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Using non-local databases for the environmental assessment of industrial activities: The case of Latin America

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ABSTRACT

Nine non-local databases were evaluated with respect to their suitability for the environmental assessment of industrial activities in Latin America. Three assessment methods were considered, namely Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA) and air emission inventories. The analysis focused on data availability in the databases and the applicability of their international data to Latin American industry. The study showed that the European EMEP/EEA Guidebook and the U.S. EPA AP-42 database are the most suitable ones for air emission inventories, whereas the LCI database Ecoinvent is the most suitable one for LCA and EIA. Due to the data coverage in the databases, air emission inventories are easier to develop than LCA or EIA, which require more comprehensive information. One strategy to overcome the limitations of non-local databases for Latin American industry is the combination of validated data from international databases with newly developed local datasets.

1. Introduction

Environmental loads associated with industrial activities are, for instance, the consumption of natural resources and energy, as well as the generation of wastes, wastewater and emissions. These loads can be assessed using different methods depending on the specific objectives and policy context of the study concerned (Finnveden and Asa, 2005; Krivtsov et al., 2004; Ruddy and Hilty, 2008). Assessment methods include, for instance, air emission inventories (Power and Baldasano, 1998; EMEP/EEA, 2009), Environmental Impact Assessment (World Bank, 1996; Morris and Therivel, 1998) and Life Cycle Assessment (ISO, 2006; Rebitzer et al., 2004).

The information needed for these assessment methods can be obtained in three ways. It can be directly measured, calculated e.g. based on individual mass balances or estimated with the help of consumption- and emission factors developed mainly with measuring data intended to be representative. Consumption factors express the amount of materials and energy consumed by an activity per amount of final product, whereas emission factors express the amount of pollutant emitted by an activity per amount of final product generated or energy consumed. Environmental databases containing emission- and consumption factors (hereafter called "environmental databases"[1]) are available that can be used in various environmental assessment methods. Some of the databases have been developed based on country-specific data, whereas others are based on more general data, such as regional or world-wide averages.

1.1. The situation in Latin America

In Latin America researchers and governmental bodies are currently undertaking efforts to collect environmental data from industry, for instance, on emissions to air and water. Furthermore, some few datasets have been developed for LCA.[2] However, comprehensive local environmental databases are still lacking by

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[1] Actually, an environmental database contains per definition environmental data, which is a broad term and consists of different types of data, not only emission and consumption data. For instance, the U.S. EPA defines an environmental database as a single organized collection of (in this case environmental) facts, records and data normally set up to meet the information needs of major parts of an organization and to make specific items easy to find (EPA, 2008). Nevertheless in this study, and for simplification reasons, the term environmental database refers to solely emission and consumption data.

[2] Chile and Mexico are developing registers on emissions from industry (CONAMA, 2006; SEMARNAT, 2008), which are partially based on measuring data. Single datasets for Life Cycle Assessment (LCA) have been developed showing the interest of the research community in overcoming this information gap (see for example Coltro et al. 2003; Kulay 2004; Coltro et al. 2006; Galdiano 2006). Brazil is in the starting phase of the development of a database for LCA (Caldeira-Pires 2006; Hischier et al. 2007). A list of further projects on databases for LCA in Latin America can be found at the website of the Latin American LCA Association (ALCALA, 2009) or in literature sources such as Curran (2006).

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and large. One of the main reasons for this situation is the deficiency in data and in data collection by industry in Latin America. For instance, the monitoring of air, water and toxic emissions at industrial facilities is imperfect and monitoring equipment is often obsolete; furthermore, the data collection and measurement methodology are questionable, and there is usually a lack of trained personnel on industrial sites (World Bank, 2005).

Due to the present lack of comprehensive local databases, analysts in Latin America are forced to use databases from other — mainly industrialized — countries. However, industry in industrialized countries is expected to be different from that in Latin America regarding technology levels and environmental performance. Thus, the application of such non-local databases bears the risk of providing inaccurate results, basically by underestimating emissions and resource consumption for Latin American industrial activities (Dessus et al., 1994; Jenkins, 2000; Aguayo et al., 2001). Surprisingly, the limitations of using non-local databases in assessing local industry are often not taken into account in local studies. Furthermore, the above mentioned studies do not analyze systematically the environmental situation of industry in the different Latin American countries. As a consequence, an assessment of the suitability of non-local databases for industrial environmental assessment in Latin American countries is lacking.

1.2. Goal and scope

The aim of this study was to evaluate the suitability of selected non-local databases for the environmental assessment of industrial activities in Latin American countries.[3] As environmental assessment can be performed with approaches implying different data requirements, the suitability of the databases was evaluated for three assessment methods, namely Life Cycle Assessment, Environmental Impact Assessment and air emission inventories.

We intended to provide government agencies and research bodies in Latin America with a critical view of some of the databases currently used to obtain environmental information. This is relevant because such information is used for developing policy measures to tackle the severe environmental problems related to industrial activities in the region. Further, the evaluation of the suitability of non-local databases described in this article can also feed into discussions about a possible need to develop local environmental databases for Latin American industrial activities.

Complementing this study we have also conducted a second one on the same topic; the second one specifically evaluates the applicability of a European database to LCA of a Brazilian fertilizer (Ossés de Eicker et al. under review). Both studies complement each other, since the one here discusses the issue in general, and the other provides a specific example.

2. Methods

The suitability of a database for environmental assessment of given industrial activities is determined by two main aspects. First, the database must fulfill the requirements of the assessment methods used in terms of the availability and characteristics of the data. Second, the data provided by the database must be applicable to the characterization of industrial activities in the area under study (in this case Latin America), which may be very different from the activity of reference in the database. In order to evaluate these suitability aspects, the following procedures were applied in this study:

1. The specific data requirements for each of the three methods considered (Life Cycle Assessment, Environmental Impact Assessment and air emission inventories) were analyzed from a general, methodological perspective, without considering the challenges or particular requirements associated with the application in Latin America (Section 3).
2. Data availability was analyzed in those non-local databases that are in use or that are potentially useful for the environmental assessment of industry in Latin America. An evaluation was made as to whether the data satisfied the requirements of the assessment methods in terms of type and quality. We also considered whether supporting descriptive information on data, was available. Finally, the cost of the databases was taken into account, because this aspect is particularly relevant for application in Latin America (Section 4).
3. The applicability of the data in the selected environmental databases to industrial processes in Latin America was assessed. This applicability depends on the similarities between Latin American countries and the countries where the data has been gathered with respect to the emissions- and consumptions profiles of their industries. Available indicators were analyzed that directly or indirectly reflected this environmental profile and the most suitable of them were applied (Section 5).
4. Finally, based upon the results of the previous steps, the suitability of the examined databases was evaluated for environmental assessments of Latin American industrial activities (Section 6).

3. Data requirements of the environmental assessment methods considered

In this study, three of the most commonly used methods for environmental assessment were examined in-depth: air emission inventories, EIA and LCA. Table 1 summarizes the main characteristics of the three methods.

According to the different characteristics of the assessment methods, different types of input data are needed. Table 2 summarizes the data requirements for the three methods examined here.

The three methods have different data requirements and, therefore, they allowed us to make a comprehensive evaluation of the suitability of the selected databases. The requirements for environmental databases are the smallest in the case of EIA, as then a large amount of data is usually measured at the site. However there is a need for data with which to estimate potential environmental impacts. EIA focuses on individual industrial plants, but for those, all relevant emissions to air, to water and to soil and also the resource consumption have to be known in order to assess the environmental impacts. For emission inventories, neither energy consumption nor information on the final products is needed. Only air emission data is considered; but it must be available for all relevant industrial sectors within the area under study. Finally, LCA is the method requiring the most comprehensive data. All environmental flows (inputs and outputs) have to be known for each processing stage of part of the life cycle of a product or of the whole life cycle, depending on the aggregation approach.[4] A Life Cycle Inventory (LCI) is the data collected on these inputs and outputs. LCA studies focus on activities defined as average in a country or even a larger geographic area, considering different technologies and environmental performance.

4. Characteristics of the environmental databases selected for this study

Databases of emission- and consumption factors for industrial activities were selected, which were either already in use or had the

[3] The term “Latin America” refers hereto all countries in South and Central America. The Caribbean countries are not included.

[4] In the “gate-to-gate” approach only the main process related to the product, e.g. its manufacturing is taken into account. The associated LCI is called a “single unit process LCI”. In the “cradle-to-gate” approach all stages are considered that take place before the production of the specific product in the facility, for example, the extraction of ores, the generation of energy and the production of the related raw materials. In the “cradle-to-grave” approach the analysis considers in addition the stages related to the final disposition of the product. The LCI is called “cumulated LCI” or “cumulated process LCI”.

Table 1
Summary of the characteristics of the environmental assessment methods considered.

Characteristics	Environmental assessment method		
	Air emission inventories	Environmental Impact Assessment (EIA)	Life Cycle Assessment (LCA)
Object of study	Group of activities in a defined area.	A single projected activity in a specific location.	A clearly defined and described system (product or service).
System boundary	All environmentally relevant air emissions are taken into account that occur within a region of interest, which may be a city, a country or a region, considering often the time span of one year (they can also reflect shorter time spans and be developed for example on a daily or hourly basis). In this study the inventories developed for a year were considered.	The system boundary can vary. Usually it includes consumption of materials and energy and the generation of emissions and wastes. It seldom considers the extraction of resources and may or may not consider the disposal of waste and wastewater. EIA considers emissions and consumption levels over a long period of time.	The system boundaries are chosen to correspond to the study object (system description) and the questions that are to be answered by the study. In all cases, the material and energy flows within the system are followed back to the sources (that is, to the resources consumed). Independently of the actual system boundaries, all types of emissions, wastes and wastewater, as well as the consumption of resources within the complete system boundaries are taken into account.
Potential applications	Assessment of emissions, comparison between sources, further application as input for modeling concentration of air pollutants.	Evaluation of permission of building of new facilities.	Evaluation of the environmental impacts of a given activity, comparison between products.

Table 2
Summary of the data required by the environmental assessment methods selected.

Data requirements	Environmental assessment method		
	Air emission inventories	Environmental Impact Assessment (EIA)	Life Cycle Assessment (LCA)
Range of activities to be covered	All main activities in the area of interest.	Only the activity under study.	Only the activities that are part of the life cycle of the product or service under study.
Energy consumption data	Not necessary. An exception is made when emissions have to be estimated with emission factors based on energy consumption, such as the AP42 database.	Mostly not necessary. An exception is made when emissions have to be estimated with emission factors based on energy consumption, such as the AP-42 database.	Necessary, with complete information about consumption of each energy carrier.
Other resource consumption data	Not necessary.	Water consumption often considered. Consumption of other resources may be necessary.	Information about all resources is necessary: ores, raw materials, auxiliaries, transportation and land use.
Emissions data	Necessary. Usually, air emissions only.	Necessary. Air and water emissions, wastes and wastewater.	Necessary. Air and water emissions, wastes and wastewater.
Final product data	Not necessary. An exception is made when emissions have to be estimated with emission factors based on amount of final product.	Variable. Mostly not necessary. An exception is made when emissions have to be estimated with emission factors based on the amount of final product.	Necessary, with complete information about generation of final products, co- and byproducts. The product may be a physical product or a service.

potential to become useful for environmental studies in Latin America. The databases were selected as representing different sampling methods and data sources and as covering a wide range of industrial activities.

The U.S. EPA provides a list of links to websites referring to LCI databases, including a very brief description of the databases (EPA, 2009). The European Commission's Joint Research Centre, Institute for Environment and Sustainability, supplies a register of LCI databases (JRC-IES, 2009). The UNEP/SETAC Life Cycle Inventory Initiative is currently developing a similar register which will include an extensive description of not only European databases but also databases originating in and applicable to other regions.

Table 3 lists the databases selected in this study and the Internet site where they can be accessed.

Tables 4 and 5 show the characteristics of the data and metadata available in the databases evaluated. Metadata[5] (ISO, 2004, 2005b) is important for correctly interpreting the data and thus for an appropriate use of the data in the final applications (Michener, 2006). Moreover, metadata allows the user to specifically adapt the original data to address the activity under study more appropriately. This is particularly important for Latin America, where experts already apply non-local databases to processes different from those for which they were originally developed.

A more in-depth description of all the databases examined can be found as an addendum to this article.

The first five databases described in Tables 4 and 5 were specifically developed to support air emission inventories, whereas the last three were constructed to deliver the LCI data necessary for LCA. None of them was specifically designed for EIA.

The 2006 IPCC Guidelines provide the less specific air emission factors in terms of technical and operating conditions and consider few (however the most relevant) greenhouse gases (GHGs). Therefore, this database is suitable for compiling GHG emission inventories when little is known about the industrial activities to be assessed. In a different manner, EPA AP-42 and the EMEP/EEA Guidebook contain emission factors for a broad spectrum of technological characteristics, emission reduction measures and operating conditions of the same activity. Thus, the latter database is more suitable when information on the local activity under study is available. The revised 1996 IPCC Guidelines (in the tiers 1 and 2) and IPCC-EFDB are an alternative when less detailed information is available on the technology of the local activities. IPPS for Mexico may be a viable option for estimating air emissions from industrial sectors in those countries where the emission factors of the other databases cannot be applied because of a lack of the necessary information about energy consumption or mass of final product in the activity under study. It is very likely that those countries have the data required by the IPPS on Manufacturing Value Added by activity sectors. The idea behind the IPPS could be useful;

[5] Depending on the database, different terms are used for the descriptive part of a dataset. In this study the term "metadata" is used in the manner defined by the International Standard Organization ISO as "data about data" and also as "data that defines and describes other data". Metadata is structured, encoded data that describes characteristics of information-bearing entities to aid in the identification, discovery, assessment, and management of the entities described.

Table 3
Environmental databases selected for the present study.

Database	Internet site
EMEP/EEA Air Pollutant Emission Inventory Guidebook developed by the UNECE Task Force on Emissions Inventories and Projections[a] (EMEP/EEA, 2009)	www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
Compilation of Air Pollutant Emission Factors, AP-42 developed by the U.S. Environmental Protection Agency (EPA) (EPA, 1995) complemented by the Factor Information Retrieval System (FIRE) database (EPA, 2005)	www.epa.gov/ttn/chief/ap42/ http://cfpub.epa.gov/oarweb/index.cfm?action=fire.main
Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories developed by IPCC/OECD/IEA[b] (IPCC/OECD/IEA, 1997) complemented with the report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories developed by Penman et al. (Penman et al., 2000)	www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm www.ipcc-nggip.iges.or.jp/public/gp/english/
2006 IPCC[2] Guidelines for National Greenhouse Gas Inventories developed by the IPCC National Greenhouse Gas Inventories Programme (NGGIP) (IPCC, 2006)	www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm
Database on Greenhouse Gas Emission Factors (IPCC-EFDB) developed by the IPCC National Greenhouse Gas Inventories Programme (NGGIP) (IPCC, 2005)	www.ipcc-nggip.iges.or.jp/efdb/main.php
Industrial Pollution Projection System (IPPS) emission factors Phase II for Mexico developed by the World Bank, corrected version developed by Aguayo et al. (Aguayo et al., 2001)	http://ase.tufts.edu/gdae/publications/working_papers/WBAirIntensities-GDAE.pdf
European Reference Life Cycle Database (ELCD) developed by the Joint Research Centre, Institute for Environment and Sustainability (ELCD, 2009)	http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
Ecoinvent database on Life Cycle Inventories developed by the Swiss Centre for Life Cycle Inventories (Frischknecht et al., 2005; Frischknecht and Rebitzer, 2005; Swiss Centre of LCI, 2009)	www.ecoinvent.ch
U.S. Life Cycle Inventory database developed by the National Renewable Energy Laboratory (NREL) (NREL, 2004)	www.nrel.gov/lci/

[a] EMEP = Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe; EEA = European Energy Agency; UNECE = United Nations Economic Commission for Europe.
[b] IPCC = Intergovernmental Panel for Climatic Change; OECD = Organization for Economic Co-operation and Development; IEA = International Energy Agency.

however, it is suspected that the emission factors in this database are low in quality (Aguayo et al., 2001).

All the databases previously discussed are best suited for developing air emission inventories, but they can also be used to supply air emission factors as a complement to other data in LCA and EIA studies.

The three LCI databases evaluated show important differences from each other and each one has advantages over the other ones. However, Ecoinvent has better availability of data and metadata. This database covers a much broader spectrum of activities and of technological alternatives for the same activity than the other two. Nevertheless, the U.S. LCI database and especially the ELCD are in an expansion stage and a large amount of new LCI datasets are to be incorporated in the near future. ELCD and U.S. LCI database use mainly data provided or at least approved by industry, which guarantees a high level of acceptance of the databases by industry. Ecoinvent uses both literature sources and industry reports and therefore covers a very wide range of process technologies. However, a disadvantage of Ecoinvent is its cost, whereas the use of the other is free of charge.

Ecoinvent is the only database of the three examined that contains LCI data in both types of aggregation, unit process LCI and cumulated LCI. With this database it is possible to represent the whole life cycle of a product by combining several single unit process LCI, choosing in most cases alternatives for different technological characteristics. This way, the analyst can select the most appropriate combination from the LCI data available and be aware of the limitations of his or her assessment due to the use of less appropriate LCI data (Norris, 2007). Moreover, the LCA analyst can evaluate the relative contribution of inputs and outputs of the different stages of the life cycle to the overall inputs and outputs of the whole life cycle of the process. Metadata is very brief in the U.S. LCI database, more detailed in ELCD and most extensive in the background documents in Ecoinvent. To sum up, the Ecoinvent database offers better insight into the data whenever the aim is to assess a life cycle with great care. The other LCI databases are more appropriate for conducting more simplified and less resource-demanding LCA studies.

The LCI of individual unit processes in Ecoinvent can also be used to support EIA studies because they can provide consumption- and emission factors which refer to very specific activities. Thus, the EIA analyst can decide whether the data in the database is appropriate for characterizing the particular activity under study. Nevertheless, it must be remembered that EIA require very precise data for the selected activity instead of rough approximates for a broad spectrum of activities with different operating and technological conditions. Therefore, any database must be carefully used for such site-specific applications.

Some of the databases have associated a qualitative assessment, others a quantitative assessment. Both types of assessment help users to be aware of the limitation of the emission factor and they make it possible to (quantitatively or qualitatively) assess the uncertainties in the environmental assessment, which is regarded as of primary importance (EPA, 1996; Maurice et al., 2000; Penman et al., 2000; Frey and Small, 2003; EPA, 2006).

5. The applicability of the environmental databases analyzed to Latin American countries

5.1. Selection of adequate indicators to evaluate the applicability

Indicators were analyzed that can be used to assess the applicability of the databases for the Latin American industry. One way to characterize the applicability is to compare the environmental performance[6] of the Latin American industry with that of industrialized countries. Several environmental indicators are available in the literature that assess industry at the country level (Jasch, 2000; Olsthoorn et al., 2001; Labuschagne et al., 2005; UNIDO, 2005a), but such indicators are scarce for Latin America.

Fig. 1 contains environmental indicators for Latin American and European countries, as well as for the U.S. The figure shows only representative countries where all indicators are available. Nevertheless, in the study, all Latin American and European[7] countries were considered.

For the intensity of energy use in the manufacturing sector (Fig. 1A) values are variable among Latin American countries and also

[6] The definition of environmental performance given by ISO 14031 has been applied, namely "results of an organization's management of its environmental aspects". The latter are defined as "elements of an organization's activities, products or services that can interact with the environment".
[7] With "European countries" EU-27 countries are meant, plus Norway, Switzerland as well as all other Eastern European countries.

Table 4
Characteristics of the data available in the databases analyzed.

Data	Database								
	EMEP/EEA[a] Air Pollutant Emission Inventory Guidebook	U.S. EPA[b] AP-42 Air Emission Factors	Revised 1996 IPCC[c] Guidelines for National Greenhouse Gases Inventories	2006 IPCC Guidelines for National Greenhouse Gases Inventories	Database on Greenhouse Gas Emission Factors (IPCC-EFDB)	IPPS[d] Pollution Intensities Phase II for Mexico corrected by Aguayo et al.	European Reference Life Cycle Database (ELCD)	Ecoinvent database	NREL U.S. LCI[e] database
Data format	Tables in pdf document	Tables in pdf document. In FIRE database, CSV file format	Tables in pdf document	Tables in pdf document	Web application, Emission factors can be exported as excel files. CD-ROM can be requested to the source.	Tables in pdf document. Excel files can be requested to the source	Own format based on ISO/TS 14048 (ISO 2002) in XML[f]	EcoSpold XML, consistent with ISO/TS 14048	
Cost	Free	Free	Free	Free	Free	Free	Free	On a fee-basis (1800 Euro)	Free
Spectrum of activities characterized	Comprehensive list of activities, including combustion and non-combustion industrial processes, transportation, product use, road transport, etc.	Comprehensive list of activities, including combustion and non-combustion industrial processes.	Several activities, including combustion and (few) non-combustion industrial processes, transportation, product use, road transport, etc.	Several activities, including combustion and (few) non-combustion industrial processes, transportation, product use, road transport, etc.	Few activities, including combustion and non-combustion industrial processes, transportation, product use, road transport, etc. Nonetheless, the database is under expansion.	28 industrial activity sectors.	Currently it consists of several processes, but it is to become a comprehensive list of products and services, including combustion, industrial products, transport systems, building materials, waste treatment, etc. Data is provided cumulated.	Comprehensive list of products and services, including combustion, industrial products, transport systems, building materials, waste treatment, etc. Data is provided cumulated or as unit process.	Few cumulated industrial processes and few common unit processes, including combustion, industrial products, transport systems, building materials.
Emissions data	Comprehensive list of air emission factors. Furthermore, for each emission a long list of emission factors is presented for different technologies and emission control measures.	Comprehensive list of air emission factors. Furthermore, for each emission a long list of emission factors is presented for different technologies and emission control measures.	Air emissions factors of greenhouse-gases and precursors. Emission factors of different levels of complexity and accuracy are provided.	Air emissions factors of few greenhouse-gases	At present basically the same as in the Revised 1996 and 2006 IPCC Guidelines, plus few emission factors from U.S. EPA AP-42 and EMEP/CORINAIR	Air emission factors for five pollutants. For each emission a single emission factor is given.	Comprehensive list of emission factors for air- and water emission and waste. For each emission a single emission factor is given.	Comprehensive list of emission factors for air- and water emission and waste. For each emission a single emission factor is given.	Fairly comprehensive list of emission factors for air- and water emission and waste. For each emission a single emission factor is given.
Energy consumption data	No	No	No	No	No	No	Yes, by fuel types	Yes, by fuel types	Yes, by fuel types
Other resource consumption data	No	No	No	No	No	No	Water, materials, land use	Water, materials, land use	Water, materials
Factors are referred to	Unit of energy consumed (combustion emissions), mass of final product (process emissions)	Unit of fuel consumed (combustion emissions), mass of final product (process emissions)	Unit of energy consumed (combustion emissions), mass of final product (process emissions)	Unit of energy consumed (combustion emissions), mass of final product or mass of input (process emissions)	Unit of energy consumed (combustion emissions), mass of final product or mass of input (process emissions)	1993 US dollars Manufacturing Value Added	Unit (mostly mass) of final product. Additionally, there are datasets that refer to the unit of fuel consumed.	Unit (mostly mass) of final product. Additionally, there are datasets that refer to the unit of fuel consumed.	Unit (mostly mass) of final product. Additionally, there are datasets that refer to the unit of fuel consumed.

[a] EMEP/EEA = Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe; EEA = European Environmental Agency.
[b] EPA = U.S. Environmental Protection Agency.
[c] IPCC = Intergovernmental Panel for Climatic Change; OECD = Organization for Economic Co-operation and Development; IEA = International Energy Agency.
[d] IPPS = Industrial Pollution Projection System.
[e] NREL = National Renewable Energy Laboratory; LCI = Life Cycle Inventory.
[f] XML = Extensible Markup Language.

Table 5
Characteristics of metadata available in the databases analyzed.

Metadata	Database							
	EMEP/EEA Guidebook	EPA AP-42	Revised 1996 IPCC Guidelines[a]	2006 IPCC Guidelines	IPCC-EFDB	Corrected IPPS for Mexico	ELCD	Ecoinvent	U.S. LCI database
Geographical area represented	Europe, 35 countries: the EU-15, the Phare 13 (Former Eastern European countries receiving monetary aid from the EU), Croatia, Cyprus, Iceland, Liechtenstein, Malta Norway and Switzerland	USA	World (but most data is from Europe or USA)	World	World and country-specific data	Mexico	Europe	Europe/ World/ Switzerland — depending on the actual dataset chosen	USA
Technology represented	Average technology and emission reduction. comprehensive sets of emission factors are provided for uncontrolled and controlled emissions, for different combustion- and emission control technologies.	Average technology and emission reduction. Comprehensive sets of emission factors are provided for uncontrolled and controlled emissions, for different combustion- and emission control technologies.	Average technology. Sets of emission factors are provided for uncontrolled emissions from different combustion technologies. Additionally, values are given for typical emission reduction.[b]	Average technology and emission reduction	Average technology and emission reduction	Average technology and emission reduction. Single values for emission factors are provided	Average technology and emission reduction. Single values for emission- and consumption factors are provided.	Average technology and emission reduction. Single values for emission- and consumption factors are provided.	Average technology and emission reduction. Single values for emission- and consumption factors are provided.
Age of data	Most data is from the Nineties, but some data is newer	Most data is from the Nineties, but some data is newer	Most data is from the Nineties	Most data is from the years after 2000 and some data is from the Nineties.	Most data is from the Nineties, but some data is newer.	Data is from the year 1997.	Data is from the Nineties and the years after 2000.	Data is from the late Nineties and the years after 2000.	Data is from the years after 2000.
Data source documentation and discussion	The source of each emission factor is documented, but not discussed.	The source of each emission factor is documented. Sources are also discussed.	The source of each emission factors is documented, but not discussed.	The source of each emission factors is documented, but not discussed.	The source of each emission factors is documented, but not discussed.	The source of the set emission factor is documented. The quality of data is discussed.	The source of each emission factors is documented, but not discussed.	The source of each emission/consumption factor is documented and in most cases discussed.	The source of each group of emission/ consumption factors is documented, but not discussed.
Comprehensive description of method used in data collection	Yes	Yes	No (description is deficient)	No (description is deficient)	No (description is deficient)	No (description is deficient)	Yes	Yes	No (description is deficient)
Description of technology of the processes characterized	Yes, from deficient to comprehensive	Yes, comprehensive	Yes, brief	Yes, brief	Yes, brief	No	Yes	Yes, comprehensive	Yes, brief
Data quality assessment of the emission- or consumption factors	Yes	Yes	No	No	In some cases	Yes [c]	No	Yes	No
Uncertainty assessment of the emission- or consumption factors	Yes, with default uncertainty value ranges.	No, but eventually possible in future with uncertainty values. [d]	Yes, for some emission factors, with default uncertainty values [e]	Yes, with default uncertainty values	In some cases	No	In some cases	Yes; uncertainty is calculated [f]	No
Review	No. Planned but not done so far.	Yes	Yes. Revision by experts and governments	Yes. Revision by experts and governments	Yes. Internal revision	No	Yes. Internal revision. External revision will be done in near future	Yes. Internal revision	No. Process initiated but not finished yet.

among European countries. However, it can be seen that energy efficiency is generally higher in Europe than in Latin America. The Latin American countries with the highest energy intensity were those with important primary industrial activities such as mining and oil extraction demonstrating that this index is strongly influenced by energy-demanding sectors and thus does not reflect the environmental situation of national industries appropriately.

With regard to the number of companies with ISO 14001 certifications per thousand million U.S. dollars GDP again, large differences can be seen among the countries (Fig. 1B). In this case it is not possible to make out any differences between Latin America and Europe and USA, but some individual countries do show very high values. One of them is Colombia, a country with a long tradition of environmental protection and ISO environmental management systems. Nevertheless, no clear pattern can be distinguished in Fig. 1B. The limitation of this index is that it includes not only the industrial but also the service sector. In addition, apart from the environmental performance of a company, there are other relevant factors that influence the adoption of ISO14001, for instance, economic reasons. Therefore, this indicator is not applicable either.

The technological indicator "share of medium- and high technology production to the total MVA" is shown in Fig. 1C. This indicator expresses the percentage of the total MVA in a country which is generated by industrial activities classified as medium- and high-tech. Technology is one main factor affecting the environmental performance of industrial activities (UNEP, 2003), and therefore such an indicator may be seen here as a very valuable approximation for the intended comparison of environmental performance between Latin American and industrialized countries. This index reflects the technological complexity of the industrial structure of a country. It also indicates the state of the country with respect to its industrial development, which generally entails moving up from resource-based and low-tech to medium- and high-tech activities (UNIDO, 2002). Furthermore, this indicator delivers a view of the overall technological level of industry and is not biased by the influence of individual sectors, in contrast to the two indicators mentioned above. Consequently, this indicator has been used to group the countries with respect to their technological level.

It can be seen that there is a gradient of values for this technological indicator rather than clear clusters for both Latin American and European countries. Nevertheless, within the Latin American countries a first "upper" group can be defined which is formed by the countries with values near the European average (that is, Brazil, Argentina, Mexico and Chile). The technological level of industry in these countries is closer to the technological level of industry in the USA and Europe than to other Latin American countries. Still, all Latin American countries have lower technological performance than the USA. A second group is constituted by countries with values comparable to the European countries with the lowest levels (Venezuela, Colombia, Costa Rica, Peru, and so on). The third group is formed by those countries that have values substantially below the minimum value in Europe, such as Bolivia, Paraguay, Honduras, Ecuador or Nicaragua.

5.2. Results of the evaluation of applicability

Table 6 presents the results of the analysis of applicability of the examined databases to Latin American countries based on the selected technological indicator.

According to our analysis the European databases EMEP/EEA and Ecoinvent are in general more broadly applicable to Latin American industrial activities than the U.S. American databases AP-42 or the U.S. LCI database. Particularly the latter one poorly reflects the situation in Latin America because it contains mainly new data. IPCC Guidelines are intended to reflect the global situation and are based on European and U.S. data and thus are as likely to be applicable as the European and U.S. American databases are. The IPPS for Mexico are theoretically applicable to all Latin American countries, but the data they are based on are suspected to have a low representativeness. In addition, both the European EMEP/EEA and the U.S. American AP-42 databases provide a list of emission factors for different process and combustion technologies and emission control measures, which contributes to the applicability of the databases to different situations.

In general all examined databases are more applicable to those countries with a higher level of technology. The two European databases are applicable to countries with a medium level of technology as well, according to the technological levels of industry analyzed above. In countries with lower technological levels of industry, air emissions can be determined with the emission factors for uncontrolled emissions from EMEP/EEA, AP-42 or IPCC Guidelines; however the European data is expected to reflect the Latin American situation in a more accurate way. A different situation can be observed with respect to the emissions of water, waste generation, the production of consumer goods and the consumption of energy and resources. Here none of the databases examined is applicable to the countries with the lowest technological level.

A limitation of the evaluation of applicability conducted here does not take into account other factors different from technology, which also influence the environmental performance of industry, such as the set of industrial practices (UNEP, 2003) and the composition of the industrial sector by the size of enterprises (Dasgupta et al., 1998; UNEP/CONIECO/UNIDO, 2001; Cole et al., 2005). A further limitation of the analysis is that country level indicators such as the one applied here are not representative of every individual activity branch. An improvement in analysis would be achieved if an indicator at the sector level were used. In fact, for some Latin American countries there is such a technological indicator at the sector level, the "sectoral productivity gap to the USA" (ECLAC, 2007), which is calculated by dividing the labor productivity of the sector in the Latin American country with the labor productivity in the corresponding sector in the USA, and then multiplying this result by 100. Unfortunately, this index is not suitable for the analysis intended here due to the fact that there are large differences in the quality of national data which make it difficult to do accurate comparisons between countries (Stumpo, 2006). Values for this indicator are nevertheless presented in Fig. 2 to show the important potential differences between countries and also within each country.

6. The suitability of the databases analyzed for the environmental assessment of industrial activities in Latin America

In Table 7 the overall suitability of the databases has been assessed. The scores summarize the results of the previous analysis of both the characteristics of data and the metadata available in the databases (Section 4) and the applicability of the databases to Latin America

Notes to Table 5:

[a] In this study metadata corresponding to the tiers 1 and 2 of the guidelines have been considered.

[b] Values correspond to large facilities in OECD countries.

[c] The quality is suspected to be very deficient due to the unexplained omission of data from heavy polluters in the development of the original emission factors by the World Bank.

[d] A study was recently conducted to evaluate and develop adjustments to account for the uncertainty of AP-42 air emission factors by RTI International in behalf of EPA. Nonetheless, the results of this recent study have still not been integrated in the emission factors database.

[e] As a complement to the guidelines, the IPCC published the report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories [27]. This report provides the user with default uncertainty values for some of the emission factors in the guidelines.

[f] Uncertainty values are calculated upon basic uncertainty values (dependent on the type of emission or consumption) and uncertainty values dependent on the quality of the data.

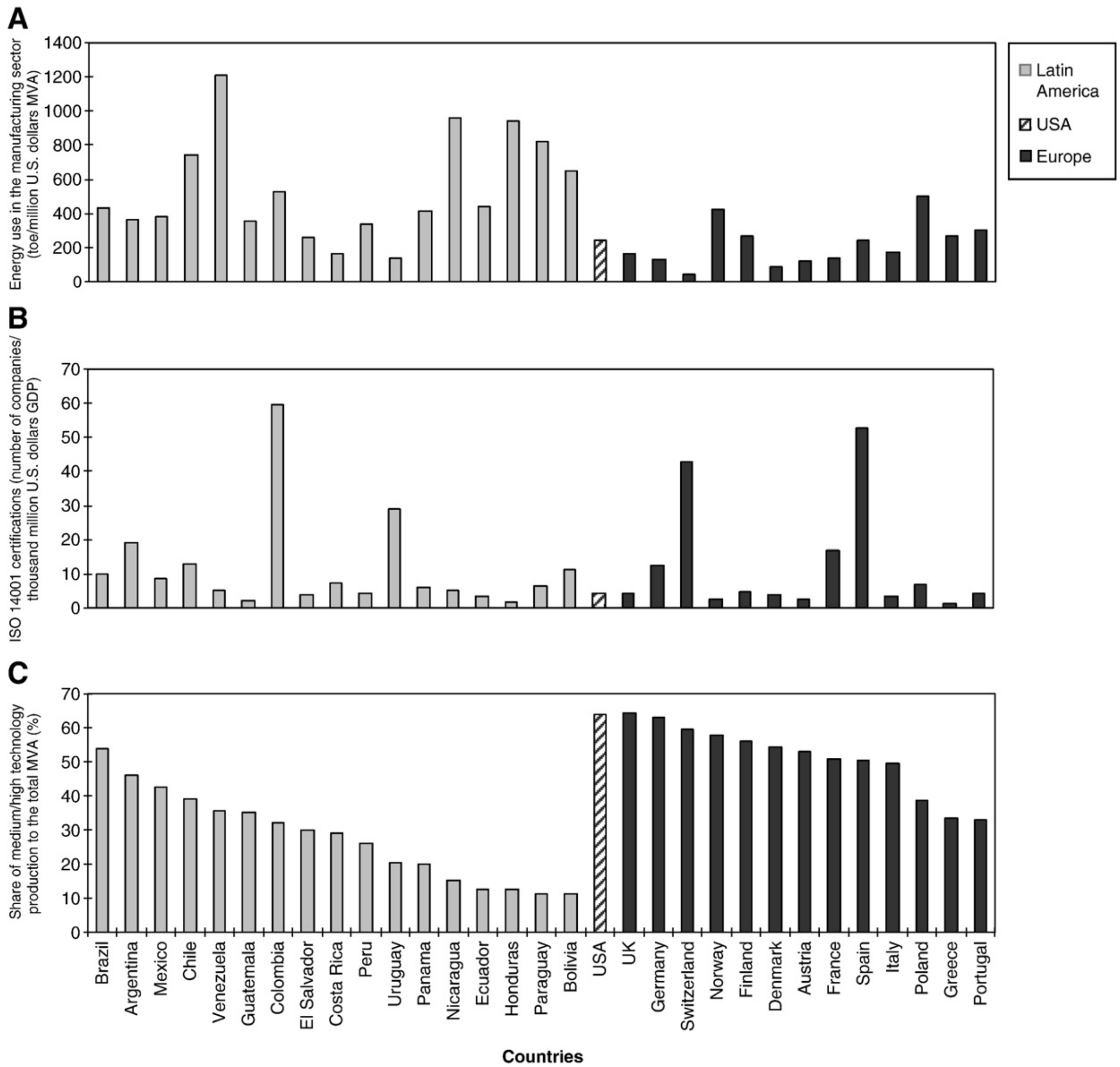

Fig. 1. Environmental and technological indicators on industry in the USA and in Latin American and European countries. Indicated are (A) the intensity of energy use in the manufacturing sector (UNIDO, 2005a), (B) the number of companies of the manufacturing and service sectors with ISO14001 certification per thousand million dollars GDP (ISO, 2005a; UNSTATS, 2007) and (C) the "share of medium- and high technology production to the total Manufacturing Value Added" (UNIDO, 2005b). Data is from the years 2004, 2002 and 2000, respectively.

(Section 5). Scores from 1 (not suitable) to 5 (highly suitable) have been assigned considering the performance of the database in relationship to the other databases evaluated here.

EMEP/EEA Guidebook and EPA AP-42 are the most suitable databases for developing air emission inventories of industrial activities in Latin America. Both databases are similar with respect to the availability of data, but the Guidebook has the better applicability. The IPCC Guidelines have a lower score for data and metadata availability than the two databases mentioned above and thus, a lower suitability. Nonetheless, the Revised 1996 IPCC Guidelines have an advantage over the other databases for the specific case when air emission inventories have to be developed with little information on the activities to be assessed. The 2006 IPCC Guidelines have a low suitability for comprehensive air emission inventories because of the reduced number of emission factors addressed. These Guidelines are more suitable for the purpose of developing consistent greenhouse gases emission inventories when little information is available about the activities to be addressed. Finally, the suitability of the IPPS for Mexico is very low, because of their very low level of applicability, which in turn is due to the potential lack of representativeness of the data. Finally, the IPCC-EFDB showed low scores for the suitability criterion, but this database may well become the most suitable one for air emission factors in the future, if it succeeds in incorporating emission factors from different sources and if experts from the international community use the platform for sharing their judgments of the emission factors, suggesting corrections and updates to the values.

The suitability of databases for LCA is generally lower than for air emission inventories. From the three Life Cycle Inventories (LCI) evaluated, Ecoinvent is the most suitable for LCA and EIA, basically because of its better data and metadata availability. The three LCI databases evaluated could also be used for developing air emission inventories, but their data availability is lower than the databases specifically created to support air emission inventories.

Table 6
Applicability of the non local databases examined to Latin American countries.

Latin American countries	Database: EMEP/EEA guidebook	EPA AP-42	Revised 1996 IPCC guidelines[a]	2006 IPCC guidelines	IPCC-EFDB	Corrected IPPS for Mexico	ELCD	Ecoinvent	U.S. LCI database
Countries with higher technological level of industry, such as Mexico, Brazil, Argentina and Chile	Applicable in the case of emission factors of controlled emissions. These European data of the Nineties reflects the current situation of these Latin American countries.	Applicable in the case of emission factors of controlled emissions. In general US data of the Nineties reflects the Latin American situation to a lesser extent than European data of the same time.	Applicable in the case of emission factors of uncontrolled emissions corrected with emission reduction values. Nonetheless, the latter correspond to large facilities in OECD-countries and do not reflect accurately the local situation.	Applicable	Applicable. The database contains emission factors from different sources, including EPA AP-42 and EMEP/CORINAIR Guidebook and should in the future contain emission factors from more sources	Limited applicability because the data might not be representative (due to the omission of high polluters).	Applicable. These basically European data from the late Nineties and the years after 2000 reflect the current situation of these Latin American countries.	Applicable. These basically European (and in some cases global) data from the late Nineties and the years after 2000 reflect the current situation of these Latin American countries.	Fairly applicable, due to expected technological differences and the fact that the data is fairly updated.
	The long list of emission factors provided for each emission and for different technologies and emission control measures makes this database applicable to different local situations of industry.	The long list of emission factors provided for each emission and for different technologies and emission control measures, makes this database applicable to different local situations of industry.	This database is applicable to different levels of information available on local activity due to the different levels of complexity and accuracy of the emission factors provided.				Nonetheless, a single emission factor is given for each emission, not a spectrum.	Nonetheless, a single emission factor is given for each emission, not a spectrum.	Nonetheless, a single emission factor is given for each emission, not a spectrum.
Countries with medium technological level of industry, such as Colombia, Costa Rica, Peru and Uruguay	Same as for countries with higher technological level	Applicable in the case of emission factors of controlled emissions, however to a lesser extent than for countries with a high level of industry and to a lesser extent than European data.	Applicable in the case of emission factors of uncontrolled emissions, as the values provided for typical emission reduction from large facilities in OECD-countries will not reflect accurately the local situation.	Applicable	Same as for countries with higher technological level	Same as for countries with higher technological level	Same as for countries with higher technological level	Same as for countries with higher technological level	Not applicable. The constraints mentioned for countries with higher technological level are for this country group even greater.
Countries with lower technological levels of industry, such as Bolivia, Paraguay, Honduras and Ecuador	Applicable in the case of emission factors of uncontrolled emissions.	Applicable in the case of emission factors of uncontrolled emissions, however to a lesser extent than European data.	Same as for countries with medium technological level	Same as for countries with medium technological level	Same as for countries with higher and medium technological level	Same as for countries with higher and medium technological level	Not applicable	Not applicable, as world data is also based on up-to-date technology in the respective sector, whereas these countries are below that level.	Same as for countries with medium technological level

[a] In this study data corresponding to the approaches tier 1 and tier 2 of the Revised 1996 IPCC Guidelines have been considered.

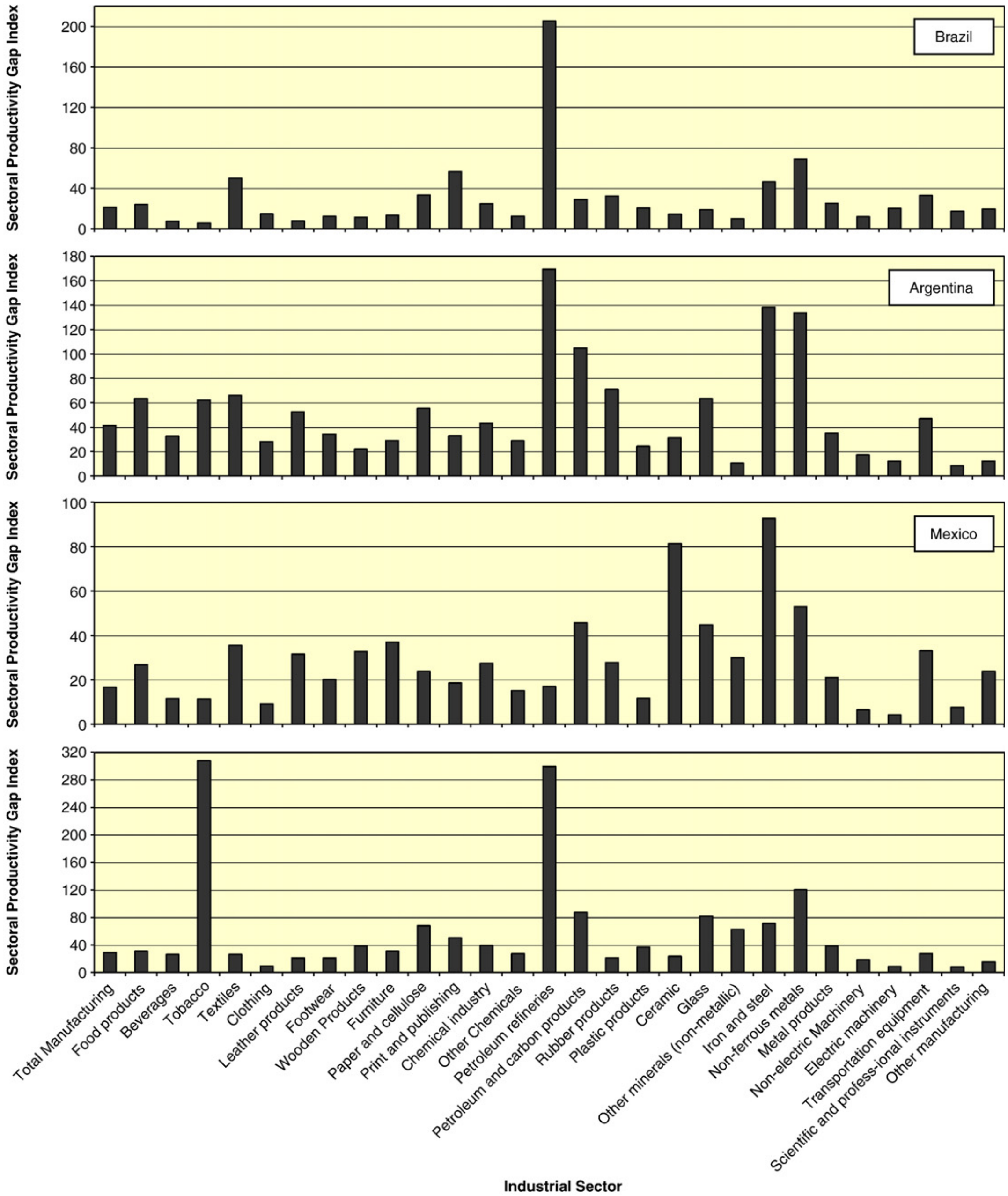

Fig. 2. Technological level of industrial activity sectors in Brazil, Argentina, Mexico and Chile, expressed as sectoral productivity gap between the country and the USA. Data is from the year 2002. Taken from ECLAC (2007). Labor productivity is used, which is defined as the value added per year (in U.S. dollars at 1985 constant prices) per number of employees. Values near 100 reflect similar productivity and values higher than 100 mean that the productivity in the Latin American country is higher than the productivity in the USA.

7. Conclusions and outlook

7.1. Conclusions

Nine databases have been evaluated in this study with respect to their suitability for the environmental assessment of industrial activities in Latin American countries. The EMEP/EEA Guidebook and EPA AP-42 are the most suitable for air emission inventories. The Revised 1996 and the 2006 IPCC Guidelines may be used when little information is available on the activities to be assessed; however they cover a much smaller group of pollutants than the two databases mentioned before. The IPPS database for Mexico has serious data limitations and may only serve as an alternative for estimating air emissions in those countries that can solely apply emission factors referring to Manufacturing Value Added. IPCC-EFCB is still under development and has not reached the necessary amount of data; but it does have the potential to become a very suitable source of air emission factors for the international community. The LCI databases evaluated are not really a good option for developing air emission inventories. However, Ecoinvent is the most suitable LCI database for LCA when compared to ELCD and the U.S. LCI database because it allows for the analysis of the individual stages of the life cycle of a product or activity. Ecoinvent is also the most suitable database for supporting EIA, because of its data and metadata availability. The other databases examined were not suitable for complete LCA and EIA studies, but for assessing certain air emissions.

Table 7
The suitability of the environmental databases analyzed for air emission inventories, LCA and EIA of Latin American industrial activities in the three country groups identified.

Suitability criterion	Environmental assessment method											
	Air emission inventories									Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA)		
	Database									Database		
	EMEP/EEA guidebook	EPA AP-42	Revised 1996 IPCC guidelines[a]	2006 IPCC guidelines	IPCC-EFDB[b]	Corrected IPPS for Mexico	ELCD[b]	Ecoinvent	U.S. LCI[b]	ELCD[b]	Ecoinvent	U.S. LCI[b]
Data availability	5	5	4	1	2	3	3	3	2	2	5	1
Metadata availability	5	5	2	3	3	1	5	5	2	4	5	1
Applicability to countries with higher technology level of industry [c]	5	4	4	4	4	1	4	4	2	4	4	2
Applicability to countries with medium technology level of industry [d]	5	4	4	4	4	1	3	3	1	3	3	1
Applicability to countries with lower technology level of industry [e]	5	4	4	4	4	1	1	1	1	1	1	1

Scores are presented ranging from 1 (minimum) to 5 (maximum) for the criteria applied.
[a] In this study the approaches tier 1 and tier 2 of the Revised 1996 IPCC Guidelines were considered.
[b] The IPCC-EFDB, ELCD and U.S. LCI databases are currently in an expansion phase. Therefore, their availability of data and metadata will change in the next time/near future/future.
[c] This group includes countries such as Mexico, Brazil, Argentina and Chile.
[d] This group includes countries such as Colombia, Costa Rica, Peru and Uruguay.
[e] This group includes countries such as Bolivia, Paraguay, Honduras and Ecuador.

In general, databases specialized on air emission factors are more advanced than databases dealing also with emissions to soil and water, resource consumption and waste generation. One main reason for this is the global dimension of air pollution problems that led to the development of emission factors by international institutions. Consequently, air emission inventories are easier to establish than LCA- or EIA-studies, where all sorts of industrial emissions and consumption levels have to be considered. In addition, non-local databases can be applied with more confidence for air emission inventories or for other methods that aim to provide only an initial, rough overview of the environmental impacts of a large spectrum of industrial activities.

When using any database one should bear in mind that it is an advantage if the database provides a comprehensive spectrum of emission or consumption factors for the same activity (as is the case for the EMEP/EEA Guidebook or EPA AP-42) rather than individual values or a narrow spectrum of values (as in the Revised 1996 IPCC Guidelines). Furthermore, it is also crucial that the database provides thorough metadata in order to allow for a proper selection of the most suitable data for the concrete project.

The evaluation of the applicability of non-local databases to Latin American industry could be considerably improved by the development of more appropriate indicators than the country-based indicator "share of medium- and high technology production to the total MVA" considered in this study. A better indicator might be the intensity of energy consumption per manufacturing value added at industrial sector level. This indicator would reflect a technology's performance, because combustion efficiency is a main aspect of technological performance. Further, it would also be an approximate environmental indicator, because the amount of energy consumed is closely related to the amount of emissions generated. Furthermore, such an indicator would reflect intersectoral differences. Any improvement in the assessment of the applicability of non-local databases to Latin American industry would help users become more aware of the limitations of the data and of the results obtained with it and therefore to avoid incorrect results that could mislead environmental stakeholders and the scientific community.

7.2. Outlook

Latin American countries could apply different strategies to cope with the difficulties of applying non-local databases:

One strategy would be to develop national databases of locally gathered data. Air pollutant data could be obtained, for example, from monitoring programs induced by environmental regulations. For other emissions or resource consumption the situation is much more difficult because there is less regulatory pressure and as a consequence companies have less motivation to collect it. Thus, over the medium term it is more probable that local databases will be developed to support air emission inventories, rather than complete databases for more comprehensive methods such as LCA.

A second strategy would be to apply a non-local database after having validated it with local data. Eventually, the validation could be conducted with selected inputs or outputs used as indicators (for example energy consumption or major air pollutants). This strategy would require investing fewer resources than developing a completely new database. The main constraint of this approach is the difficulty of determining which indicators would be appropriate and obtaining representative data for the validation.

Finally, a third strategy would be to complement locally collected data with a non-local database already available. The local environmental data could be integrated into the non-local database instead of creating a new database, thus saving costs and time. Furthermore, this would improve the data sharing in the international community. In the case of LCI databases, unit process LCI data should be preferred over cumulated LCI data in order to allow the combination of local and non-local LCI data. This third strategy requires that local stakeholders evaluate which industrial sectors deserve priority in data collection because they are not appropriately characterized in the non-local database. Nevertheless, such analyses are not trivial and require in-depth knowledge of the technological characteristics of local industrial processes. Futhermore, the non-local data applied should be validated for the local situation.

In any case, environmental studies conducted with local or non-local databases should include a discussion of the quality of the data in the database and its applicability to the local situation. Whenever possible, an assessment of uncertainties should be done. Pointing out the limitations of the databases and the results obtained by using them would generate more transparent and reliable information on the environmental impacts of industry.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.eiar.2009.08.003.

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