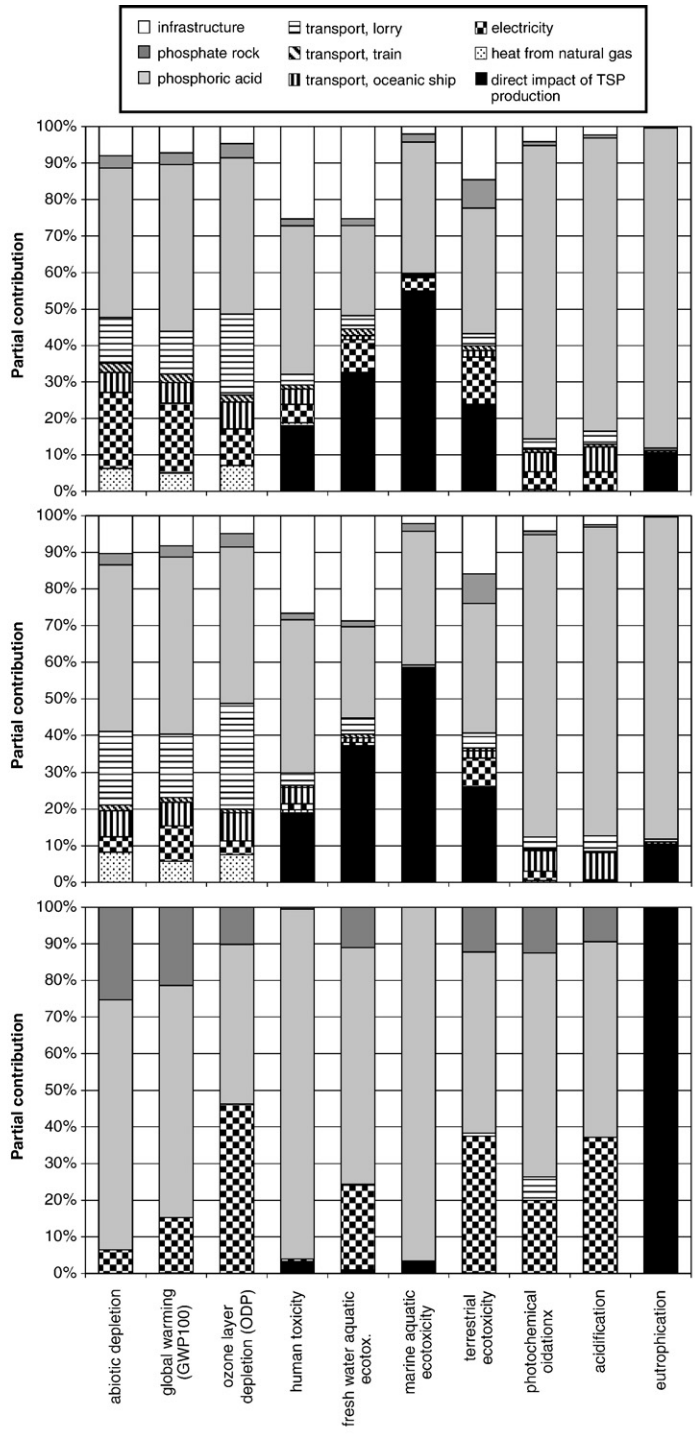

Fig. 5. Impact assessment (CML method) of the life cycle of TSP with (I) the original European, (II) the modified European and (III) the Brazilian data. The percentages indicate the partial contribution of the process steps to the impacts on the whole life cycle of TSP.

of gate-to-gate LCIs with cradle-to-gate LCIs and the reduced number of background processes. These limitations could lead to inaccurate results both with regard to the partial contribution of single process steps to the overall environmental impact, as well as with regard to the type and level of environmental impact associated with the product. Nevertheless, it is important to state that the Brazilian study has the merit of being the pioneer in developing such national LCI data despite a limited availability of local data.

The small differences at LCI level for selected inputs and outputs between the local Brazilian and the European LCIs indicate that the LCI datasets in ecoinvent can, in its modified form, thus be regarded as applicable for characterizing the Brazilian TSP. It can even be said that the minor differences between the modified and the original European LCI data indicate that the original data could be used directly for a first approach. In a further step, the quality of the analysis could be improved by making the adaptations necessary to reflect the local product under study.

A further finding of this study is the limitation of using LCI data from different databases to characterize the life cycle of a product. Even LCI data from databases that consider background processes may

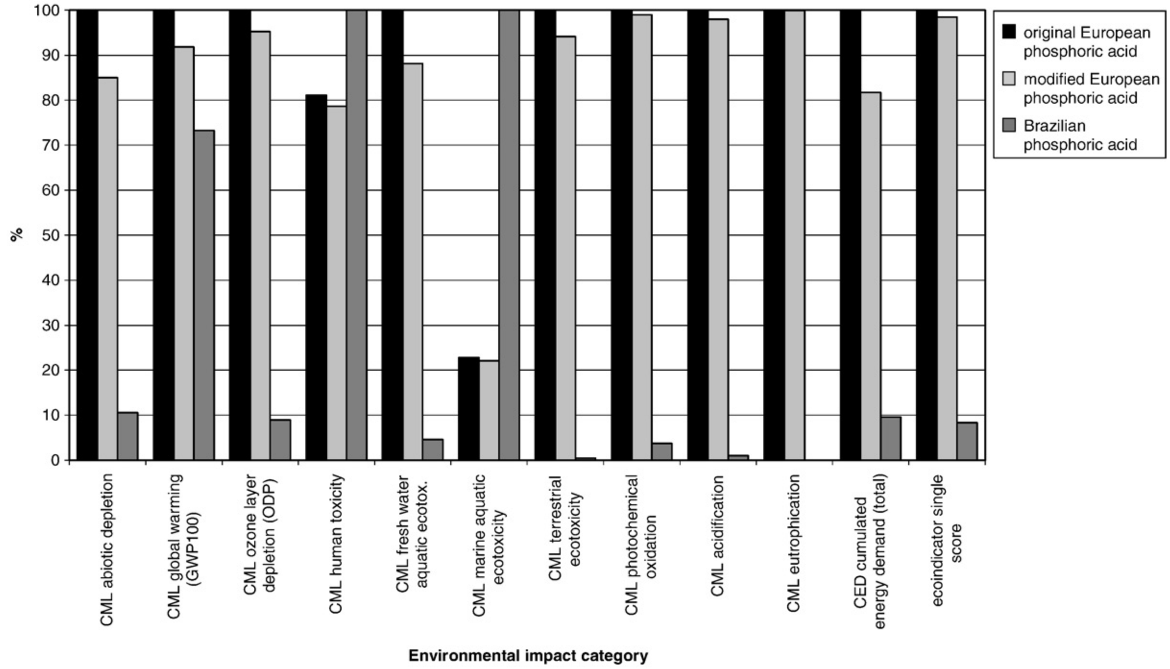

Fig. 6. Comparison of the environmental impacts of the original European, the modified European and the Brazilian phosphoric acid using CML, CED and ecoindicator.

show important differences, as it is stated in this study for the case of the inventory data used in the Brazilian dataset for electricity, transportation and natural gas. Nonetheless, independent LCA studies each one using a different database may be useful in detecting the variations between the products evaluated. This observation can be attributed to methodological choices in the databases.

6. Conclusions

This study shows, based on the example of TSP, that modified European LCI data from the ecoinvent database are applicable to the task of characterizing a local Brazilian production of TSP. Based on the results presented, it can be even concluded that the ecoinvent data comprises a better option than the Brazilian data, as they are more complete. Further, in the ecoinvent database it is possible to assign an uncertainty margin to the original European data, addressing the potential differences with respect to the technological and environmental situation in Brazil.

It cannot be determined to what extent the conclusions of this case study may be extended to further materials and processes, and thus be generalized. Generally however, industrial processes are expected to have fewer variations than, for instance, agricultural processes, where climatic factors play a large role.

All in all, when conducting LCA studies, important differences can be expected between local and non-local industrial processes with regard to their environmental loads, which have an influence on the overall LCIA results (Ciroth et al., 2002a,b). The reason for these differences can be of geographical or technological origin (Ciroth et al., 2002a,b). Also differences in legislation or socio-economic issues (Weidema et al., 2003), etc., can lead to these results. This means that it is always necessary in LCA studies to evaluate the similarities and differences in the technological and environmental performance of the process under study with respect to the process characterized in the LCI database. This is by no way an easy task, and requires a high level of expertise. It is equally important to use local LCI data in the assessment whenever possible.

Due to the lack of local LCI data in Latin America the application of non-local LCI data will continue to be a crucial issue. And along with this, current methodological issues such as the dilemma between "leaving the data gap" or "use un-representative data" will continue to beg an answer.

Furthermore, when considering the development of new individual LCI data or even a new LCI database, priority should be given to those processes that have a great impact on LCIA results and, wherever possible, to reduce differences largely with reasonable effort (Ciroth et al., 2002b; Hischier et al., 2007). New locally generated LCI data may not be easily compatible with existing LCI data from non-local databases. In such cases it would be advisable to generate such new data using the methodological criteria of an existing database. In addition, for harmonization reasons the need for standardized lists of environmental flows has to be taken into account (Hischier et al., 2001). Finally, the new locally developed LCI data could be integrated into already available databases. This would reduce the costs of administration and update of the data, and would improve data sharing, making LCI data for a large number of (local) processes available to LCA analysts all over the world.

References

Bare JC, Hofstetter P, Pennington DW, Udo de Haes HA. Life cycle impact assessment workshop summary. Midpoints versus endpoints: the sacrifices and benefits. Int. J. Life Cycle Assess. 2000;5:319–26.

Björklund AE. Survey of approaches to improve reliability in LCA. Int. J. Life Cycle Assess. 2002;7:64–72.

Brent AC, Rohwer MB, Friedrich E, Von Blottnitz H. Status of life cycle assessment and engineering research in South Africa. Int. J. Life Cycle Assess. 2002;7:167–72.

Ciroth A, Hageluken M, Sonnemann GW, Castells F, Fleischer G. Geographical and technological differences in life cycle inventories: shown by the use of process models for waste incinerators. Part I. Technological and geographical differences. Int. J. Life Cycle Assess. 2002a;7:295–300.

Ciroth A, Hageluken M, Sonnemann GW, Castells F, Fleischer G. Geographical and technological differences in life cycle inventories: shown by the use of process models for waste incinerators — Part II: Technological and geographical differences. Int. J. Life Cycle Assess. 2002b;7:363–8.

Ciroth A, Fleischer G, Steinbach J. Uncertainty calculation in life cycle assessments: a combined model of simulation and approximation. Int. J. Life Cycle Assess. 2004;9:216–26.

Coltro L, Garcia E, Queiroz G. Life cycle inventory for electric energy system in Brazil. Int. J. Life Cycle Assess. 2003;8:290–6.

Coltro L, Mourad AL, Oliveira PAPLV, Baddini JPOA, Kletecke RM. Environmental profile of Brazilian green coffee. Int. J. Life Cycle Assess. 2006;11:16–21.

Coulon R, Camobreco V, Teulon H, Besnainou J. Data quality and uncertainty in LCI. Int. J. Life Cycle Assess. 1997;2:178–82.

Curran MA. Report on activity of Task Force 1 in the Life Cycle Inventory Programme: data registry — global life cycle inventory data resources. Int. J. Life Cycle Assess. 2006;11:284–9.
Da Silva GA, Kulay LA. Environmental performance comparison of wet and thermal routes for phosphate fertilizer production using LCA — a Brazilian experience. J. Clean. Prod. 2005;13:1321–5.
Ellison SRL, Rosslein M, Williams A, editors. Quantifying uncertainty in analytical measurement. Second ed. CITAC Guide number 4: CITAC; 2000.
Frischknecht R, Rebitzer G. The ecoinvent database system: a comprehensive web-based LCA database. J. Clean. Prod. 2005;13:1337–43.
Frischknecht R, Jungbluth N, Althaus HJ, Doka G, Dones R, Heck T, Hellweg S, Hischier R, Nemecek T, Rebitzer G, Spielmann M. The ecoinvent database: overview and methodological framework. Int. J. Life Cycle Assess. 2005;10:3–9.
Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Dones R, Hellweg S, Hischier R, Humbert S, Margni M, Nemecek T, Spielmann M. Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent v2.0 No. 3. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland; 2007.
Galdiano GdP. Inventário do ciclo de vida do papel offset produzido no Brasil. [Life cycle inventory of offset paper produced in Brazil.] Master's thesis. Polytechnic School. São Paulo, Brazil: University of São Paulo; 2006. www.poli.usp.br/Bibliotecas/default.asp.
Goedkoop M, Effting S, Collignon M. The Eco-indicator 99 — a damage oriented method for life cycle impact assessment. Manual for designers. Second ed. The Netherlands. PRé Consultants BV: Amersfoort; 2000.
Guineé JB, editor. Handbook on life cycle assessment. An operational guide to the ISO standards: Ministry of Housing, Spatial Planning and Environmental (VROM); and Centre of Environmental Science (CML) — Leiden University; 2001.
Hischier R, Baitz M, Bretz R, Frischknecht R, Jungbluth N, Marheineke T, McKeown P, Oele M, Osset P, Renner I, Skone T, Wessman H, De Beaufort ASH. Guidelines for consistent reporting of exchanges from/to nature within Life Cycle Inventories (LCI). Int. J. Life Cycle Assess. 2001;6:192–8.
Hischier R, Ugaya C, Anderi da Silva G, Lamb CMR, Rodriguez D. Capacity building for a national life cycle inventory database — lessons learned in the real world. Case study of a Swiss–Brazilian capacity building project. 2nd International Conference on Life Cycle Assessment (CILCA), Sao Paulo, Brazil; 2007. 26 to 28 February.
ISO International Standard Organization. International vocabulary of basic and general standard terms in metrology. Geneva; 1993.
ISO International Standard Organization. ISO 14042:2000(E) Environmental management — life cycle assessment — life cycle impact assessment; 2000.
Kongshaug G. Energy consumption and greenhouse gas emissions in fertilizer production. Hydro agri Europe, Norway. EFMA (European Fertilizer Manufacturers' Association) seminar on EU legislation and the legislation process in the EU relative to fertilizer, Prague; 1998. 19 to 21 October.
Kulay LA. Uso da análise de ciclo de vida para a comparação ambiental das rotas úmida e térmica de produção de fertilizantes fosfatados. [Application of life cycle assessment for environmental comparison of the humid- and thermal routes for production of phosphate fertilizers.] Ph.D. Polytechnic School. São Paulo, Brazil: University of São Paulo; 2004.
Ossés de Eicker, M., Hischier, R., Hurni, H., Zah, R., Using non local databases for the environmental assessment of industrial activities: the case of Latin America. Environmental impact assessment review. *Under review*.
Rabinovich SG. Measurement errors and uncertainties: theory and praxis. Second ed. New York: Springer; 2000.
Skone TJ. www.LCAccess — global directory of LCI resources. Int. J. Life Cycle Assess. 2001;6:73–5.
Sonnemann G, De Leeuw B. Life cycle management in developing countries: state of the art and outlook. Int. J. Life Cycle Assess. 2006;11:123–6.
Suppen N, Carranza M, Huerta M, Hernandez MA. Environmental management and life cycle approaches in the Mexican mining industry. J. Clean. Prod. 2006;14:1101–15.
Udo de Haes HA, Lindeijer E. The conceptual structure of life cycle impact assessment. In: UdodeHaes HA, & et al., editors. Life cycle impact assessment: striving towards best practice, Pensacola: SETAC; 2002. pp. 103–119.
UNEP United Nations Environmental Programme. Evaluation of environmental impacts in life cycle assessment. Meeting report. UNEP, Division of Technology, Industry and Economics, Production and Consumption Branch; 2003.
Weidema B, Fress N, Holleris Petersen E, Olgaard H. Reducing uncertainty in LCI. Developing a data collection strategy. Environmental project No 862; 2003. http://www2.mst.dk/Udgiv/Publications/2003/87-7972-989-4/pdf/87-7972-990-8.PDF.
Weidema B, Meeusen MJG. Agricultural data for life cycle assessments. The Hague. Agricultural Economics Research Institute; 2000.

Margarita Ossés de Eicker. Life Cycle Assessment and Modelling Group, Technology and Society Lab, EMPA (Swiss Federal Laboratories for Materials Testing and Research). She graduated as a biologist from the Universidad Nacional de Cordoba, Argentina in 1996. After that she worked in the environmental management department of the food-products holding Arcor in Argentina. Since 2002, Margarita Ossés de Eicker has worked at EMPA and has conducted her PhD thesis at the University of Berne on adapted environmental assessment methods for Latin American cities. Her field of work includes sustainable use of information technologies, Geographic Information Systems and Life Cycle Assessment.

Roland Hischier. Life Cycle Assessment and Modelling Group, Technology and Society Lab, EMPA. Roland Hischier holds a master's degree in natural sciences from the Swiss Federal Institute of Technology (ETH) Zürich. He is deputy manager of the ecoinvent Centre, the homebase of the international life cycle inventory database ecoinvent. His research is focused on methodological issues in the area of the inventory analysis and the interface between inventory analysis and impact assessment as well as the use of the tool LCA. He has been active in several international working groups dealing with various aspects of LCA methodology. He is a member of the board of the Swiss discussion forums on LCA. He teaches in a variety of professional schools of the graphical and packaging industry in an effort to impart his experience and knowledge in the area of ecology and life cycle thinking.

Luiz Alexandre Kulay. Environmental Engineering Department, SENAC University. Luiz Kulay is a researcher in environmental management techniques. His particular focus is on life cycle assessment, mainly with a view to generate conditions favourable to its use in corporate decision-making processes. He received his doctoral degree at the Department of Chemistry Engineering from the Polytechnic School of the University of Sao Paulo in 2004 and since then has been project advisor in several research projects on life cycle assessment. In SENAC Luiz Kulay is responsible as Associate Professor for the disciplines of Environmental Chemistry for Air and Soil Compartments; Process Modelling for Environmental Engineering and Cleaner Production, and Life Cycle Assessment.

Martin Lehmann. Life Cycle Assessment and Modelling Group, Technology and Society Lab, EMPA. He graduated as a geographer from the University of Zurich in 1998. Apart from geography, his studies included environmental sciences, geology and biology. Martin Lehmann started his professional carrier at the Finland Futures Research Centre (FFRC, 1998–2002), where his research was focused on topics like information society, dematerialisation, and the future of work and university education. Since 2003, Martin Lehmann has been working as a Research Fellow at EMPA and has contributed to different projects dealing with the impacts of technology, products and energy carriers on environment and society at different levels.

Rainer Zah. Life Cycle Assessment and Modelling Group, Technology and Society Lab, EMPA. Rainer Zah graduated 1993 as Engineer of Environmental Sciences at ETH Zürich. He conducted his Master's Thesis in 1993 at the Institute for Aquatic Sciences and Water Pollution Control (IGW), ETH/EAWAG, Dübendorf. There he performed research on sustainable resource management of catchments and GIS until 2001. In 2000 he obtained his PhD on the topic "Patterns, pathways and trophic transfer of organic matter in a glacier stream ecosystem in the Alps" in the Department of Aquatic Ecology at the Institute for Aquatic Sciences and Water Pollution Control (IGW), ETH/EAWAG, Dübendorf. Rainer Zah has performed teaching activities at the Institute for Aquatic Sciences and Water Pollution Control (IGW), ETH Zürich. Since 2001 he has been project leader in the Unit "Sustainable Information Technology" at EMPA St. Gallen. There he heads up the group "Life Cycle Assessment and Modelling Group". His field of work includes Geographic Information Systems, remote sensing, sustainable application of information technologies and database development.

Hans Hurni. Natural Resources Management, Centre for Development and Environment, University of Bern, Switzerland. Hans Hurni is a professor in geography with a specialisation in sustainable development. His particular focus is on soil erosion processes, the development of soil conservation technologies and approaches, sustainable mountain development, and natural resources protection and integrated management. Land use dynamics and climate change were the main topics of his PhD thesis in 1980, while his habilitation (thesis empowering him to teach) in 1990 focused on soil erosion and conservation in agricultural environments. He was a manager of the Simen Mountains National Park, seconded there by WWF in the 1970s, followed by a job initiating and directing a national soil conservation research programme in Ethiopia in the 1980s. Since 2001 he has directed the Swiss National Centre of Competence in Research NCCR North–South, a multi-disciplinary research programme in partnership with over 140 institutions in developing and transition countries and in Switzerland.