ADAPTING EXISTING LIFE CYCLE INVENTORY OF BUILDING PRODUCTS FOR THE BRAZILIAN CONTEXT

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Summary

The construction sector is responsible of several environmental impacts among which energy and water consumption, climate change and waste generation. For instance, the primary energy consumption for regulatory uses (heating, air-conditioning, ventilation and hot water) on a 50-year period for a French building is about the same as the embodied energy for its manufacturing and construction processes. In this context, new assessment tools are required to assess the global environmental performances. Thus, there is a growing need to assess the environmental performance of buildings by means of Life Cycle Assessment (LCA). Databases are also needed to make available Life Cycle Inventory data of building materials and processes for each national context. However, in Brazil, few data have been provided so far by the building industry e.g. by means of Environmental Product Declaration (EPD). Two solutions can be distinguished: development a new national LCI database or adaptation of existing LCI databases. If the first option is the most relevant, it requires time and resources, while the second solution is scientifically acceptable and practicable.

The aim of this paper is to present an approach to adapt existing LCI data of building products for the Brazilian context in order to propose a set of consistent and representative LCI datasets. The approach is based on literature researches, analyses of Brazilian and generic LCI data and on the adaptation of European LCI data for the Brazilian context for some key parameters e.g. the energy mixes, the types and distances of transportation. The feasibility of the methodology is then supported by case studies comparing the environmental indicators of concrete, considering the use of Brazilian, original and adapted LCI data.

The approach can be easily applied to other building products. The comparisons show the weaknesses of some Brazilian data e.g. in terms of completeness of the system boundaries. The results for primary energy and global warming potential indicators show that the adapted LCI data

is found to have less impact than the indicators calculated with the original LCI (differences between 5 and 10%). This is mainly explained by the efficiency of the Brazilian energy mix despite the large consumption of the non-renewable energy due to the type and distance of transportation. The adapted LCI must now be improved e.g. by working closely with Brazilian producers to get more accurate data on the foreground processes.

Key-words: performance, environmental requirements, Life Cycle Inventory – LCI, Life Cycle Impacts Assessment – LCIA.

1. Introduction

The construction sector is responsible of several environmental impacts and Life Cycle Assessment (LCA) databases are needed to assess the environmental performances of any construction product or process. The environmental impacts are closely related to the type of product, the suppliers and to the national characteristics of waste and energy processes.

Many countries, such as UK, France, Japan and Australia, have developed sectorial LCA databases to assess the environmental impacts of buildings over their life cycle. These databases are then used for building sustainability assessment using LCA-based indicators (global warming potential, energy use, waste generation, and other related impacts). However, sectorial databases often present cumulative LCI (Life Cycle Inventory) or selected indicators that cannot be adapted to other countries. These data often related to EPD describe the impacts of producers that sold their product in the given country. As a result, it is generally not recommended to directly reuse data for other contexts (e.g. South America).

In opposite, LCA data can also be made available by major background data providers. For example, the Swiss Ecoinvent database provides more than 4500 unit processes describing the impacts of materials products and processes mainly for the Swiss and European context. In this case, the data are breakdown into processes with raw data and LCI that can be adapted for a new context by means of LCA software (e.g. GaBi, SimaPro).

As the development of new LCI databases can be time and cost consuming, adapting existing background LCI databases to other national context can be seen as a consistent and more adapted way than having no data at all or non-adapted data.

The main benefits for the country (e.g. Brazil) is to take into account the completeness of these background databases (e.g. for the energy and transportation processes) but also to be able to change the foreground date based on the national practices (e.g. share of energy carriers or distance and truck load for the transportation of building materials).

Looking more specifically at the Brazilian context in South America (scope of this paper), few LCA data exist on the impacts of building materials (GOLDEMBERG; AGOPYAN, JOHN, 2011). When data are available, there are calculated using different rules and no central database has been developed to date.

Therefore the aim of this paper is to present an approach to adapt existing LCI data of building products for the Brazilian context in order to propose a set of consistent and representative LCI datasets which can be used to conduct an environmental assessment of buildings. This assessment will be, not to a specific product, but represent the building industry because it will be done based one generic database.

2. Research method and analysis

The approach is based on literature researches, analyses of Brazilian and generic LCI data, and on the adaptation of LCI data for the Brazilian context.

The Brazilian data of building materials used on this paper were taken from previous studies (Lima, 2010; Souza, 2012; Saade et. al., 2010; Campos, 2011 and Punhagui et. al.,2012). Some studies has also been conducted by producer associations such as the IABr (2010) that conduct a study related to the LCA of steel.

The existing Brazilian data is used only in order to compare them to adapted LCI data from the Ecoinvent database v2. The adaptation of LCI data for the Brazilian context considered aspects relating to energy mix, types and distances of transportation. Ecoinvent version 2.2 was the generic database selected, and the LCI adaptation was done using the software SIMAPRO Version 7.3.

The feasibility of the methodology is then supported by case studies comparing the environmental indicators of concrete, considering the use of Brazilian, original and adapted LCI data.

3. Approach to adapt existing life cycle inventory of building products for the Brazilian context

Ideally, country-specific data for the life cycle inventory analysis should be collected in the respective country and no ‘transferability’ approach would be necessary. Nevertheless, while this data collection process is in progress or still to be started, a systematic approach need to be defined in order to enable the performance of LCA studies in any country with reliable results (Colodel, 2008).

Colodel (2008) proposed an approach organized in four main steps:

- assumptions and conditions;
- overview the country indicators at branch level: ‘top down’ approach;
- overview of the influencing parameters at a process level: ‘bottom-up’ approach;
- transfer factor calculation/ ‘adjusted’ inventory.

Then, this paper show an approach organized from these four steps that detail the aspects that must be considered to Brazilian context. Table 1 presents the approach detailed. This approach has ten steps, organized in four groups: scope and database definitions (step 1 and 2); data collecting considering overview of the country technologies and manufacture process (step 3 and 4), calculated method (definition of LCA method and also uncertainties method e.g. steps 5, 6 and 7), and the results analyze (steps 8, 9 and 10).

The approach takes into account five impacts indicators: Consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation. Somme researchers suppose the consumption of primary energy, related to non-renewable resources, must adopted as an environment impact indicators, because most of the others impacts indicators have strict relation to the consumption of non-renewable energy (LASVAUX, 2010). In addition, the Brazilian building sector have already some macro indicators related to these indicators, so it was choose in this approach for permitting some analyses and comparisons.

Table 1- Steps to adapt existing LCI data for the Brazilian context (adaptation of Colodel, 2008; HODKOVA and LASVAUX, 2012)

1- Goal and scope definition
Set the building product functional unit and building process phase to analyze (cradle to gate or cradle to grave)
2- Selection of a Generic LCI data (the proposal is to adopt Ecoinvent database)
In the Ecoinvent there are specific documents that demonstrate the context and the parameters in which the building products were inventoried. These documents present the main technologies adopted, type and distances of transportation, standard deviations, etc. (KELLENBERGER , 2007 and Frischknecht, 2007). In addition, the inputs of Ecoinvent database can be modified using for example the software SIMAPRO. In this approach the SIMAPRO will be used in order to modify the Ecoinvent LCI to Brazilian context.
3- Identify the Brazilian context and indicators – Overview the differences related to energy mix, technologies/process, market size, etc – *Top down approach*
3.1- Identify the indicators considering the Brazilian context and building product – mostly energy mix and technologies/process; 3.2 – Identify if the Brazilian context serve for all country or it is restricted to certain parts; 3.3 - Verify the differences between the inputs considered in the Ecoinvent data base and the Brazilian context. KELLENBERGER (2007) detail the Ecoinvent information; 3.4- Compare the technologies and the process between Brazilian context and the onefrom Ecoinvent. Only process with similar technology can be compared. This means that the flows of each unit process must be the same for both countries, exception to type of transportation; 3.5- Make certain considerations and set transfer factors related to the analyze of countries inputs – making attention to functional unit to set the transfer factor.
4- Adapt the generic data base inputs related to the process - Overview the inputs of the inventories concerning the process - amount of raw materials, transport distance, etc – *Bottom up*
4.1- Compare the amount of raw materials from Ecoinvent and from Brazilian context; 4.1.1- Verify the amount of raw materials with the most important impacts and not consider that materials have less than 2% of influence; 4.1.2- In the SIMAPRO, modify the inputs/ flux until the forth level, or at least second level; 4.1.3 - Set correct transfer factor taking care to the functional unit; 4.2- Compare type and distance of transportation between the Ecoinvent LCI and the Brazilian context /data; 4.2.1 Consider an average distance of 100 km to Brazil (hypothesis adopted when it does not know the real mean data)- 100 km go and 100 km back, in the back tour the transport vehicle is without load, as a result only the vehicle weight will be considered; 4.2.2 – Make attention to functional unit to set the transfer factor, take care to relation among amount of raw materials, distance of transportation, and load transported.
5-Verify the data quality of the inputs data – identity the uncertain values adopted on Ecoinvent
5.1- For the changed inputs - identity the uncertainties of the inputs from Ecoinvent, calculate the uncertainties of the Brazilian context using the Pedigree Matrix method (Pedersen and Wesnaes, 1996) and compare the two uncertainties. Chose three of the most important inputs to verify the uncertainty, or select the inputs that influence more the impact. It is not suggested modifying the uncertainty adopted in LCI Ecoinvent, avoiding to rise the deviations. The analysis will serve to justify the use of the module adapted. 5.2 - For the non-changed inputs – adopting a process similar to 5.1
6- Set the impacts indicators to be considered and analyzed
The hypotheses considered take into account: Consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation
7- Selecting on SIMAPRO the method to calculate the impacts, also considering the standard deviation by Monte Carlo simulation

7.1 - It is proposed to select the French method that integrates the IPCC[1], CML[2] and CED [3]method. Adopting the French method will be possible to analyze the indicators related to consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation; 7.2 – Determining the Number of iterations for Monte Carlo Simulations – As the Monte Carlo method is time consuming we have consider 500 iterations. (The number of iterations change a little the results and their deviations, so it is an aspect to study in the future)
8- Results presentation- Set a worksheet model to be fulfilled for each LCI adapted, granting reliability and transparence
8.1 – Fulfilled one worksheet to each LCI adapted, making evident all hypotheses and considerations (methodology, adaptation, uncertainties, results, calculus demonstration). 8.2 – Present the impact indicators data in terms of mean value and of the minimum and maximum value, with standard deviation. 8.3 – The primary energy source must be the addition of non–renewable energy and renewable energy – considering the need of software that perform environmental assessment;
9- Data Analyses - Macro Comparisons among environmental indicators calculated by Brazilian LCI, original and adapted LCI
9.1 – Calculate the environmental indicators of building product using the LCI from Ecoinvent data without adaptation – impact indicators also calculated from SIMAPRO, considered 500 iterations in Monte Carlo simulations; 9.2 –Calculate the environmental indicators of building product using the LCI from Ecoinvent data adapted – impact indicators also calculated from SIMAPRO, considered 500 iterations in Monte Carlo simulations; 9.3 - Calculate the environmental indicators of building product using the LCI from Brazilian data, if existed, even if this data not fit the methodology proposed (weak data), the propose is only compare macro-values; 9.4 – Compare the results among these environmental indicators, analyzing the macro-values, deviations and tendency, trying validate the indicators with LCI adapted.
10- Others observations
10.1 Remove any type of transportation means input “0” at SIMAPRO; 10.2 Include other type of transportation need consider the uncertainty; 10.3 The LCI take into account in general cradle to gate – until end production -   transportation of the raw material extracted and at the plant is considered – the transportation out of production plant is not considered.

4. Case studies on building materials

The table 2 shows the details considered to adapt LCI concrete data to the Brazilian context using the approach proposed at table 1.

Table 2- Methodology applied to adapt the module concrete normal at plant to Brazilian context

Step	Method	Considering
1	Goal and scope definition	$1m^3$ of normal concrete adapted to Brazilian context - module consider cradle to gate (production phase)
2	Identify the Generic EPD data base selected	module base: concrete normal, at plant/CHU - Ecoinvent
3	Identify the Brazilian context and indicators – overview the differences related to mostly energy matrix and	use the Brazilian energy matrix
		changing means of transportation-consider only dumpers for cement and bricks, and mixer truck to concrete

[1] IPCC 2001 is a method developed by the International Panel on Climate Change. Climate Change 2001. IPCC Third Assessment Report. The Scientific Basis. Available on http://www.grida.no/climate/ipcc_tar/

[2] CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterization methods for the impact assessment.

[3] Cumulative Energy Demand (CED). Details on the CED method may be found in Bösch *et al.* (2007)

	technologies/process, etc				
4	Adaptation of the generic data base inputs related to the process - Overview the inputs of the inventories concerning the process - amount of raw materials, transportation distance, etc	production phase -concrete production including transportation of raw materials to the concrete production site			
		change transport distances			
		remove transportation by boat and train			
		remove transportation by 20 and 28t			
		include 32T truck to transport cement, sand and gravel (100 km round-trip to sand/gravel and 200 km round trip to cement)- consider the same uncertainties of 20-28t			
		change amount of electric energy at plant - 2, 05KWh/m^3 (Brazil data, from Souza 2012)			
		remove natural gas			
		losses were not considered neither water losses			
5	Verify the data quality of the inputs data	inputs/flow	Uncertainties		
			from Ecoinvent	calculate for Brasilan context	
		cement	1,3	1,3	
		electricity	1,22	1,22	
		lorry 28t	2	2	
		lorry>32t	2	2	
6	Identify the impacts indicators to be considered and analyzed –	Consumption of primary energy (non-renewable)			
		climate change (kgCO2 equiv)			
		water consumption			
		waste generation			
7	Selecting on SIMAPRO the method to calculate the impacts with the uncertainty estimations calculated by Monte Carlo simulation	French Method (because its included CML, IPCC and CED)			
		500 iterations to perform Monte Carlo simulation			
8	Results	Module adapted: Normal Concrete, at plant/CH U-module BR-Ecoinvent/SIMAPRO			
9	Validation and Macro Comparisons	Macro Comparisons among environmental indicators calculated by Brazilian LCI, original and adapted LCI			
10	Others points/observations	transportation of concrete is classified in construction site phase, as EN 15978 (2012)			

The table 3 shows the LCI original and the adapted LCI. The table 4 shows environmental indicator of concrete calculated with the adapted existing LCI data.

Table 3 - Adaptations of Life cycle inventory (LCI) data from Ecoinvent to Brazilian context – normal concrete, at plant

Original Ecoinvent Inputs				Changed Inputs	Ecoinvent adapted inputs			deviation comparisons	
No.	Parameters	initial amount	functional unit	Parameters Changed	new input	assumptions	demonstrative calculus	Ecoinvent	Brazilian context
1	concrete mixing plant CH U	4,57E-07	unit						
2	diesel, burned in building machine GLO U	22,7	MJ						
3	disposal, concrete, 5% water, to inert material landfill	16,9	kg						
4	disposal, municipal solid waste, 22.9% water, to municipal incineration	0,0951	kg						
5	electricity, medium voltage, at grid CH U	4,36	kwh	Brazilian energy matrix	2,0500	Brazil specific data (Souza, 2012)		1,21	1,21
6	gravel, round, at mine CH U	1890,00	kg						
7	heavy fuel oil, burned in industrial furnace 1MW, non-modulating CH U	3,09	MJ						
8	light fuel oil, burned in industrial furnace 1MW, non-modulating CH U	13,3	MJ						
9	lubricating oil, at plant RER U	0,0119	kg						
10	natural gas, burned in industrial furnace low-NOx >100kW RER U	1,16	MJ	remove	0,0000	not used to concrete production in Brazil (generic data)			
11	Portland cement, strength class Z 42.5, at plant CH U	300	kg	module cement BR	300kg			1,3	1,3
12	steel, low-alloyed, at plant RER U	0,0238	kg						
13	synthetic rubber, at plant RER U	0,00713	kg						
14	tap water, at user CH U	186,00	kg	Changed amount	170,00	Brazil specific data (Souza, 2012)			
15	transport, barge RER U	4,92E+01	tkm	remove	0,0000	changed by lorry			
16	transport, freight, rail CH U	6,82	tkm	remove	0,0000	changed by lorry			
17	transport, lorry 3.5-20t, fleet average CH U	0,998	tkm	remove	0,0000				
18	transport, lorry 20-28t, fleet average CH U	9,44	tkm	remove	0,0000	transport of cement, sand, gravel to construction site by truck	*	2	2
19	transport, lorry >32t	0	tkm	included	193,0900		*	2	
19	treatment, concrete production effluent, to wastewater treatment, class 3 CH U	0,0143	m3						
20	concrete, normal, at plant CH U	1	m3						
21	Heat, waste	15,7	MJ						

* calculus demonstration sheet is prepared but is not showed in this paper

Table 4- Environmental indicator of normal concrete at plant -module BR (adapted of Ecoinvent data based on Brazilian context)

The environmental parameter declaration		unit	Value adapted	SD (500 number of runs)	Min value (2, 5%)	Max value (97, 5%)
	Functional unit	flux/m^3				
1.	Primary energy sources		1280,00	230,000	926	1790
1.1	Renewable primary energy use		108,00	17,100	81,2	151
	hydraulic electricity	kwh				
	wood and vegetal coal	MJ				
	biomass	MJ				
	others	MJ				
1.2	Non-Renewable primary energy use		1170,00	222,00	836	1660
	petroleum and derivatives	MJ				
	natural gas	MJ				
	mineral coal	MJ				
	uranium	MJ				
	nuclear					
1.3	Water consumption	l	3510	376,00	2830	4370
2.	Parameters of environmental impacts					
2.1	Climate change	Kg CO2	232	38,70	164	317
3	Waste Generation					
3.1	Waste dangerous disposed	kg	6,89E-02	3,42E-02	2,78E-02	1,58E-01
3.2	Waste non-dangerous disposed	kg	1,10E+00	4,92E-01	4,28E-01	2,33E+00
3.3	Inert waste	kg	3,35E+01	1,17E+01	1,63E+01	6,07E+01
3.4	Radioactive waste	kg	2,66E-03	5,61E-04	1,79E-03	3,99E-03

5. Comparison among Brazilian, generic and adapted LCI data.

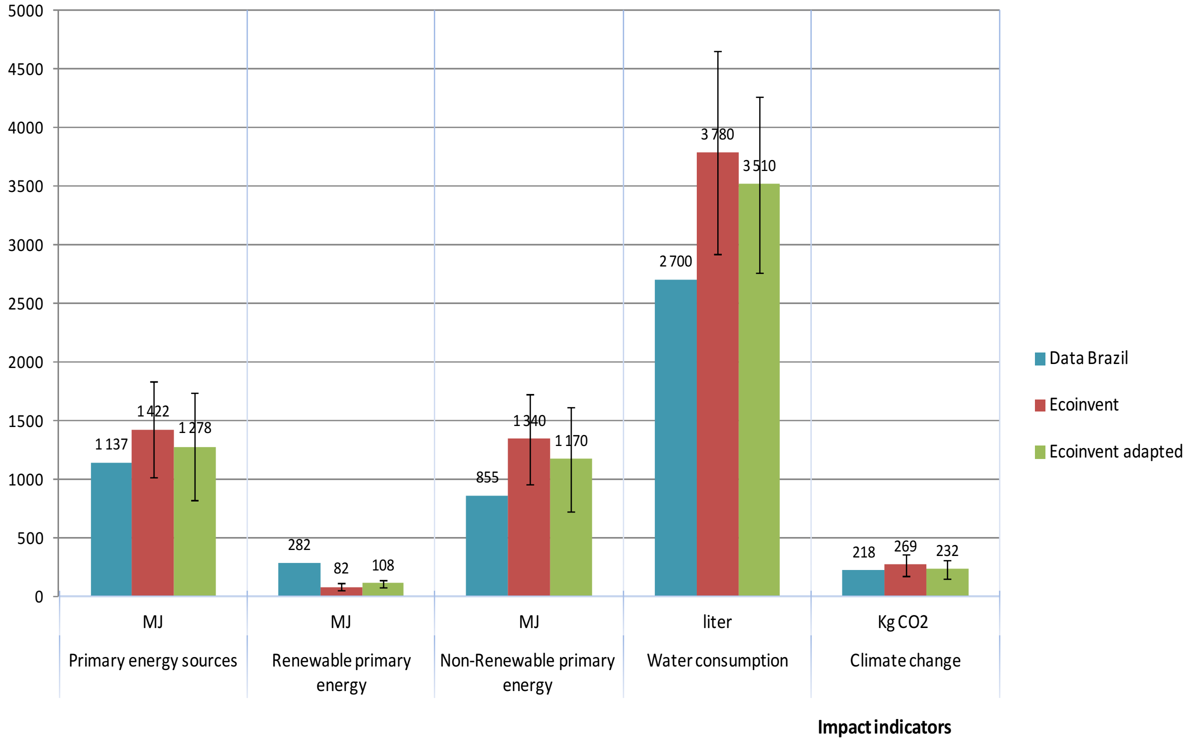
The approach set the phase 9 - Data Analyses – which aims the comparison among environmental indicator came from three types of LCI: Brazilian, original and adapted LCI:

1- Brazilian environmental indicators: it was organized the environmental impacts data of six building products, according to EN 15.804 (2012): cement, sand, brick, crude steel, concrete and concrete block. However, only data of normal concrete is show in this paper.

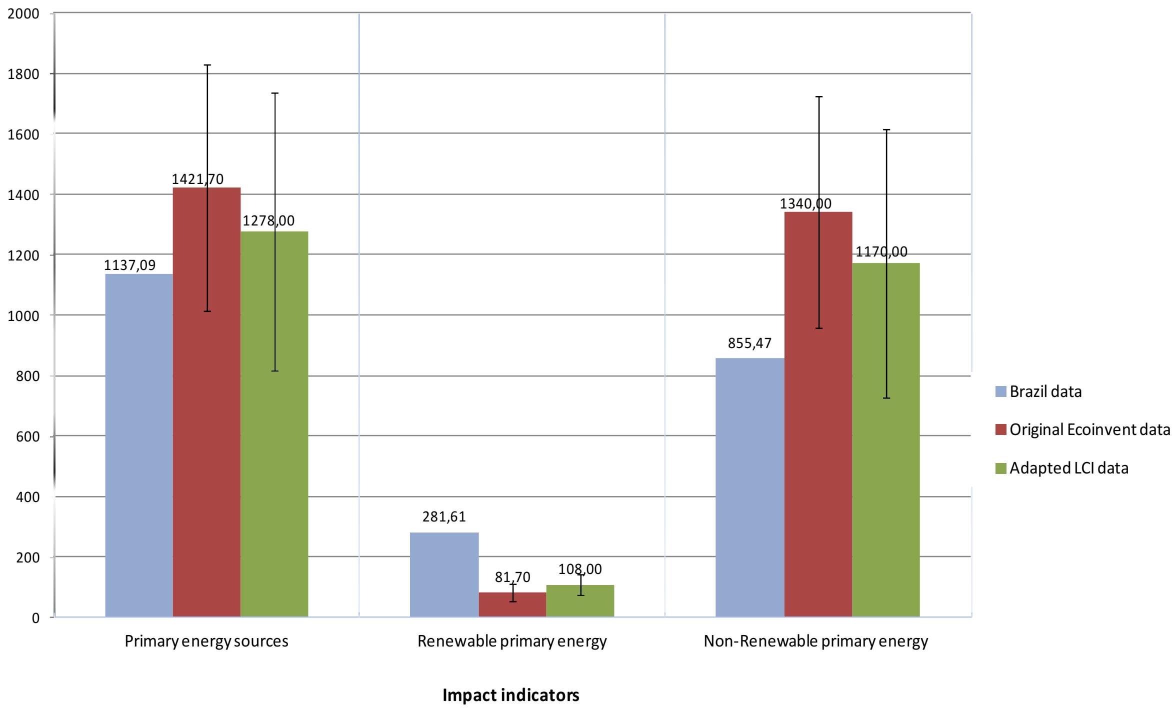
2- environmental indicators from original LCI (from Ecoinvent): seven building products had their impacts calculated by SIMAPRO using the LCI data from Ecoinvent without adaptations: cement, normal concrete, concrete block, mortar, reinforced steel, fiber cement board, gypsum plaster board. These LCIs consider only the production phase. However, only the data of normal concrete is show in this paper.

3- environmental indicators from adapted LCI: seven building products had an LCI adapted in order to fit the Brazilian conditions: cement, normal concrete, concrete block, mortar, reinforced steel, fiber cement board, gypsum plaster board. Only the indicators from adapted LCI of normal concrete is show in this paper. The table 2 and 3 show the adapted LCI concrete data. The table 4 shows the environmental indicator of the concrete calculated by SIMAPRO using the adapted LCI.

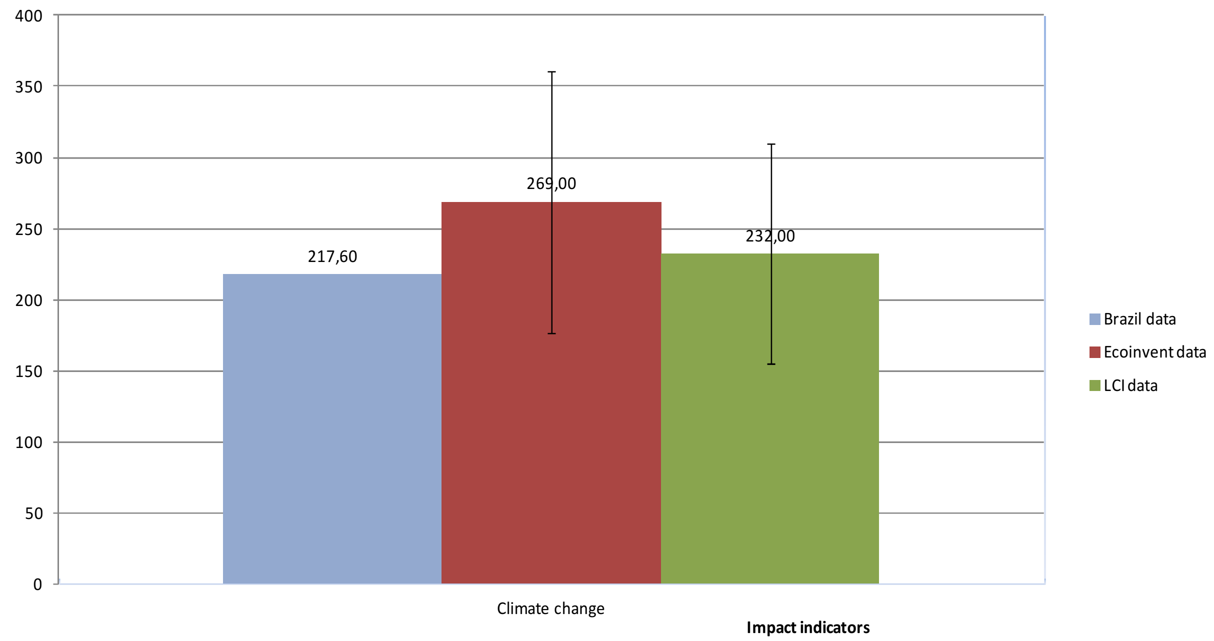
The graphics 1 to 3 show this comparison. The uncertainties was taken into account to data from original and adapted LCI, because the Brazilian LCI does not have this information; but this information is very important because the mean value is analyzed and not an specific producer.



Graphic 1 – Comparison among impact indicators (primary energy, water consumption and climate change) calculated from Brazilian, Ecoinvent and adapted LCI data



Graphic 2 – Comparison among primary energy, renewable energy and non-renewable energy indicators calculated from Brazilian, Ecoinvent and adapted LCI data



Graphic 3 – Comparison among climate change indicators calculated from Brazilian, Ecoinvent and adapted LCI data

6. Conclusions

As the Brazilian building sector does not have organized and centralized LCI or LCA database, adaptation of overseas data (from Europe) is suggested in this paper to facilitate the environmental assessment of buildings using consistent yet not fully representative datasets. Once producers are willing to get involved, original data can be modified and raw data from producers could replace the Ecoinvent data based on the Swiss context (i.e. adapted Ecoinvent data).

To date, our approach is a first step, as some parameters were adapted such as the transportation distances and the energy mixes. The methodology is based on previous research studies from Colodel (2008) and Hodkova et al (2012).

Case studies looking at the concrete building materials (considering Brazilian, original and adapted LCI) show the weaknesses of some Brazilian data e.g. in terms of completeness of the system boundaries. The results for primary energy and global warming potential indicators show that the adapted LCI data is found to have less impact than the indicators calculated with the original LCI (differences between 5 and 10%). This is mainly explained by the efficiency of the Brazilian energy mix despite the large consumption of the non-renewable energy due to the type and distance of transportation. The adapted LCI must now be improved e.g. by working closely with Brazilian producers to get either a more accurate generic data for Brazil or different specific data representing different concrete manufacturers producing concrete for the Brazilian construction sites.

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