Journal of Cleaner Production 188 (2018) 888–899

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

New method to calculate water ecotoxicity footprint of products: A contribution to the decision-making process toward sustainability

Rita de Cássia Monteiro Marzullo [a, *], Patricia Helena Lara dos Santos Matai [b], Dione Mari Morita [c]

[a] Laboratory of Life Cycle Assessment, Institute of Energy and Environment, University of São Paulo (USP), São Paulo, Brazil
[b] Department of Mines and Petroleum, Polytechnic School/USP, São Paulo, Brazil
[c] Department of Hydraulic and Environmental Engineering, Polytechnic School/USP, São Paulo, Brazil

ARTICLE INFO

Article history:
Received 5 December 2016
Received in revised form
30 March 2018
Accepted 30 March 2018
Available online 6 April 2018

Keywords:
Sustainability
Life Cycle Assessment
Water footprint
Eco-labeling
Local impacts
Industrial effluents
Environmental indicator
Water ecotoxicity footprint

ABSTRACT

Sustainability depends on the adoption of attitudes by the productive sector to achieve cleaner production processes. Earth provides the resources necessary for life, but the anthropic concept of survival is inserted in acts of consumption and production to meet the demand that hinder the achievement of sustainability itself. On the other hand, both the supply chain and the end consumer need information which may assist decision-making about buying products that do not harm the environment. The conscious consumption is a growing practice worldwide and manufacturers should adopt a proactive approach to monitor pollution and the impacts caused by their products. Aquatic ecotoxicity can affect multiple trophic levels, compromising water quality for both human consumption and ecosystems biodiversity. Since water is an essential resource for life, this study proposes a method for calculating the Water Ecotoxicological Footprint of products and presents an illustrative example of application to achieve a single indicator that can be used in comparative assessments or benchmarking. Obtained by quantifying tangible variables in a system of monitoring, management of water use and disposal of effluent (wastewater) in industrial and agricultural environments, this indicator aims to contribute to the decision-making process towards sustainability since it may be showed as an informative label on the packaging of each product answering the question: “How much does this product contribute to the aquatic ecotoxicity?” or “How much does this product contribute to the loss of biodiversity?”. From a product life-cycle perspective, the spatial and temporal dimensions were inserted by using a geographic information system (GIS) for local assessments. Public policies can be established to encourage the identification and mitigation of aquatic ecotoxicity impact throughout the product supply chain.

1. Introduction

In a complex society, with a growing population, the supply of demands for food and infrastructure/services is essential to guarantee a better quality of human life; however, this supply puts pressure on the environment. It is estimated that 60% of natural resources have been degraded or are used unsustainably (Millennium Ecosystem Assessment, 2005).

Water is an essential natural resource for life and the preservation of its quality is fundamental in the context of sustainability to the vast majority of international organizations and groups, including those with a mandate focused on economic development.

We are in the ecological era and industries should consider the green brand equity, investing more resources in green brand image, green satisfaction, and green trust (Chen, 2010). However, the transition to a green economy requires the adoption of specific policies by each region/country so that it is not optional but extremely necessary, as there is already a consensus and acceptance that environmental degradation is a major threat to economic growth. The investment in the environment increases productivity, protects the stock of resources and boosts economic growth (ILO, 2013).

With the advent of global concern about climate changes, researches for the replacement of non-renewable energy by

* Corresponding author.
E-mail address: rita.monteiro.usp@gmail.com (R.C.M. Marzullo).

https://doi.org/10.1016/j.jclepro.2018.03.307
0959-6526/

renewable one have increased in recent decades (EIA, 2013a, b).

Blottnitz and Curran (2007) reviewed the assessments conducted on bioethanol as renewable transportation fuel and concluded that all the bioethanol production "is mildly to strongly beneficial from a climate protection and a fossil fuel conservation perspective". However, our need for a sustainable transportation fuel should also consider the impact on water resources. Every organism needs water to live; therefore, the water aware issue is thus a prerequisite for sustainability.

The substitution of petroleum-based gasoline for bioethanol, for example, has the potential to change many environmental impacts related to land and water use in several communities. We need to improve our understanding of trade-offs associated with bioenergy expansion and footprinting indicators can help it.

With global climate change, rainfall levels are changing gradually and some regions of the planet are getting drier while other areas are becoming wetter. Since water is distributed unequally, this fact issues a warning sign regarding water supply, now and in the future. Water shortages hinder the growth of several economic activities, sacrificing industry, power generation, human consumption and agriculture, which are increasingly competing for water in a setting that can seriously affect food security (Lozan et al., 2007).

The presence of pollutants in the aquatic environment cause long term effects in population level at the endpoints. These effects can be evaluated through experiments in the several generations (Muyssen and Janssen, 2004). The discharges of pollutants into the environment and the global forecasted temperature increase have caused a permanent reduction of the biodiversity in aquatic ecosystems (Sala et al., 2000; Thuiller, 2007).

There are several possible sources of contamination of water bodies: inadequate disposal of effluents or solid waste from industries, mining operations, runoff with pesticides and fertilizers in agricultural areas, among others. Besides, new chemicals are emerging at an accelerated rate in the market and their impacts on the environment and on human beings are still unknown (Morita, 2010). Therefore, the simple control on the discharge of few chemicals in water bodies does not protect the aquatic environment.

Ecotoxicity can be an indicator to evaluate the level of conservation of living biota and the integrity of the environmental services provided by it. According to Wenzel et al. (1997), some chemicals have toxic effects when released into water bodies in concentrations that affect living organisms, the function and structure of aquatic or terrestrial ecosystems.

Ecotoxicity represents not only the result of the effects of isolated substances, but also the interaction between them in a given environment, disturbing the existing balance between organisms. Synergistic, additive and antagonistic interactions that can increase or reduce the harmful effects on aquatic organisms should be considered. Industrial and agricultural effluents represent the major contributions as toxic loads into watersheds and thus, the importance to determine their ecotoxicity to the water bodies is evident (Zagatto and Bertoletti, 2008).

This paper provides a contribution to sustainability by a proposal of a new method for obtaining a Water Ecotoxicity Footprint (WEF) indicator of products. This indicator is obtained by quantifying tangible variables in a water usage monitoring system in industrial and agricultural environments.

Besides obtaining a water usage indicator per volume, understanding the impact of ecotoxicity on aquatic environments, as an indicator of "footprint" or "footprinting", is an essential stage in the development of strategies to reduce and to mitigate these impacts with cleaner production processes. Thus, this work is motivated by the challenge of answering the following question to the end consumer:

> "*What is the real contribution of the product to aquatic ecotoxicity?*"

This method allows an answer to this question in an eco-labeling process. Gen (2015) defines eco-labeling as a voluntary method which identifies overall environmental performance of a product or service based on life cycle considerations.

According to DSouza (2000), environmental labels are used by business to communicate the environmentally friendly message to consumers and they can use it as a guide to choose environmentally friendly products.

The International Organization for Standardization (ISO) divided environmental labeling in three types: type I includes multi-criteria third-party programs intended to end consumers; type II involves self-declared environmental claims, and type III provides quantified environmental data in environmental product declarations based on Life Cycle Assessments Standard (ISO 14020:2000; ISO 14024:1999; ISO 14025:2006; ISO 14040:2006).

According to the World Trade Organization's "Code of Good Practice" (WTO, 2015), technical regulations, standards and procedures for conformity assessment may not be prepared, adopted or applied with the intention of creating obstacles to international trade. Therefore, as Rubik and Frankl (2005) suggested, environmental product information, such as eco-label, needs to be linked to national and international government policies.

2. New method framework proposal

This work began with the challenge of using the Life Cycle Assessment method (LCA) perspective to calculate the Water Ecotoxicity Footprint (WEF) of products considering the spatial and temporal dimensions. Although the LCA method is considered and recognized as being particularly useful in sustainability assessments, it must be supported with more site-specific tools that can more appropriately address issues such as land use and water use (Bare, 2014).

Starting from a critical appraisal of the LCA method, it was possible to propose a new method that is an association between the guidelines in the standards in LCA (ISO 14040 and ISO 14044), the standard regarding water footprint (ISO 14046) and the impact assessment method suggested by USEPA (1985) and used by CETESB (2013). The geographical variable is added for the evaluation of the local impact by employing the Geographic Information System (GIS).

The name "*Water Ecotoxicity Footprint* " (WEF) is aligned with the new ISO 14046 standard, which recommends always adding a qualifier to the name "water footprint" (e.g., water availability footprint, water eutrophication footprint or water ecotoxicity footprint). The same standard also mentions that the name "water footprint" may only be used alone if the assessment comes from an LCA with a complete and comprehensive approach, including the largest possible number of impact categories at the midpoint or end point.

The proposed method is based on LCA phases, adding preliminary Macro and Micro evaluations to the scope of the study with the inclusion of local geographic variables. Several studies underline the importance of spatial and temporal appropriate scale level (considering local conditions) in assessments for decisions that have a large potential for environmental impact, including the LCA approach (Bare, 2010, 2014)

3. Results and discussion

The results of this work present a set of equations to obtain the WEF of any product. It also contains an illustrative example[1] about some structural phases to get WEF from hydrous ethanol (ethanol by weight 93.0%) produced by an "X" plant in the state of São Paulo, Brazil, using as raw material the sugar cane grown in Corumbataí river basin, a sub-basin of the Water Resource Management Unit formed by Piracicaba/Capivari/Jundiaí rivers (PCJ Basin).

3.1. PHASE 1: goal and scope definition

Similarly to conducting a LCA, the goal of a WEF assessment be clearly defined. In this illustrative example, the goal is to answer the question:

> "*What is the real contribution of hydrous ethanol, produced in "X" plant, to aquatic ecotoxicity?*"

Normally, in an LCA study, the environmental impacts are often described as "potential impacts" because they are not specified in time and space and are related to an arbitrary functional unit (Guinée, 2004). However, the determination of WEF impact needs to be local in space and time. In order to solve the difficulty in relating the performance of the product to the local impact of its production, the premise of an "*annual production control volume*" was taken into consideration, herein called "*local functional unit*", for calculating the total reference flow. This "local functional unit" should always match the total amount of product manufactured at that location, within the chosen time boundary (reference year). For example, the total production of hydrous ethanol by an "X" plant within the time boundary of 2011 was 59,861 tons.

Therefore, calculating WEF involves planning stages (the year before), monitoring stages (reference year) and the calculation itself (at the end of the reference year).

In a LCA study, the product system definition does not consider the geographical locations. When employing software that uses pre-existing databases for developing an LCA, the control of the whole range of possibilities is very complex, making it difficult to use the results in comparative approaches, regarding local impacts. Thus, our method adopts the premise of the product system boundary to be fixed in the second tier (secondary suppliers) in order to allow a comparison between environmental performances of the products by WEF. The boundary is placed in the producer output gate, i.e., the use phase has not been considered for a while. Fixing the product system boundary is grounded in relevance. As far as the Unit Process moves away from the producer, in the upstream chain, its relevance decreases in WEF calculation. Appendix 1 shows an illustrative example of reference flow to obtain the *local functional unit* within the boundary of hydrous ethanol product system. For the calculation of the ethanol reference flow, the performance factors suggested by the inventory of Cavalett et al. (2013) were adopted, where it was possible to conclude that for each 1 GJ of energy used as ethanol hydrate function, 545.45 kg of sugarcane were required.

The chosen method for the WEF Assessment should be clearly specified in the study scope. The method suggested here was named with the following acronym: WEF/IEE/POLI/USP/BR (method for obtaining the water Ecotoxicity Footprint (WEF) developed under the Institute of Energy and Environment and Polytechnic School of the University of São Paulo, Brazil).

In addition to a detailed description of the technology in scope, it is necessary to have the site definition together with the information of where it is operating. For such reason, in our method, the site where the product is manufactured is defined by the preliminary macro and micro evaluations. Once the WEF is strictly differentiated by conditions from production site, the same products with the same function, produced in different water basins, can have different WEF. The method allows the following comparisons, with different possibilities of conclusion and technological innovation opportunities aiming at improving environmental performance:

- The same technology in different places;
- Different technologies in the same place.

This method introduces the concept of Macro and Micro preliminary assessment within the scope of the study for calculating the WEF with the mapping of river basins in which the Unit Process contained in the Product System are located.

3.1.1. Preliminary macro evaluation

A macro preliminary assessment uses a Geographic Information System (GIS) to locate each Unit Process (UP) within a new concept of *Spatial Product System.* In this preliminary evaluation, information on administrative location (counties or states), water basins and subbasins can be obtained. It is also possible verify if the UPs are in places where water resources are under pressure and/or restrictions on water use.

In the illustrative example, the "X" plant and sugar cane polygons are located in the Paraná water basin; Piracicaba, Capivari and Jundiaí river basins (PCJ river basins); Corumbataí river subbasin, São Paulo State, Brazil (Fig. 1). The PCJ is one of the most important basins in Brazil because it supplies drinking water to 14 million people and it is a conflict target between 2 metropolitan regions, São Paulo and Campinas, due to its water resources. There are many rivers under pressure in these basins.

3.1.2. Preliminary micro evaluation

At this stage, more specific information and data about subbasins, where each UP is located, are stored in the GIS. In the illustrative example, Fig. 2 shows the soil erosion vulnerability map of PCJ river basins and hypsometric map of Corumbataí river subbasin. It is worthy to note that the sugarcane polygons are in an area with very high soil erosion vulnerability, which may result in load of sediments contaminated with pesticides to the river.

Santos (2008) evaluated ecotoxicity in samples of water and sediment of Corumbataí river during 2 years. It performed acute toxicity tests with *Chironomus xantuhus, Daphnia magna, Hydra attenuate, Lactuca sativa and Pseudokirchneriella subcapitata*. All water and sediment samples showed toxicity for most organisms tested and the values were higher in sediments. Corumbataí subbasin has soil predominantly sandy type, with rugged terrain where the predominant history of sugarcane culture employs a wide range of agrochemical products. Herbicides have been detected for agricultural activities in the samples with concentrations sufficient to achieve toxicity in some tested organisms. The presence of these herbicides suggests that Corumbataí subbasin is highly susceptible to contamination by intensive agriculture in the region. The contamination level of this subbasin, on a large scale, threatens the aquatic biota (Monteiro et al., 2008).

[1] Illustrative example with no real river flow and ecotoxicological tests results (only simulation).

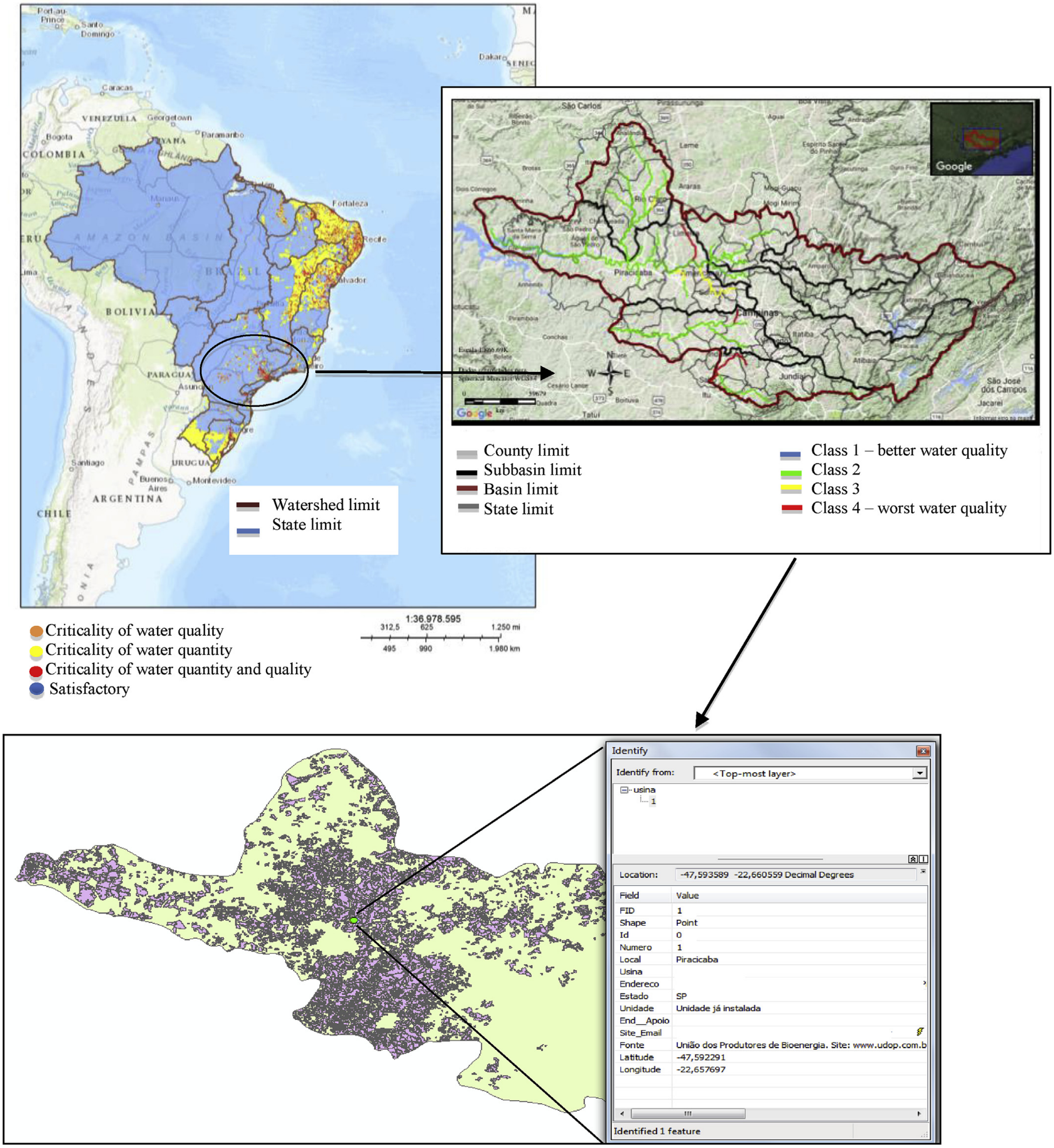


Fig. 1. Preliminary macro evaluation of ethanol produced at the "X" plant.
Source: authors' simulation with shapefiles from INPE, ANA, PCJ and CANASAT project with data compiled in Rudorff (2010) and Adami et al. (2012).

3.2. PHASE 2: Inventory planning and analysis

Following the process of sustainable evolution suggested by Marzullo and Matai (2011), our method introduces the concept that each Unit Process in any productive sector should monitor its LCI (Life Cycle Inventory) in a gate-to-gate boundary within the context of a proactive approach to cleaner production and sustainability. Monitoring is a management practice able to identify improvements throughout the production process.

According to Marzullo and Matai (2012), the inventories for a Water Footprint Assessment should be characterized according to the method to be used for impact assessment. Our method requires

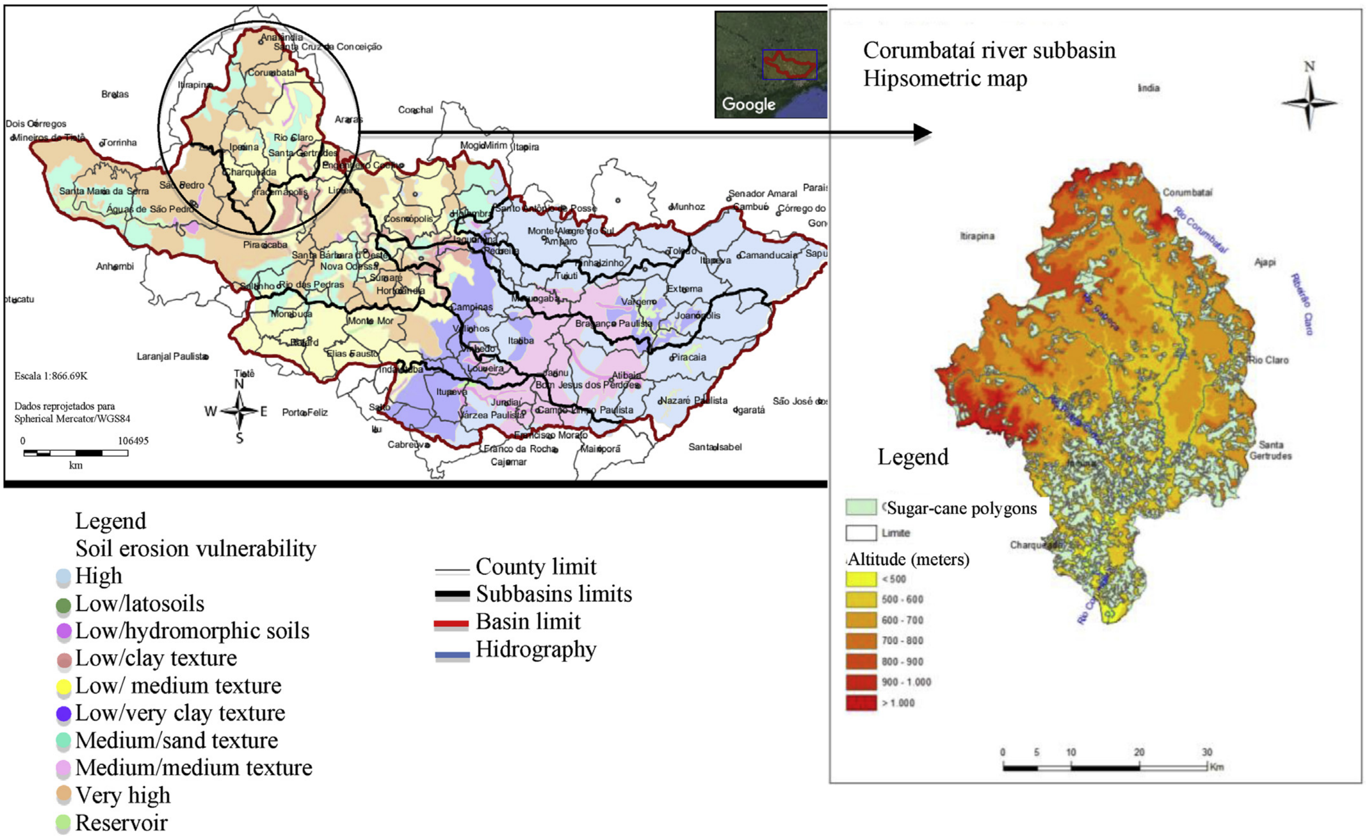


Fig. 2. Preliminary micro evaluation of ethanol produced at the "X" plant.
Source: elaboration of the author with shapes provided by PCJ, CEAPLA, INPE and Canasat INPE

data from ecotoxicity tests in effluent as well as the flow rate (water outflow) in each Unit Process.

In general, most inventories used in LCA do not categorize the local use of water source and regional availability, or the effluent discharge as a flow ($m^3 . s^{-1}$). However, midpoint impact assessment categories, such as ecotoxicity, water use, land use and rare earth/mineral use, are site specific (Bare, 2010, 2014; Židonienė and Kruopienė, 2015). Therefore, it is necessary to regionalize the inventory concerning the use of water, considering functionality aspects (origin and quality) as well as effluent flow rate of recipient water bodies.

Normally, LCA inventories from databases provide a wide range of pollutants, from simple to complex substances. International databases (such as Ecoinvent from Swiss Centre for Life Cycle Inventories) involve over 300 parameters that may or not represent all the pollution potential and real impact on a water body. In an LCI monitoring system, as suggested, determining all these parameters can be economically unfeasible, especially in underdeveloped and developing countries. Besides that, the current aquatic ecotoxicity impact evaluation methods do not consider the synergistic action of effluent pollutants in the environment or the formation of metabolites, which according to Morita (2010), can be more harmful to the environment than the original substances.

Agrochemical compounds, for example, can be transported by surface runoff, leaching and atmospheric deposition according to their mobility, persistence, water solubility and soil adsorption capacity (Arms, 2005).

Pathogenic fungi on vegetables or fruits can cause crop failures due to fungal diseases and it is normally controlled with the use of fungicides with high potential of aquatic toxicity (Ribeiro et al., 2000). Under climate change conditions, with warmer and more humid climate expected, higher agricultural application of pesticides is required, especially fungicides, contributing to impacts on human health (Boxall et al., 2009). Moreover, changes in rainfall patterns due to temperature variations cause extreme events like heavy rainfall during summer that influence the movement, partitioning, and distribution of chemical pollutants, such as agrochemicals, into the aquatic environment (Noyes et al., 2009) and the thermal and chemical stressors act synergistically (Jacobson et al., 2008).

When making a comparative assessment of data contained in available sugarcane agricultural inventories (Swiss Centre for Life Cycle Inventories, 2009, 2013, and Cavalett et al., 2013) with field data collected by Arms (2005) it was found that the assessment of the water footprint in any impact assessment methodology would be very inaccurate with the use of databases. With the calculation of the potential freshwater ecotoxicity impact using PestLCI v.2.0 and USETOX models, Nordborg et al. (2014) found the contribution of pesticide use in selected biofuel feedstock production. However, the use of databases without considering the use of pesticides in time as well as the local topography conditions, synergistic action of pollutants and the receiving water body characteristics hinders the understanding of the real contribution of such biofuel to aquatic ecotoxicity.

The toxicity test in wastewater discharged into the aquatic environment is an integral part of regulation and control to protect aquatic ecosystems used in countries as US and Canada (Dorne, 1996).

Ecotoxicological tests characterize wastewater comprehensively. In addition to cover all chemical constituents, this kind of test yields the resulting toxic effect of interactions between these chemicals and the presence of metabolites.

The need for ecotoxicological monitoring of wastewater is an issue discussed internationally since the 1980s (Buikema et al., 1982). The sampling frequency must be representative from variations of the production process over the time, and ecotoxicity tests must be performed with the most sensitive organism (Bertoletti, 2013). According to Bertoletti (2006), the choice of test organism refers to its sensitivity to chemical agents. The sensitivity of an organism will depend on many factors, such as nutritional level, age, sex, stage of development, genetic characteristics, competition between individuals or species, as well as environmental factors such as light and temperature.

Our WEF calculation method shows the real contribution of each product to the aquatic ecotoxicity and not only the potential contribution (as suggested in most Life Cycle Impact Assessment methods in an LCA). The limitation in obtaining data from various laboratory tests to compose Life Cycle Inventories may be solved by performing only one ecotoxicological test of the effluent that can be documented in a life cycle inventory context.

The inventory monitoring system should be established to allow monitoring each Unit Process interaction with the environment. This system can be individual to each Elementary Process or each Unit Process, according to the technological boundary used and the level of detail required in order to better understand the use of water resources and the impact of effluents disposal on water bodies.

The inventory of an agricultural Unit Process must be differentiated. The water intake is by precipitation and collection of surface water for irrigation. This input of water is therefore linked to the water requirement of each crop production and precipitation rates of each region. The runoff is characterized as the effluent of an agricultural unit. This inventory must be created from the hydrology of the region and monitoring takes place by rain gauges located in different sites and also georreferenced, as showed in Fig. 3.

The agricultural effluent ecotoxicity depends on the pesticides seasonal application, on rainfalls of each region, on runoff flows and on the receiving water body. For this reason, time monitoring of pesticides consumption is recommended on a weekly spreadsheet, besides intersecting information in an inventory of each cultivated area.

The inventory analysis phase in our method is used to quantify and to monitor:

- Volume of water entering the Unit Process (classified by source) [L^3]
- Volume of water leaving the Unit Process (effluent) [L^3]
- Effluent flow rate [$L^3 . T^{-1}$]
- Receiving water body name and geografic coordinates
- Reference flow of receiving water body [$L^3 . T^{-1}$]
- Effluent ecotoxicity test result [%]

Following Mutel's (2012) suggestion, all the input and output accounting aspects have to be georeferenced through a GIS-Geographic Information System.

3.3. PHASE 3: Impact assessment

The impact assessment phase consists of obtaining an indicator at the midpoint on aquatic ecotoxicity. Obtaining this indicator comprises the calculation of the WEF itself. This assessment will only be possible after the end of time boundary adopted to establish the reference flow and consequent relevance of each Unit Process. Relevance depends on the amount of each material or raw material entering the product system, in the time boundary to be studied for the production of the "local functional unit". Such relevance is established by the quantity consumed of this product divided by the total produced by the same supplier, in the same geographical location, in the same year (marketshare).

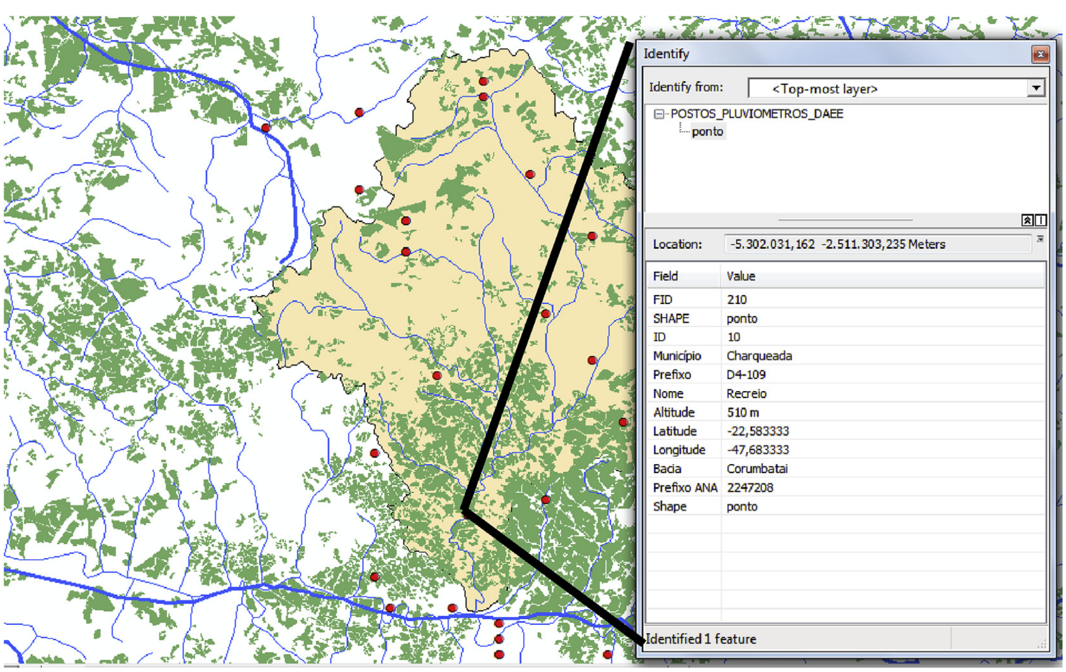


Fig. 3. Location of rain gauges and sugarcane polygons in the Corumbataí river subbasin.
Source: Author's elaboration with shapefiles from INPE, CANASAT and CEAPLA.

Table 1
Method for normalization and ecotoxicological relevance classification for each Unit Process.

	NORMALIZED VALUE	INDICATOR CLASSIFICATION		
EDRi < Li	(RT)i ≤ 1,000			1
EDRi = Li	1,001≤ (RT)i ≤ 1,499			2
EDRi > Li	1,500 ≤ (RT)i ≤ 2,999			3
EDRi > Li	3,000 ≤ (RT)i ≤ 5,999			4
EDRi > Li	6,000 ≤ (RT)i ≤ 9,999			5
EDRi > Li	(RT)i ≥ 10,000			6

This method for calculating the WEF suggests some steps in the impact assessment phase:

- First, before the preparation of inventories, it is necessary to know the local legislation of each Unit Process to be inventoried, because depending on the location of the industry and the legislation, the local environmental agency may propose monitoring with different ecotoxicity tests as well as the monitoring of different flows of the receiving water body (e.g. reference flow or $Q_{7,10}$ flow).
- Second, the local variable should be included by calculating the Effluent Concentration on the Receiver Body (equation (2)).

To obtain the WEF, it is necessary to take into account the ecotoxicological relevance (RT_i), the productive relevance (PR_i) and the reference flow relevance (RFR_i).

The RT_i (ecotoxicological relevance) for each Unit process is obtained by comparing the normalized limits allowed in an increasing scale of values.

For normalization, the method determines that the limit allowed for aquatic ecotoxicity set forth by the local environmental protection agency (L_i) must have value 1 and the ecotoxicological relevance of each elementary process (e) or Unit process - RT_i - will be the value that EDR moves away from 1, calculated according to Equations (1) and (2) and classified according to the scale of values and colors suggested in Table 1:

$$RT_i = \frac{EDR_i}{L_i} \tag{1}$$

$$EDR = \frac{EAF}{(EAF + MFRWB)} \cdot 100 \tag{2}$$

Where:

RT_i = ecotoxicological relevance
EDR = Effluent Dilution in the Receiving Water Body (%)
EAF = Effluent Average Flow ($m^3 . s^{-1}$)
MFRWB = Minimum Flow of the Receiving Water Body - $Q_{7,10}$ ($m^3 . s^{-1}$)

For example, in São Paulo State (Brazil), the limit established by CETESB (2013) - Environmental Protection Agency (L_i) on aquatic ecotoxicity is calculated according to equation (3):

$$L_i = \frac{EC(I)_{50,48h} \text{ or } LC(I)_{50,96h}}{100} \tag{3}$$

Where:

100 = factor used to ensure the absence of chronic toxic effects, the representation of various trophic levels and ecotoxicity temporal variations.
$EC(I)_{50,48h}$ = effluent dilution that causes acute effect (immobility) to 50% of microcrustacean *Daphnia similis* population, 48-h exposure, expressed in %.
$LC_{50,\ 96h}$ = effluent dilution that causes acute effect (mortality) to 50% of a population of fish *Danio rerio* or *Pimephales promelas* in 96 h, expressed in %.

Only the calculation of ecotoxicological relevance is not sufficient to obtain the WEF. Each Unit Process provides a different contribution to the product WEF. Thus, it is necessary to take into account the productive relevance and reference flow relevance according to equation (4).

$$WEF_i = RT_i . PR_i . RFR_i \tag{4}$$

Where:

WEF_i = Water Ecotoxicity Footprint for each Unit Process "i"
RT_i = ecotoxicological relevance for Unit Process " i"
PR_i = Productive Relevance
RFR_i = Reference Flow Relevance

Ecotoxicological Relevance (RT_i): normalized value that expresses the classification of each elementary process and Unit Process. This relevance is calculated from an ecotoxicity test in its respective effluent, whereas this effluent is released individually into the receiving water and represents the weight of ecotoxicity to calculate the product WEF.

Productive Relevance (PR_i): equivalent to the allocation factor for economic criterion in LCA, it is calculated to allocate the ecotoxicological load discharged in the effluent from all products outside of that Unit Process. In case of an agricultural Unit Process, the allocation factor should be equal to the necessary cultivated area for each product since WEF is directly related to the application of pesticide for a given perimeter. For example, in the agricultural Unit Process for sugarcane production, a certain percentage (allocation factor) is intended to produce sugar and another one to produce ethanol.

Reference Flow Relevance (RFR_i): means the relevance of individual WEF_i to the total WEF_t. In other words, how much the analyzed reference flow for each product entering the system represents from its total production, in its Unit Process, called market share.

When the Unit Process "i" has several elementary processes, they must be aggregated by an Aggregation Factor (AF_1), considering the ecotoxicological load[2] of the effluent or the effluent flow from its respective elementary unit according to equation (5):

$$WEF_i = \sum WEF_e.AF_i \tag{5}$$

Where:

WEF_i = Water Ecotoxicity Footprint for each Unit Process "i"
WEF_e = Water Ecotoxicity Footprint for each elementary process "e"
AF_1 = Aggregation Factor calculated from the effluent flow.

At this stage, the study has a list of all WEF_i of each Unit Process (as illustrated in Annex 2), already weighted for the product being studied. It is only necessary to group the WEFi into a single WEF of the product by a second Aggregation Factor (AF_2) according Equation (6) and illustrated in Appendix3.

$$WEF_{p,i} = \sum WEF_i.AF_2 \tag{6}$$

where:

$WEF_{p,i}$ = PARTIAL Water Ecotoxicity Footprint of product " p" produced in Unit Process "i"
WEF_i = weighted Water Ecotoxicity Footprint for each Unit Process "i"
AF_2 = Aggregation Factor calculated from effluent flow.

In the future, when everyone will have the culture and the responsibility to monitor their own effluent, each manufacturer/supplier can provide its customers with two types of data: Partial Water Ecotoxicity Footprint WEF_p whose calculation is made using WEF_i data and FULL Water Ecotoxicity Footprint, whose calculation is made according to equation (7).

$$WEF_{f,p} = \sum WEF_i.FA_3 \tag{7}$$

Where:

$WEF_{f,p}$ = FULL Water Ecotoxicity Footprint of product " p" produced in the Unit Process " i"
$WEF_{,i}$ = weighted Water Ecotoxicity Footprint for each Unit Process " i"
AF_3 = Aggregation Factor calculated from the ecotoxicological load of wastewater.

3.4. PHASE 4 - Results interpretation

During the result interpretation phase, all Unit Processes which have the greatest contribution to aquatic ecotoxicity impact should be evaluated.

The interpretation phase is important to identify the critical areas with major contribution to aquatic ecotoxicity.

During the decision-making process for choosing sustainable products, depending on the analyzed product, the WEF obtained indicator could become an indicative "frog" label on the packaging (following WEF color classification showed in Table 1). This way, the end consumer will be aware that the product to be consumed does not contribute to aquatic ecotoxicity.

4. Conclusion

Monitoring is a management practice able to identify improvements throughout the production process. Each product has a different WEF depending on the location where it is produced, i.e., the same product with the same function may have different WEFs.

The use of a "local functional unit" solves the LCA limitations listed by Guinée (2004): the functional unit ceases to be arbitrary and the conditions of space and time are considered, providing the assessment with a more dynamic approach.

Our method considers a monitoring system in space and time, starting from the principle that within an Environmental Management System, aspects and their impacts shall be minimized and controlled independently of the volume produced. Thus, the environmental legislation should be satisfied independently of effluent flow rate and should not cause aquatic ecotoxicity in the water body. This premise is intended to solve one of LCA limitations listed by Guineé (2004) regarding LCA to be a tool based on linear modeling.

Local impacts on water quality should be taken into account in a life cycle perspective because of the essential role of water in ecosystem functioning. Within a sustainability context, water has a higher value than the monetary one. Our method suggests inventory-monitoring processes within a LCA perspective for Environmental Management and decision-making. When trying to answer the question "what is the real contribution of the product to aquatic ecotoxicity?" the power to choose moves to the consumer, triggering a continuous monitoring process in the production chain with significant improvement in water quality. The obtained indicator considers other levels of the production chain, strengthening the systemic vision required for sustainability.

Quantifying the environmental aspects within a process of tracking inventories, as suggested, requires a new vision of values to achieve sustainability. Currently, the monetary value of an externality is not considered a liability. It means that normally, the environmental liability is not provisioned to cover the obligation that the company would have to pay to cover damage at the three levels of impact: human health, ecosystem quality and resource depletion. If there were a requirement for financial allocation to cover the costs of externalities, the cost of hiring professionals to monitor their gate-to-gate inventories could reduce the environmental liabilities with consequent increase in profit.

Another aspect of a new vision of values is that the need of hiring new workers to environmental monitoring practice creates more jobs, consequently heating the economy.

As any impact on water bodies should be evaluated locally, the insertion of geographic indicators for calculating WEF allows the aquatic ecotoxicity impact category to be evaluated as a real impact rather than a potential one (constantly evaluated in LCA assessments).

The use of this method allows visualizing break-even points of productive regions with high WEF and can help in the qualitative characterization of water resources at different levels of criticality, complementing the quantitative indicator of water footprint. The

[2] Ecotoxicological load = (ecotoxicological relevance).(effluent flow).

product WEF indicator meets the need to adapt land use and the occupation of river basins to avoid contamination of water resources. Incorporating ecotoxicity tests application in a monitoring system of polluting activity is an important tool to assess the performance of effluent treatment plants, ensure water quality and ecosystem services. The calculation of effluent dilution in the receiving water body and its comparison in a scale of values allows each Unit Process to have a local WEF indicator. The indicator obtained by our method allows information and comparison for producers who want to minimize the impact of their product and for end consumers who, in turn, use their decision-making when choosing sustainable products.

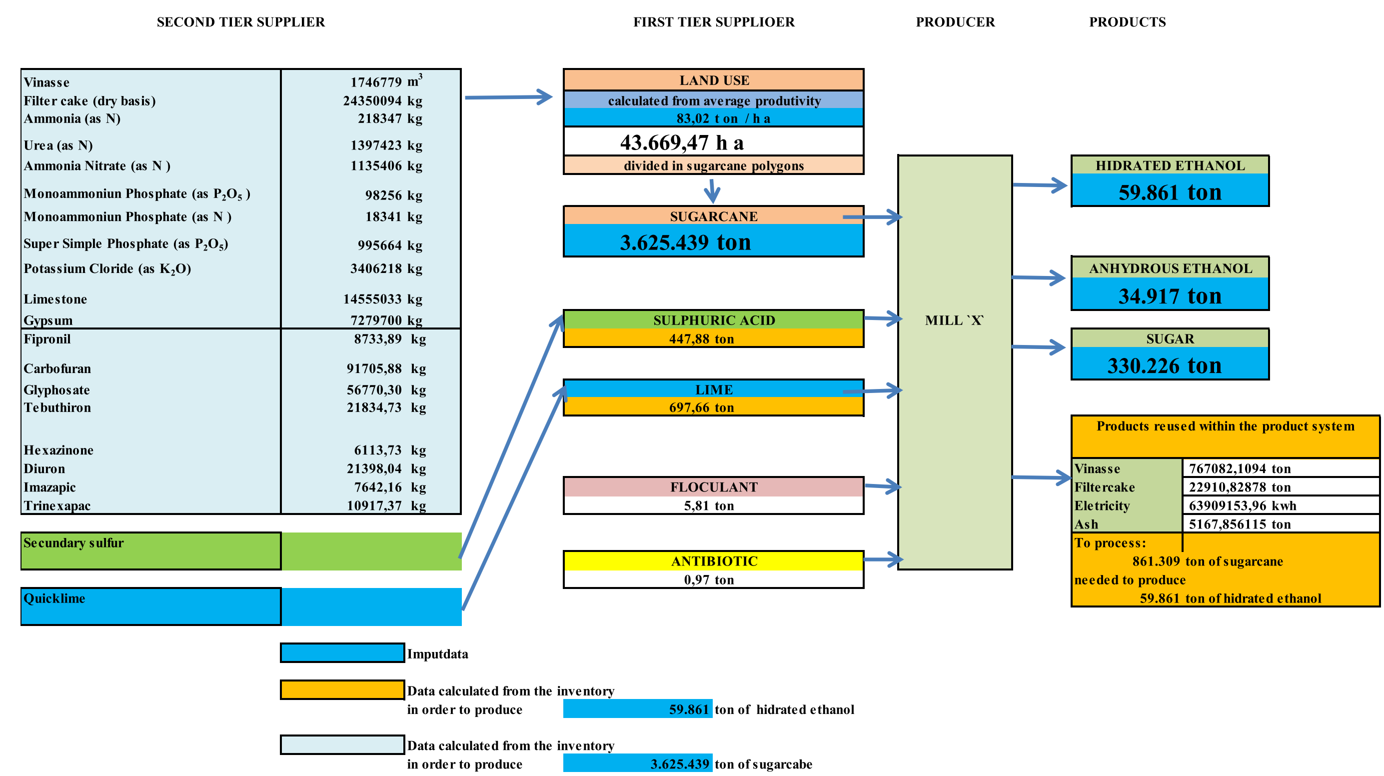
Our method addresses the issue of Life Cycle environmental impact assessment considering that the compilation of these impacts as a “footprinting” indicator is a stage towards the development of water use reduction strategies and impact mitigation. The quantitative indicator (flow) and the qualitative indicator (WEF) can be extracted using this method, thus serving as a tool in environmental management processes.

Therefore, the WEF of products may serve as a subsidy for establishing public policies, allowing products with low WEF to have tax incentives to offset environmental protection costs, or products with high WEF to have higher taxation.

Acknowledgment

The authors thank the Brazilian government (Coordination for the Improvement of Higher Education Personnel, CAPES, Ministry of Education) for the financial support to develop the doctoral thesis.

Appendix 1. Reference flow to calculate “local functional unit” to ethanol anhydrous produced at “X” plant, within the chosen time boundary (reference year).



Appendix 2. WEF calculation to each Unit Process.

UP	TYPE	ELEMENTARY PROCESS PHASE	PROCESS UNIT	EFFLUENT TYPE	EAF (m^3/s)	ECOTOXICITY $(EC)_{50}$	AF1 (calculated from effluent flow)	MF RWB (m^3/s)	E.D.R.	ENVIRONMENTAL AGENCY LIMIT (Li)	ECOTOXICOLOGICAL RELEVANCE (RT)	COLOR CLASSIFICATION	PRODUCTIVE RELEVANCE (PR)	REFERENCE FLOW RELEVANCE (RFR)	WEIGHTED $(WEF)_e$	$(WEF)_i$	COLOR CLASSIFICATION
1	INDUSTRIAL	Cleaning	COMUM	at point	0,769	80%	16%	20	3,7%	0,80%	4,630	4	14,50%	100%	0,67	0,108	
		Soaking		at point	0,087	60%	2%	20	0,4%	0,60%	0,725	1	14,50%	100%	0,11	0,002	
		Preparation of lime		at point	0,010	40%	0%	20	0,1%	0,40%	0,131	1	14,50%	100%	0,02	0,000	
		Cake wash		at point	0,010	60%	0%	20	0,1%	0,60%	0,087	1	14,50%	100%	0,01	0,000	
		filter capacitors		at point	0,122	70%	3%	20	0,6%	0,70%	0,869	1	14,50%	100%	0,13	0,003	
		Energy		at point	0,792	80%	17%	20	3,8%	0,80%	4,762	4	14,50%	100%	0,69	0,115	
		Others		at point	0,086	89%	2%	20	0,4%	0,89%	0,479	1	14,50%	100%	0,07	0,001	
		Broth heating	HIDRATED	at point	0,009	65%	0%	20	0,0%	0,65%	0,067	1	100%	100%	0,07	0,000	
		Fermentation		at point	1,527	87%	32%	20	7,1%	0,87%	8,152	5	100%	100%	8,15	2,613	
		Distillation	ETHANOL	at point	1,350	98%	28%	20	6,3%	0,98%	6,451	5	100%	100%	6,45	1,828	
					4,763											4,671	4
WEF PLANT "X"																	
2	AGRICULTURAL SUGARCANE	Grouping of the polygons by region of the pluviometric station	D4-059	difuse	1,000	4,0%	21,7%	15,0	6,3%	0,04%	156,25	6	24%	100%	37,50	8,152	
			D4-012	difuse	0,800	5,0%	17,4%	15,0	5,1%	0,05%	101,27	6	24%	100%	24,30	4,227	
			D4-112	difuse	1,200	4,0%	26,1%	15,0	7,4%	0,04%	185,19	6	24%	100%	44,44	11,594	
			D4-074	difuse	0,700	3,0%	15,2%	15,0	4,5%	0,03%	148,62	6	24%	100%	35,67	5,428	
			D4-109	difuso	0,900	4,0%	19,6%	15,0	5,7%	0,04%	141,51	6	24%	100%	33,96	6,645	
					4,600											36,046	6
WEF AGRICULTURAL UNIT PRECESS																	
3	INDUSTRIAL	Ammonium (as N)		at point	0,058	65,0%		16	0,4%	0,65%	0,56	1	100%	10%	0,06	0,06	1
4	INDUSTRIAL	Urea (as N)		at point	0,077	56,0%		19	0,4%	0,56%	0,721	1	100%	6%	0,04	0,04	1
5	INDUSTRIAL	Ammonium Nitrate (as N)		at point	0,084	28,0%		21	0,4%	0,28%	1,423	2	100%	5%	0,07	0,07	1
6	INDUSTRIAL	Monoammonium phosphate (as P_2O_5)		at point	0,093	10,0%		23	0,4%	0,10%	4,027	4	100%	2%	0,08	0,08	1
7	INDUSTRIAL	Monoammonium phosphate (N)		at point	0,046	36,0%		19	0,2%	0,36%	0,671	1	100%	3%	0,02	0,02	1
8	INDUSTRIAL	Super Simple Phosphate (as P_2O_5)		at point	0,045	5,0%		15	0,3%	0,05%	5,982	4	100%	6%	0,36	0,36	1
9	INDUSTRIAL	Potassium Chloride (as K_2O)		at point	0,056	15,0%		25	0,2%	0,15%	1,490	2	100%	4%	0,06	0,06	1
10	INDUSTRIAL	Calcareous (hydrated lime)		at point	0,039	15,0%		27	0,1%	0,15%	0,962	1	100%	1%	0,01	0,01	1
11	INDUSTRIAL	Plaster		at point	0,048	30,0%		28	0,2%	0,30%	0,570	1	100%	2%	0,01	0,01	1
12	INDUSTRIAL	Fipronil		at point	0,089	95,0%		12	0,7%	0,95%	0,775	1	100%	8%	0,06	0,06	1
13	INDUSTRIAL	Carbofuran		at point	0,076	96,0%		14	0,5%	0,96%	0,562	1	100%	5%	0,03	0,03	1
14	INDUSTRIAL	Glyphosate		at point	0,037	85,0%		16	0,2%	0,85%	0,271	1	100%	2%	0,01	0,01	1
15	INDUSTRIAL	Tebuthiron		at point	0,029	63,0%		19	0,2%	0,63%	0,242	1	100%	4%	0,01	0,01	1
16	INDUSTRIAL	Hexazinone		at point	0,058	83,0%		21	0,3%	0,83%	0,332	1	100%	7%	0,02	0,02	1
17	INDUSTRIAL	Diuron		at point	0,077	95,0%		23	0,3%	0,95%	0,351	1	100%	1%	0,00	0,00	1
18	INDUSTRIAL	Imazapic		at point	0,084	63,0%		19	0,4%	0,63%	0,699	1	100%	4%	0,03	0,03	1
19	INDUSTRIAL	Trinexapac		at point	0,093	89,0%		15	0,6%	0,89%	0,692	1	100%	6%	0,04	0,04	1
20	INDUSTRIAL	Secondary sulfur		at point	0,046	53,0%		25	0,2%	0,53%	0,347	1	100%	4%	0,01	0,01	1
21	INDUSTRIAL	Lime (calcium oxide)		at point	0,045	56,0%		27	0,2%	0,56%	0,297	1	100%	1%	0,00	0,00	1
22	INDUSTRIAL	Sulfuric acid		at point	0,056	78,0%		28	0,2%	0,78%	0,256	1	100%	3%	0,01	0,01	1
23	INDUSTRIAL	Hydrated Lime		at point	0,039	67,0%		12	0,3%	0,67%	0,484	1	100%	2%	0,01	0,01	1
24	INDUSTRIAL	Flocculant (polyacrylamide)		at point	0,048	55,0%		14	0,3%	0,55%	0,621	1	100%	1%	0,01	0,01	1
25	INDUSTRIAL	Antibiotic (Kamoran family)		at point	0,089	13,0%		21	0,4%	0,13%	3,246	4	100%	5%	0,16	0,16	1

Appendix 3. WEF calculation to ethanol anhydrous produced at plant "X".

Unit Process	MEDIUM EFFLUENT FLOW (m^3/s)	AF2	$(WEF)_i$	COLOR CLASSIFICATION	$(WEF)_{x,i}$ = AF2 * $(WEF)_i$
Mill	4,763	45,271%	4,671	4	2,1146
Agricultural	4,600	43,722%	36,046	6	15,76
Producer of Amonia (as N)	0,058	0,551%	0,06	1	0,00031
Producer of Urea (as N)	0,077	0,732%	0,04	1	0,00032
Producer of Ammonium Nitrate (as N)	0,084	0,798%	0,07	1	0,00057
Producer of Monoammonium phosphate (as P2O5)	0,093	0,884%	0,08	1	0,00071
Producer of monoammonium phosphate (N)	0,046	0,437%	0,02	1	8,8E-05
Producer of Simple Super Phosphate (as P2O5)	0,045	0,428%	0,36	1	0,00154
Producer of Potassium Chloride (as K2O)	0,056	0,532%	0,06	1	0,00032
Calcareous Producer (hydrated lime)	0,039	0,371%	0,01	1	3,6E-05
Produced of plaster	0,048	0,456%	0,01	1	5,2E-05
Producer of Fipronil	0,089	0,846%	0,06	1	0,00052
Producer of Carbofuran	0,076	0,722%	0,03	1	0,0002
Glyphosate Producer	0,037	0,352%	0,01	1	1,9E-05
Producer of Tebuthiron	0,029	0,276%	0,01	1	2,7E-05
Producer of Hexazinone	0,058	0,551%	0,02	1	0,00013
Secondary Sulfur Producer	0,046	0,437%	0,01	1	6,1E-05
Producer of virgin lime (calcium oxide)	0,045	0,428%	0,00	1	1,3E-05
Producer of Sulfuric Acid	0,056	0,532%	0,01	1	4,1E-05
Hydrated Lime Producer	0,039	0,371%	0,01	1	3,6E-05
Producer of Flocculant (polyacrylamide)	0,048	0,456%	0,01	1	2,8E-05
Producer of Antibiotic (Kamoran family)	0,089	0,846%	0,16	1	0,00137
TOTAL	10,521			∑	17,88

References

Adami, M., Mello, M.P., Aguiar, D.A., Rudorff, B.F.T., Souza, A.F., 2012. A web platform development to perform thematic accuracy assessment of sugarcane mapping in South-Central Brazil. Remote sensing division (DSR), National Institute for space research (INPE). Rem. Sens. 4, 3201–3214. https://doi.org/10.3390/rs4103201.

ANA – National Water Agency, 2016. National Water Resources Information System (SNIRH). Quantitative-qualitative Water Balance [Portuguese-Brazil]. ANA, Brasília. http://portal1.snirh.gov.br/ana/apps/webappviewer/index.html?id=7cdec1481509484c98de92df11a9b562.

Armas, E.D., Monteiro, R.T.R., Amâncio, A.V., Correa, R.M.L., Guercio, M.A., 2005. The use of pesticides in sugar cane at the Corumbataí river basin and the risk of water pollution [Portuguese-Brazil] Quim. Nova 28, 975–982. https://doi.org/10.1590/S0100-40422005000600008.

Bare, J.C., 2010. Life cycle impact assessment research developments and needs. Clean Techn. Environ Policy 12, 341–351.

Bare, J.C., 2014. Development of impact assessment methodologies for environmental sustainability. Clean Techn Environ Policy 16, 681–690.

Bertoletti, E., Zagatto, P.A., 2006. Application of ecotoxicological tests and relevant legislation [Portuguese-Brazil]. In: Zagatto, P.A., Bertoletti, E. (Eds.), 2006. Aquatic Ecotoxicology: Principles and Application [Portuguese-Brazil]. Rima, São Carlos, pp. 347–382.

Bertoletti, E., 2013. Ecotoxicological Control of Liquid Effluents in the State of São Paulo [Portuguese-Brazil]. CETESB. ISSN 0103–2623. Available at: http://www.cetesb.sp.gov.br/userfiles/file/publicacoes/manual-controle-ecotoxicologico-2013.pdf.

Boxall, A.B.A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P.D., Haygarth, P.M., Hutchinson, T., Kovats, R.S., Leonardi, G., Levy, L.S., Nicols, G., Parsons, S.A., Potts, L., Stone, D., Topp, E., Turley, D.B., Walsh, K., Wellington, E.M.H., Williams, R.J., 2009. Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. Environ. Health Perspect. 117, 508–514.

Blottnitz, H., Curran, M., 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J. Clean. Prod. 15, 607–619.

Buikema Jr, A.L., Niederlehner, B.R., Cairns Jr., J., 1982. Biological monitoring. Part IV – toxicity testing. Water Res. 16, 239–262.

Cavalett, O., Chagas, M.F., Seabra, J.E.A., Bonomi, A., 2013. Comparative LCA of ethanol versus gasoline in Brazil using different LCIA methods. Int. J. Life Cycle Assess. 18, 647–658.

CEAPLA - Centro de Análise e Planejamento Ambiental; CEAPLA/IGCE/UNESP/Rio Claro- SP– Environmental Atlas. [Portuguese-Brazil]. http://ceapla2.rc.unesp.br/atlas.

Chen, Y.S., 2010. The drivers of green brand equity: green brand image, green satisfaction, and green trust. J. Bus. Ethics 93, 307–319.

D'Souza, C., 2000. Bridging the communication gap: dolphin safe eco-labels". Corp. Commun. Int. J. 5, 185–190.

Dorne, P.B., 1996. An industrial perspective on whole effluent toxicity testing. In: Grothe, D.R., Dickson, K.L., Reed-Judkins, D.K. (Eds.), 1996. Whole Effluent Toxicity Testing: an Evaluation of Methods and Prediction of Receiving System Impact. SETAC Press, Pensacola FL, pp. 16–37.

EIA - U.S. Energy Information Administration, 2013a. International Energy Statistics. US Department of Energy, Washington DC. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm.

EIA - U.S. Energy Information Administration, 2013b. Annual Energy Outlook 2013 with Projections to 2040. US Department of Energy, Washington DC. Available inhttp://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf.

GEN - Global Ecolabelling Network, 2015. What is ecolabelling? Available at: http://www.globalecolabelling.net/what_is_ecolabelling/. (Accessed 5 December 2015).

Guinée, J.B., 2004. Handbook on Life Cycle Assessment Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht, the Netherlands.

ILO – International Labour Organization, 2013. Report V. Sustainable Development, Decent Work and Green Jobs. ILO, Geneva. Available at:http://www.ilo.org/wcmsp5/groups/public/—-ed_norm/—-relconf/documents/meetingdocument/wcms_207370.pdf. (Accessed 19 April 2013).

INPE - National Institute of Space Research. Canasat. [Portuguese-Brazil]. Available at: http://www.dsr.inpe.br/laf/canasat.

ISO/DIS 14046.2 – Draft International Standard, 2013. Environmental Management — Water Footprint —Principles, Requirements and Guidelines. International Organization Standardization, Geneva.

ISO 14020, 2000. Environmental Labels and Declarations - General Principles. International Organization Standardization, Geneva.

ISO 14024, 1999. Environmental Labels and Declarations - Type I Environmental Labelling - Principles and Procedures. International Organization Standardization, Geneva.

ISO 14025, 2006. Environmental Labels and Declarations - Type III Environmental Declarations - Principles and Procedures. International Organization Standardization, Geneva.
ISO 14040, 2006. Environmental Management - Life Cycle Assessment — Principles and Framework. International Organization Standardization, Geneva.
Jacobson, T., Prevodnik, A., Sundelin, B., 2008. Combined effects of temperature and a pesticide on the Baltic amphipod *Monoporeia affinis*. Aquat. Biol. 1, 269–276.
Lozan, J.L., Grassi, H., Hupfer, P., Menzel, L., Schoenwiese, C.D., 2007. Global Change: Enough Water for All? Wissenschaftliche Auswertungen/GEO, Hamburg (Germany).
Marzullo, R.C.M., Matai, P.H.L.S., 2011. LCA in Industry: a process of sustainable evolution. In: Poster Presented in International Conference on LCA: CILCA 2011 – Coatzacoalcos – México.
Marzullo, R.C.M., Matai, P.H.L.S., 2012. Characterization of the life cycle inventories to assess the impacts of multiple uses of water by calculating the water footprint [Portuguese-Brazil]. In: Anais Proc. Third Brazilian Congress on Life Cycle Assessment, Maringá – SC. http://www.ctc.uem.br/iiicbgcv/congresso.php.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being Synthesis. Island Press, Washington, DC.
Monteiro, R.T.R., Armas, E.D., Queiroz, S.C.N., 2008. Leaching and Contamination of the Corumbatai River by Herbicides [Portuguese-Brazil], SBCPD 381p, Embrapa Maize and Sorghum, Congress of the Latin American Weed Association, 18, Ouro Preto, ISBN 8598410039, 9788598410036.
Morita, D.M., 2010. Prevention and Control of Water Pollution and Soil Pollution Caused by Hazardous Industrial Wastes [Portuguese-Brazil]. Habilitation thesis. University of São Paulo. Polytechnic School, Brazil. Available at: http://www.teses.usp.br/teses/disponiveis/livredocencia/3/tde-21022011-114327/en.php.
Muyssen, B.T.A., Janssen, C.R., 2004. Multi-generation cadmium acclimation and tolerance in *Daphnia magna Straus*. Environ. Pollut. 130, 309–316.
Mutel, C., 2012. Integrating GIS based regionalization into LCA calculations: the example of water. ETH Zurich, Institute for Environmental Engineering, Ecological Systems Design Group. In: 50th LCA Discussion Forum. Tuesday December 04, 2012. ETH Zurich, GEP Pavillon Available in: http://www.lcaforum.ch/Downloads/DF50/tabid/98/Default.aspx.
Nordborg, M., Cederberg, C., Berndesmodeling, G., 2014. Potential freshwater ecotoxicity impacts due to pesticide use in biofuel feedstock production: the cases of maize, rapeseed, salix, soybean, sugar cane, and wheat. Environ. Sci. Technol. 48, 11379–11388.
Noyes, P.D., McElwee, M.K., Miller, H.D., Clark, B.W., Van Tiem, L.A., Walcott, K.C., Erwin, K.N., Levin, E.D., 2009. The toxicology of climate change: environmental contaminants in a warming world. Environ. Int. 35, 971–986.
PCJ – Piracicaba, Capivari and Jundiaí Rivers Basins Agency, 2016. PCJ's Geographic Information System [Portuguese-Brazil]. PCJ Agency, Piracicaba (SP). Available at:https://sig.agenciapcj.org.br:9083/k2gisapp/map.
Ribeiro, I.C., Veríssimo, I., Moniz, L., Cardoso, H., Sousa, M.J., Soares, A.M.V.M., Leão, M.J., 2000. Yeasts as a model for assessing the toxicity of the fungicides penconazol, cymoxanil and dichlofluanid. Chemosphere 41, 1637–1642.
Rudorff, B.F.T., et al., 2010. Studies on the rapid expansion of sugarcane for ethanol production in Sao Paulo state (Brazil) using landsat data. Remote Sens. 2, 1057–1076. https://doi.org/10.3390/rs2041057. National Institute for Space Research (INPE), Remote Sensing Division (DSR), Sao Jose dos Campos, 12227-010, Sao Paulo State, Brazil.
Rubik, E.F., Frankl, E.P., 2005. The Future of Eco-labelling. Greenleaf Publishing, Sheffield.
Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Osterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. Science 287, 1770–1774.
Santos, M.A.P.F., 2008. Water and Sediment Quality Assessment of the Corumbataí River Sub-basin (SP) by Ecotoxicological Tests [Portuguese-Brazil]. Doctoral thesis. University of São Paulo. Center for Nuclear Energy in Agriculture, Piracicaba, Brazil. Available at: http://www.teses.usp.br/teses/disponiveis/64/64153/tde-18052009-110830/publico/Maria_Alice_Santos.pdf.
Swiss Centre for Life Cycle Inventories, 2009. Ecoinvent database. Version 2.0. Available. http://www.ecoinvent.org. (Accessed 10 November 2013).
Swiss Centre for Life Cycle Inventories, 2013. Ecoinvent database. Version 3.0. Available. http://www.ecoinvent.org. (Accessed 10 November 2013).
Thuiller, W., 2007. Biodiversity - climate change and the ecologist. Nature 448, 550–552.
USEPA - U.S. Environmental Protection Agency, 1985. Technical Support Document for Water Quality Based Toxics Control. USEPA, Washington, D. C.
WTO - World Trade Organization's, 2015. Agreement on Technical Barriers to Trade. Available in: https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm.
Wenzel, H., Hauschild, M., Alting, L., 1997. Environmental Assessment of Products. Kluwer Academic Publisehrs, Dordrecht, the Netherlands v.1 e 2.
Zagatto, P.A., Bertoletti, E., 2008. Aquatic Ecotoxicology: Principles and Applications [Portuguese-Brazil]. Editora Rima, São Carlos (SP).
Židonienė, S., Kruopinė, J., 2015. Life Cycle Assessment in environmental impact assessments of industrial projects: towards the improvement. J. Clean. Prod. 106, 533–540.