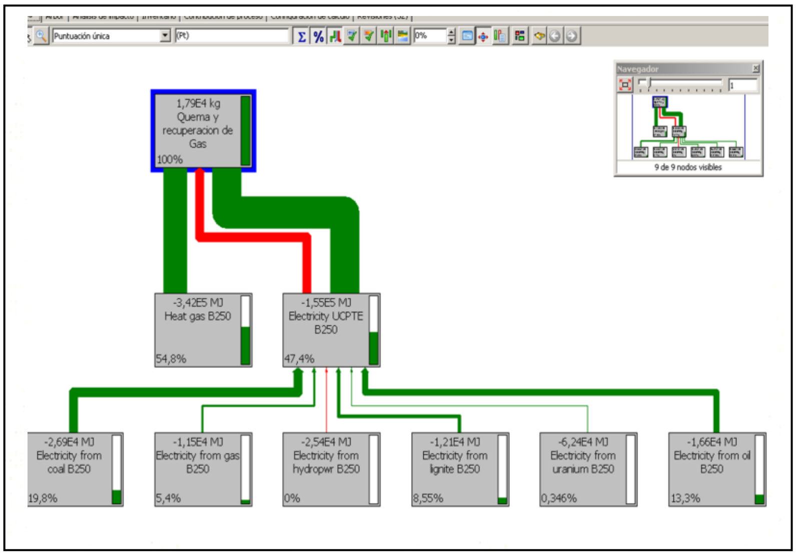
Field: Agri-business

Life cycle assessment for a sustainable agriculture



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Boosting Adult System Education In Agriculture - AGRI BASE

Erasmus+ K2 Action Strategic Partnership

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1. Introduction

Agriculture, like all human activity, involves an exploitation of the natural environment. For centuries, farmers have provided food to the population, while modeling the landscape and preserving crops, breeds and unique species. However, the process of agrarian intensification of the last century has brought with it a series of environmental, and even social, impacts. Intensive agriculture, with the search for greater productivity, mainly in economic terms, has sometimes led to the limit of ecosystems.

It is therefore necessary to re-establish the balance between agriculture, livestock and the environment. 80% of the territory of the European Union (EU), and therefore the conservation of natural resources, halt the loss of biodiversity or reduce the effects of climate change.

One of the most important environmental challenges arising from the intensification of agriculture is the preservation of soil fertility, the main patrimony of the farmer. In Europe, there is a large amount of agricultural areas with risk of medium-high desertification and / or organic matter levels below what is desirable to maintain its productive capacity.

Nor should we forget climate change, which contributes the agricultural sector with almost 10% of greenhouse gas emissions. Mitigating and adapting to their impacts is another urgent challenge, as no one suffers more directly than farmers and the climatic phenomena of livestock, such as floods and droughts, increasingly extreme.

But agriculture and the environment are not incompatible. Agriculture has been singled out by the EU as a key sector in halting the loss of biodiversity in 2020 (EC COM 2011).

A model must be pursued in which farmers and herdsmen produce healthy, quality food while properly managing the natural resources - soil and water - minimize and properly manage their waste and cope with the impacts of climate change.

There may be a general view among society that products from this type of intensive farming are harmful to the environment. In order to assess the environmental quality of a product, transparent, quantifiable and objective parameters must be set at maximum. These parameters should include aspects such as the consumption of biotic and abiotic resources, energy consumption, land use, harmful emissions to air, water and soil and potential toxicity to humans and ecosystems. This means accepting that the environmental quality of a product can not be defined with a single parameter, but with a series of values or indicators that the user and / or administration should prioritize.

The introduction of a product or service in the market carries with it a series of stages either ranging from its conception until its disappearance, directly or transforming itself into other products that have an impact on the environment in which they are developed. Aspects such as energy, economic, environmental, labor, etc., require a prior decision to minimize negative impacts that could arise.

In the last decades, companies has made great efforts to improve its environmental behavior. The companies are investing more resources in monitoring and minimizing consumption and emissions in the production plant, in a scenario characterized by a constant increase of the legislative pressure in environmental matters and by the increasingly demanding consumers (Iglesias, 2004).

Less often, the limit of what happens inside the production process is transferred and it is analyzed that it occurs "upstream" and "downstream" of the productive process. In general, companies have been worried about a cost-effective analysis of the product, valuing the price of materials, employees, labor, hours of work and final price of sale to the public, among many other variables. It is now a matter of including in the total cost of the product or service the costs associated, directly or indirectly, with the environmental impacts originated in the whole life cycle, the so-called eco-costs.

2. What is Life cycle assessment?

The key tool for analyzing the globality of the system and evaluating the major environmental impacts of a product or service is the life cycle assessment. The ACV examines environmental aspects and potential impacts throughout the life cycle of a product or activity. The life cycle of a product or service considers the entire "history" of the product or service, from its origin as raw material until its end as waste. All intermediate phases such as transportation and preparation of raw material, manufacturing, transport to markets, distribution, use, etc. are taken into account (Antón Vallejo, 2004).

In a complete LCA, the products or services are attributed all the environmental effects derived from the consumption of raw materials and energy needed for their manufacture, the emissions and residues generated in the production process as well as the environmental effects from the end of life of the product When it is consumed or can not be used. The tendency of this tool is to evaluate the product or service "from cradle to grave". LCA is a system that analyzes a by-product "from the cradle to the grave", regarding to the production and management. It starts on the acquisition of raw materials and ends on the waste management.

From the environmental point of view, management of industrial and agricultural productions is always a beneficial option in order to achieve the sustainability of the system. In this regard, one of the main predictive tools for reaching a holistic environmental management is the Life Cycle Assessment. The LCA allows selecting the option with greater sustainability and consequently a lower environmental impact from those suitable alternatives that take into account production, management and abandonment of a by-product and/or waste. Numerous studies related to the LCA in products, processes and paths conducted in different topics and locations highlight its relevance.

Since the growing ecological awareness among the whole society, methods such as LCA which aims the minimization of the environmental impacts have been welcome. The industrial and business sectors are already implementing these methods, not only due to the environmental improvements but also thanks to the greater understanding that they provide related to the materials and energy flows. Therefore, they are usable tools that companies use to identify the critical points of the process. It can be mentioned that the European Parliament has asked the European Commission for developing the basic framework of a policy-oriented product by the LCA.

The ACV is a tool beyond the purely environmental decision, since it encompasses all inputs and outputs, direct or indirect, allowing to handle all environmental factors. In addition the methodology used is quantitative, so that the decision-making can be applied, before making a decision, since the results delivered match the objectives.

It also accounts for the concern for the environment and economic benefits in the analysis of traditional accounting management, delivering a new management tool to companies.

The ACV is an essential tool for the implementation of programs of management and eco-labeling. The LCA provides a unifying, scientific and transparent basis. This basis is directly related to environmental impacts at all stages through which a product crosses and is therefore sensitive to changes in the market and to technological advances.

In the future, this tool will be the basis for evaluating those products that are able to enter international trade, since the developed countries will not be willing to finance pollution, since they themselves are making strong investments in these aspects (García Salmones, 2003).

A company that is consistent with a correct environmental thinking and with the current legislation should follow the next steps in its environmental management, to advance in this aspect. First comply with the legislation, then implement an EMS, then carry out an ACV of your product or service and finally aim for eco-efficiency, which is to obtain the same or better performance with fewer resources and generating less pollutants (discharges, emissions, Etc.) or contaminants that are simpler to manage.

Figure 6.3. Presents the steps that a company would have to follow in order to implement an EMS and an EMS system.

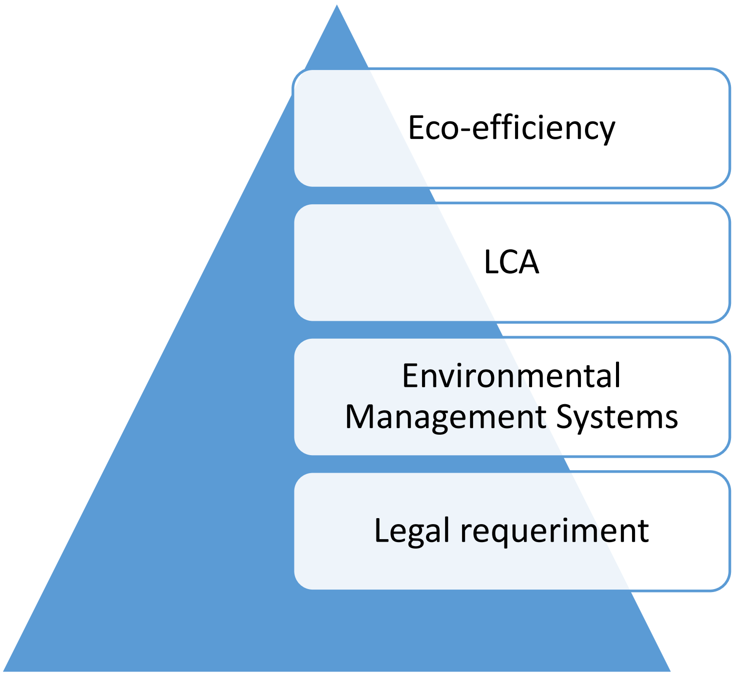

Figure 6.3. Pyramid that a company will follow for the implementation of an EMS

3. PHASES OF THE LCA

A LCA study consists of four steps:

- Purpose and scope
- Inventory analysis
- Impact analysis
- Interpretation

The main technique used in LCAs is the creation of models. In the introductory phase, a model of the complex technical system used to produce, transport, use and eliminate a product was elaborated. This results in a flowchart or process tree with all relevant processes. In general, all relevant influxes and flows are collected, as in many cases it is difficult to interpret.

During the stage of the interpretation of the impact in the life cycle, a totally different model is used to describe the relevance of inflows and inflows. For that, a model of an environmental mechanism is used. With the use of several environmental mechanisms, the outcome of the LCA can be translated into several categories of impact.

3.1 Purpose and scope

In this phase the subject of study is defined and the reasons that lead to it are included. Also in this phase the functional unit is established. The functional unit describes the main function of the analyzed system. An ACV does not serve to compare products among themselves, but services and / or quantities of product that carry out the same function. For example, it is not worth comparing two different kilos of paint that do not serve to perform the same function, covering an equivalent area with a similar duration.

In the case of agricultural systems the main function is food production. In these cases, normally a functional unit is considered one kilo of fresh product. The functional unit provides a reference in respect of which the inputs and outputs of the system can be normalized in a mathematical sense.

We can classify the functional unit into two types:

• Of physical type: For example 1.000 kg of paint. In this case, the emission results will be expressed, for example, as the functional unit of CO_2 weight emitted per 1,000 kg of paint.

• Functional type or efficiency of the product: For example, the liters of paint needed to paint a square meter of wall. In this case, the results of the parameter are expressed as unit weight of CO_2 emitted per square meter of pairs.

The functional unit may include durability of the product or compliance with quality standards.

Due to its global nature a full LCA can be very extensive. For this reason, limits should be established that should be perfectly identified. The system boundaries determine that unit processes should be included within LCA. Several factors determine the limits of the system, including the intended application of the study, the hypotheses raised, the exclusion criteria, the economic data and limitations and the intended recipient.

The purpose and scope of a LCA study should be clearly defined and consistent with the intended application. In this phase the scope and contents of the following aspects are fixed:

• Objective: The objective of a LCA study should indicate unambiguously the intended application, the reasons for carrying out the study and the intended recipient, ie who is going to communicate the results. The definition of the partial objectives should include the use of the results of each objective, as well as the persons responsible for the information.

• Scope: The definition of the scope of ACV establishes the limits of the evaluation, ie, which is the system to be studied and which evaluation method will be used. The scope must be sufficiently well defined to ensure that the depth and level of the study are compatible with the objective set out above. Generally and depending on the type of study, the iterative nature of the LCA may need to be reviewed and, if necessary, modified while the study is under development to reviews.

• Functional unit: As already mentioned, the evaluation is performed on the basis of unit of measure defined in each case. The functional unit sets the quantity of product to be used. All information used during the inventory phase will be related to the functional unit.

• System limits: Inputs and outputs are defined in relation to the limits of the system that defines the process or processes that are part of the LCA. It should be kept in mind that during the ACV the actual progress of the work performed, it may advise to modify the boundaries between processes. That is, the limits are not a rigid definition. As already indicated above, not only processes between them define the limits, but also the field of application if it refers to the environment of the company or is an open global LCA.

• Data quality: The outcome of the LCA is a direct function of the quality of the data, its reliability and accuracy. The subsequent final outcome of the LCA will be affected by the quality of the data. It is highly advisable that the quality of the data is not only a value in itself, but its readiness and ease of checking, checking, etc. For this reason it is convenient that the data collection is done in an orderly manner and containing fields of the type:

data source, responsible person, date, quantities, units, etc. All this allows you to consult in a simple and quick.

3.2 Inventory Analysis

At this stage, the data collection and the definition of the procedures for calculating the inputs and outputs of the system are performed throughout all stages of the product life cycle. This is one of the most delicate stages, since there are no databases adequate to the characteristics of each state and each company.

The analysis defines the inputs and outputs of the system to the environment, the limits of study, the functional units, etc. The study validation depends on the quality of the data used in the life cycle inventory. Indeed, the best system of life-cycle assessment is done with data collected experimentally in situ since LCA has a very important local component. Furthermore, the LCA is able to run using information from databases and literature if experimental data are missing. For that reason, the choice of databases has a great relevance. The database Ecoinvent © (Frischknecht et al., 2007) contains an inventory lifecycle result set from several Swiss institutes. It updates and involves databases very known such as ETH-ESU 96 (Frischknecht et al. 1996) and BUWAL 250 (Buwal, 1998), among others.

This phase comprises obtaining the data and calculation procedures to identify and quantify all adverse environmental effects associated with the functional unit. In a generic way we will call these environmental effects "environmental burden". This is defined as the output or input of matter or energy of a system causing a negative environmental effect. This definition includes both emissions of pollutant gases, water effluents, bad waste, consumption of natural resources, noise, radiation, odors, etc. When working with systems involving several products, this phase will assign the flows of matter and energy as well as the emissions to the environment associated with each product or by-product.

The steps to be performed within this second phase are as follows:

• Establish the process flow diagram: A block diagram should be drawn up stating the stages in the process under study. The flow chart should be as wide as you want according to the objectives and goals and data collection and above all be very clear the limits that are set and not include anything that is not within it.

• Data collection: The collection of data must be done in a planned and organized way as it is the basis of the final result. This is an activity that guarantees a quality in the final results takes a lot of time and effort. This aspect is directly related to the level of detail required by each process. Parallel and to indicate on the flow chart must include a mass analysis.

• Perfecting or debugging system boundaries: After initial data collection, the previously specified system boundaries must be redefined, as they can be redefined as a consequence of the decisions in the previous subphase. This may be a consequence of checking that certain values are not significant or that certain sub-processes that have been included have been found to have no influence on the purpose of the LCA.

• Data processing: It is very important that the data that is obtained is processed properly to obtain clear results from them. It is advisable in this sub phase to use electronic spreadsheets or programs already on the market designed specifically for LCAs.

• Interpretation of data: This sub phase analyzes the data collected and is compared with the objectives and scope of the studies. For example, if you are analyzing an emission of a certain element, the unit of measurement can be ppm, in mg / Nm3, etc. But to compare it with the objective the positive thing would be to see the number of times that this emission surpasses or not the lack with respect to the allowed emission. Here the quality of the data takes on greater importance, so the analysis must contain aspects such as its coverage with respect to time, technology, geography, precision, depth, representativeness, coherence, uncertainty, etc.

3.3 Impact analysis: classification, characterization, standardization and assessment

Assessment of potential environmental impacts, using life cycle inventory data. This process relates the causes: environmental burdens (represented by the inputs and outputs of the system) and the effects on the environment: environmental impacts.

The objective of this phase is to interpret the data obtained in the inventory, analyzing and then evaluating the impacts produced by the environmental loads identified.

To do this and the previous phases in a correct way, it has had to iterate in order to identify the most influential parts in the process, this fact is not reflected in this documentary part of the work, but it must be taken into account at the time of Interpret the results obtained from it.

The elements that comprise this life-cycle impact assessment will be those determined in the SETAC nomenclature (elements with slight modifications to the ISO nomenclature). The steps to follow will be, classification, characterization, normalization and valorization. These phases include a series of studies and external data.

In the classification sub-phase, the environmental loads of the system are assigned to the different impact categories according to the type of expected environmental effect. To do so, it will be necessary to define those categories considered as most relevant, in order to be able to cover the impacts produced according to the data obtained in the environmental phase.

In order to obtain environmental indicators, it will be necessary to apply models to impact categories, this will be the main objective of the characterization. There are several models to perform this characterization, in our case we will develop the way of working more used, in it, the data of the different environmental loads are added within an impact category using weight factors or equivalence that are called " characterization". With this characterization we will be able to obtain a single value, environmental indicator for each impact category.

The result of the characterization is an "environmental profile" of the system in question, composed of the set of environmental indicators of all impact categories. Different groups of research in the international field have been developing different groups of characterization factors.

The impact assessment techniques transform the result from an inventory into a list of few data. They are interpreted based on their ability to affect the environment. The evaluation is carried out using a number of categories of impact (which varies depending on the method chosen), such as the reduction of the ozone layer, acidification, nitrification of water, toxicity or depletion of resources. This assessment involves the characterization and standardization which will be used in this study.

The characterization aims to implement the modelling of the impact categories taking into account environmental indicators such as ISO 14044: 2006, which are described as a quantifiable representation of an impact category. One way to characterize the inventory data, that is to transform the results assigned to the LCIA into the common unit corresponding to the indicator of the category, is to multiply every substance that contributes to every category of impact for its characterization factor. This factor indicates the relative contribution of the substance to the category of impact. For instance, the characterization factor for CO_2 at Climate Change Impact Category may be equal to 1, whereas the characterization factor for CH_4 would be 21. This means that the emission of 1 kg of methane affects to the climate change in the same way that 21 kg of CO_2. These characterization factors must be scientifically justifiable and internationally accepted. The indicators of an impact category will be the sum of contributions by all substances that are part of this category. In this way, an environmental profile of the system can be obtained and involves the set of environmental indicators from the considered categories of impact.

In the table below, we see an example of characterization for global warming and acidification. With the data obtained from the environmental inventory, classifying the data according to the categories determined in the previous section, the values of the characterization can be obtained.

Tabla 1. Characterization for Global Warming and Acidification

Element	Global warning	Acidification
CO_2	1	
CH_4	35	
N_2O	260	
NO_X		0.70
SO_2		1
NO_2		0.70
NH_3		1.88
HCL		0.88
HF		1.60

The normalization phase, includes a series of techniques to evaluate the significance of the environmental profile obtained in the characterization. In other words, we will be able to put each category of impacts on the same scale of importance in order to be able to evaluate the results later.

According to the SETAC, the characterization data are normalized by dividing them by the actual or predicted magnitude of the corresponding impact category for a geographic area and a moment in the reference time.

Finally, within the impact assessment we have the evaluation of the results obtained. In this phase the relative importance of the different categories of impact is evaluated qualitatively or quantitatively. The way to do it will depend on the data that we have to carry out the valuation. Valuation factors for each category will be derived based on other values that are considered important, such as monetary values (cost of restoring environmental damage), or other criteria imposed by management or proposed by a panel of experts. It will be very important to note that these valuation factors will change with time and space.

3.4 Interpretation

At this stage, with the results of the previous ones, and bearing in mind the previously defined objectives and scope, the conclusions of the study and, if pertinent, the product improvement recommendations are determined. It may include so-called sensitivity analyzes, which examine how changes in the value of certain parameters of the system studied affect the results of environmental impact.

Interpretation is the phase of a LCA in which inventory analysis results are combined with impact assessment. The results of this interpretation can take the form of conclusions and recommendations for decision-making. It allows determining in which phase of the product life cycle the main environmental loads are generated and therefore points of the system evaluating can or should be improved. In cases of comparison of different products it will be possible to determine which presents a better environmental performance.

4. LCA methods

There are several methods for conducting LCA that vary among countries, trends, categories of impact and characterization values within categories. We recommended the CML-IA method, due to:

(a) the CML-IA deals with the problem from an intermediate view,

(b) impact categories included in the CML-IA method are used in many LCAs studies,

(c) the baseline-standard indicators are based on the principle of the best available practice or 'problem-oriented approach' and

(d) are suitable for simplified studies.

The method provides a list of categories of impact grouped into:

(a) categories of mandatory impact (category indicators used in most LCAs),

(b) additional impact categories (operational indicators that exist but are rarely included in studies LCA) and

(c) other impact categories (there are no operational indicators available, thereby it is impossible to include them in a quantitatively way into the LCA).

The categories more used in agriculture are:

Abiotic depletion. This impact category is concerned with the protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

Global warming. Climate change can result in adverse affections upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale.

Acidification. Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

Eutrophication (also known as nitrification). It includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Nitrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO_4 equivalents per kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale

5. Applications

5.1. Study case 1. Life cycle assessment of the wetland for slurry depuration

The swine livestock is present in almost all the Spanish surface, especially in Aragón, Catalonia and Murcia. The number of animals in the Región of Murcia (census 2015: 2,084,784 pigs) is the third in Spain, only Lleida and Huesca having a bigger livestock. This quantity of pigs generates an annual production of 6.5 Hm3 of slurries (Ministry of Environment, May 2009). For the great amount of pig farms in the Región of Murcia (due to a high demand of pig production), the intensive pig production suppose an important environmental impact. This great amount of farms entails an associate problem due to the big amount of produced slurry, and has to be correctly managed in order to avoid an environmental damage.

The slurry average composition, with a high content of N and moisture (≅ 95%), gives it an added value for agriculture. Agronomic application of manure is one of the most respectable practices for the environment, if it does not imply a pollution problem. There are many management systems for slurry treatments; i.e. the direct use of slurry in the fertilization of soils (agricultural valorization), mechanical separation of phases to reduce volume and subsequent land application as amendments (phase solid) or the irrigation system (liquid phase), biological treatment (anaerobic or aerobic digestion), composting, cogeneration plants, and so on (Gonzalez, 2003).

Not in all cases we can apply the same choice; it is necessary to seek a viable alternative for each case. One of the most economical choices, and therefore more interesting, is the agricultural valorization through direct application to the field. However, this alternative is feasible as long as you have enough useful agricultural surfaces and a controlled application is considered (Daudén and Quilez, 2003). This control involves not to exceed the limits set by the directive of the European Council EU 91/676/EEC of 12 December 1991, developed in Spain by "Real Decreto 26/1996" of 16 February (BOE n ° 61 March 11) to prevent pollution of water by the effect of nitrates from agricultural activities. That is why the quantity and quality of manure produced, and the distance to the fields, is attenuating in this management alternative.

In the case of hypothetical problems with these limitations, the use of constructed wetlands has emerged as an attractive option to manage this byproduct. Constructed wetlands are waterwater treatment systems that allow the removal of pollutants by means of physical, chemical and biological mechanisms. Basically, in these wetlands there is a horizontal flow of the liquid fraction of slurry to result in a cleaner liquid, suitable for irrigation. Constructed wetlands have been widely used to treat wastewater, both domestic and industrial, as well as to improve water quality (Hammer, 1989; Vymazal, 05). The wetlands treatment helps to reduce the volume of slurry poured directly into the field, and provides an agronomic effluent with higher quality that can be used as nutrient solution. This management option in low rainfall areas such as Southeast Spain (<300 mm per year) also provides an additional water injection.

From an environmental point of view, the management of a byproduct should be always a beneficial option and should pursue the sustainability of the system. In this sense, one of the best environmental predicitive tools is life cycle assessment (LCA). The study of production, management and disposal alternatives for a product and its analysis with a LCA can be very important; you can choose the most sustainable option and therefore the one that generates the smallest environmental impacts. Many researchers have used this methodology for products and processes, in different fields and locations. The papers of LCA in slurry treatment of Lopez-Ridaura et al. (2009) and the review of LCA in agriculture and food reported by Roy et al. (2009) and De Vries et al. (2010) should be taken into account.

This e deals with the use of LCA methodology for one of the different manure management alternatives, specifically the subsurface horizontal flow constructed wetland. The study of the inputs and outputs of these wetlands try to characterize the wetlands process and constructions in different environmental impact category.

Goal definition and scope

Before the slurry goes into the wetland, it is gone on a pretreatment. First, there is a slurry tank where raw slurries from several farms are mixed together, then the raw slurry passes to a worm gear solid-liquid separator, which removes most of the solid fraction (to be composted), leaving only a stream with the liquid fraction of slurry, which will be treated into the wetland. This pretreatment is to prevent the possible clogging of the wetland, achieving a more effective treatment and increasing the useful life.

The wetland consists in a pool of 25.0x2.5x1.0 m^3 (=63 m^3). After the excavation, the pool is armed with 200 kg/cm^2 concrete, and covered with ethylene propylene diene monomer rubber (EPDM rubber) of 2 mm of thickness for waterproof. The pool has three zones. The surface area receives the liquid fraction from the sludge clarifier. This area is in contact with the profile of the wetland, so that infiltration can happen, and lies immediately above the wetland, having the same height and width, and a length of 2.5 meters. After this zone, and separated by a stonewall, it is the effective wetland, 20 meters long and with two matrixes; the lower with 80 cm of washed gravel of 40 mm of diameter and the upper matrix with 20 cm of washed sand. The sand layer is a physical support for the plant, *Phragmites australis* (reed), that carries out the main removal of the pollutants. The density of planted reed is 10 plants/m^2. The gravel layer is the active layer, where the plant rhizomes lie down and where the slurry passes through. The wetland has a slope of 0.05, ending in a PVC pipe that carries the resulting liquid into a reservoir (2.5 m long), for its accumulation, forming the third area of the pool. The detailed description of the wetland, as well as tests in terms of plant species, hydraulic retention time and materials used have been issued in Caballero et al. (2009).

The nutrient-rich fluid leaving the wetland has been physical-chemically characterized, and it will be referred as a nutrient and irrigation water. The processes included in the study were set from the liquid fraction entering the wetland. The average hydraulic retention time (i.e., the time that the slurry is retained in the wetland) is 12 weeks. For make the LCA of this system has been chosen as the functional unit 1 m^3 of slurry.

Inventory analysis

The variables considered for the life cycle assessment are shown in Tables 2, 3 and 4. Table 2 shows the inputs, taking into account both the product to be purified and construction to be carried out, considering the useful life and the functional unit.

Table 2. Inputs

Influent (m^3)	
Liquid Slurry	1
Rain water	0.53
Composition of the liquid fraction of the slurry (mg/L)	
Magnesium	41.10
Calcium	160.44
Ion potassium	1238.67
Ion sodium	350.38
Sulfate	84.20
Bromide	4.67
Chloride	667.30
Nitrate	91.58
Organic nitrogen	311.37
Ion ammonium	1373.01
Nitrogen	1684.38
Zinc	13.41
Copper	2.19
Phosphate	104.00
Phosphorus pentoxide	76.74
Phosphorus	34.87
Suspended solids	16042.33
COD (chemical oxygen demand)	5379.73
Construction materials	
Excavation with hydraulic digger (m^3)	0.068*

EPDM (kg)	0.219*
PVC pipe (kg)	0,006*
Gravel (kg)	88.6*
Concrete nor reinforced (kg)	0.0458*
Sand (kg)	69.95**

*Data divided by the 30 years of useful life (1 m^3 slurry); **data divided by the 8 years of retirement and reposition (1 m^3 slurry)

Table 3 presents the data of the direct emissions to the atmosphere, taken from Loyon et al (2007):

Table 3. Air direct emissions (Loyon et al, 2007)

Air emissions (kg/m³ slurry)	
Ammonia	0.166
Carbon dioxide	4.360
Methane	3.574
Nitrogen oxides	ND*

*ND: not detected

In Table 4 has also been considered the waste disposal for plant recycling and sand each 8 years.

Table 4. Outputs

Effluent (m³)	
Water	0.836
Composition of the effluent (mg/L)	
Magnesium	89.51
Calcium	100.52
Ion potassium	949.95
Ion sodium	364.00
Sulfate	192.91
Bromide	1.13
Chloride	620.09
Nitrate	645.19
Organic nitrogen	87.73
Ion ammonium	604.93
Nitrogen	692.66
Zinc	0.45
Copper	0.15
Phosphate	23.63
Phosphorus pentoxide	17.44
Phosphorus	7.46
Suspended solids	1005.19
COD (chemical oxygen demand)	1010.61
Disposal to treatment (kg)	

Disposal, biowaste, to agricultural co-fermentation	2.574
Waste inert to landfill (sand)	69.95
Concrete	0.05
Waste to land (kg)	
Amount of soil waste of the excavation	177.32

Impact assessment and interpretation

Fig. 2 shows the characterization of each impact category expressed as total percentage, including the wetland process and building. As it can be seen, the wetland process has a great importance in the case of abiotic depletion, acidification, eutrophication, global warming and photochemical oxidation. These results are coincident with those reported by Renou et al. (2008) for a wastewater plant, in respect to acidification, eutrophication and climate change or global warming. Although these authors also found a similar pattern for toxicity category, our study showed a negative and smaller impact for the wetland process than that reported by building. Also the civil work represented a larger contribution in the abiotic depletion and ozone layer depletion impact categories.

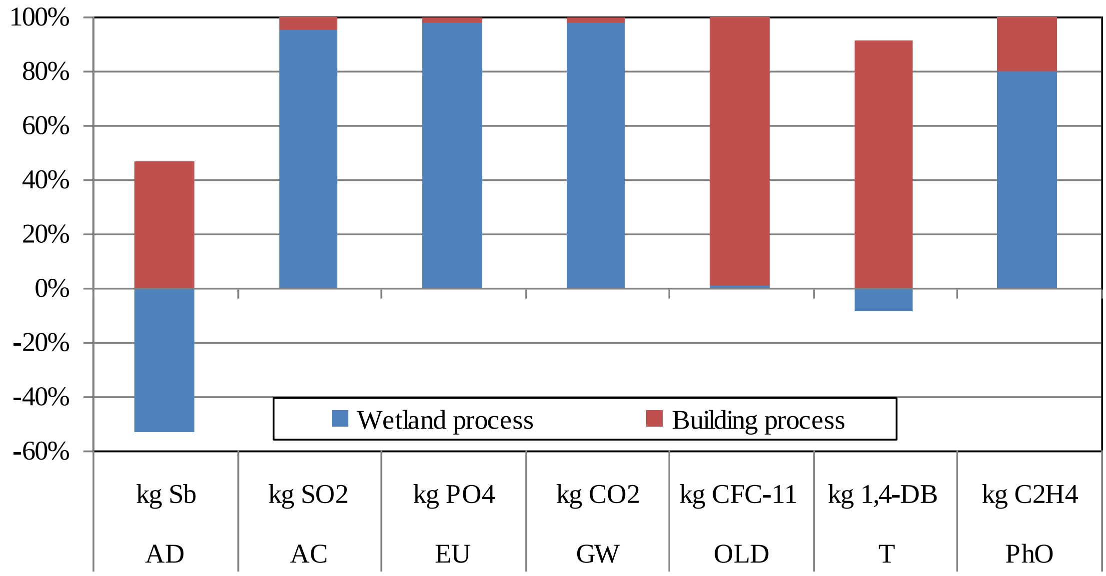

Fig. 2. Percentage of impacts associated with abiotic depletion (AD), acidification (AC), eutrophication (EU), global warming (GW), ozone layer depletion (OLD), *toxicity (T), and photochemical oxidation (PhO), for the wetland process and its building.*

Fig. 3 shows the data of acidification and global warming for both wetland and building processes. The acidification impact category proved to affect the four areas of protection; i.e. human health, natural resources, natural environment and man-modified environment. However, the climate change impact affected all areas except natural resources.

If we focus on the wetland process for both cited impact categories, the biggest damage is caused by the process itself, being important the negative values obtained by avoided products, such as irrigation water or fertilizers as N, K, and P in a lesser extent. This fact makes the final balance not as bad as it was expected. Similar results were found by López-Ridaura et al. (2009) for slurry treatment.

On the other hand, the high equivalence factor for ammonia emissions within the acidification impact category (Huijbregts, 1999) resulted in a high impact by the wetland process. The same conclusion can be drawn for climate change, with a high impact due to carbon dioxide and methane generated during the wetland process, and considered important factors for global warming characterization (Council Directive 2008/1/EEC, 2008).

For the building process, all impacts proved to be positive for acidification and climate change. The EPDM rubber, gravel and sand were the major contribution factors. The reason for the importance of these materials is that it is necessary a great amount of them compared to the rest, also generating a great amount of wastes, together with their transport for recycling or manufacturing.

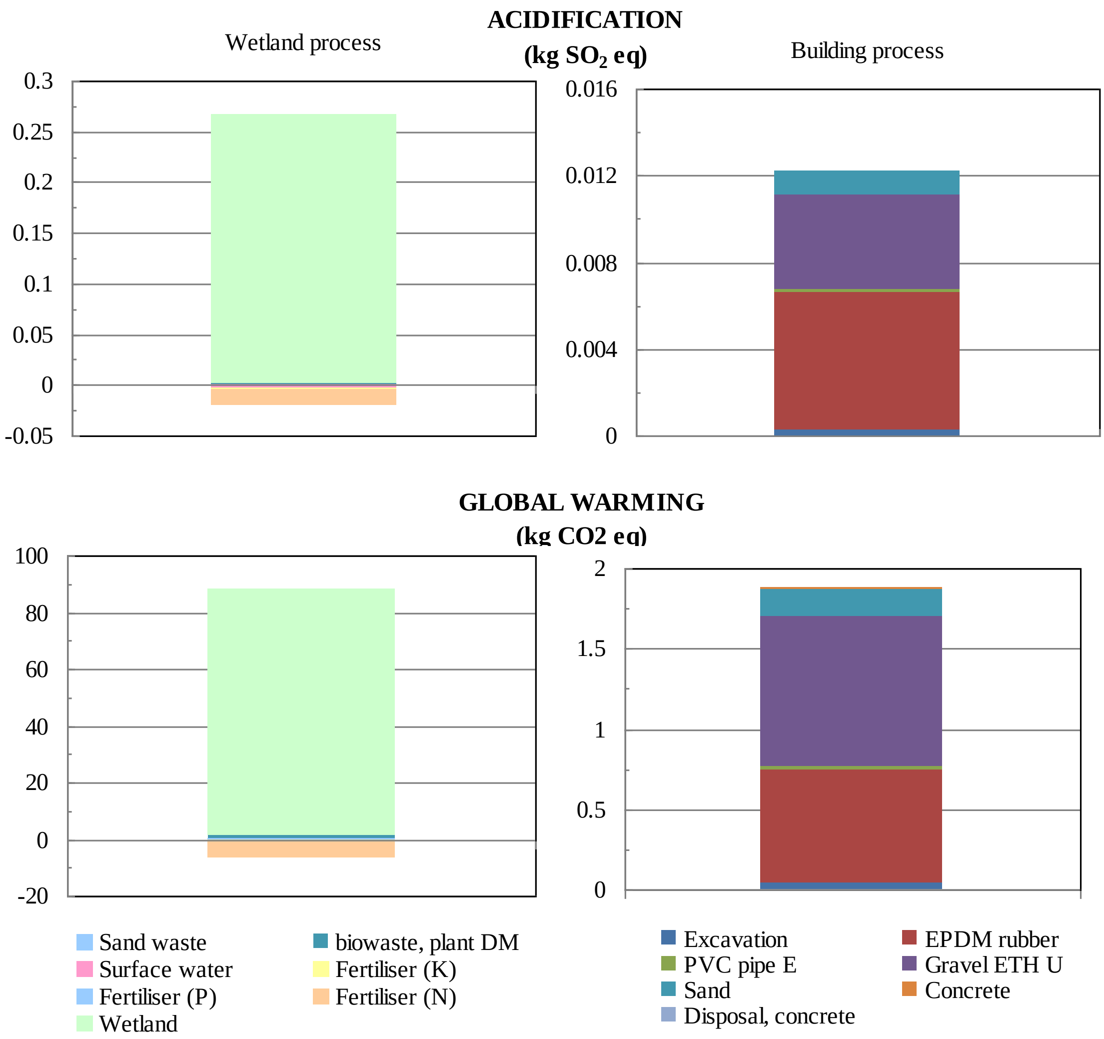

Fig. 3. Contribution of the different component of wetland process and wetland building to acidification and global warming impact categories expressed per m^3 of treated slurry.

Fig. 4 shows the data for the impacts associated to abiotic depletion and toxicity, both for wetland process and construction. The abiotic depletion impact category affects the protected areas, natural resources, natural environment and man-modified environment. However, toxicity affects the areas of protection, human health, natural resources and natural environment.

In the case of abiotic depletion, avoided products make the wetland process takes a negative value, since they reduce the impact that would cause the manufacture of fertilizers, in terms of resources and energy. The highest values occur both for nitrogen, potassium and irrigation avoided.

For the toxicity associated with the wetland process, the largest negative values were due to avoided irrigation water, followed by sand waste and biowaste plant DM, in this last case with negative impacts (positive values). The residues from the recycling of these products are those that affect this toxicity. However, although the effluent had heavy metals, the concentrations were so small that is not reflected in the comparative data.

For the wetland construction, as for global warming and acidification, the biggest impacts on abiotic depletion and toxicity were originate with EPDM rubber, gravel and sand, possibly due to the reasons raised above.

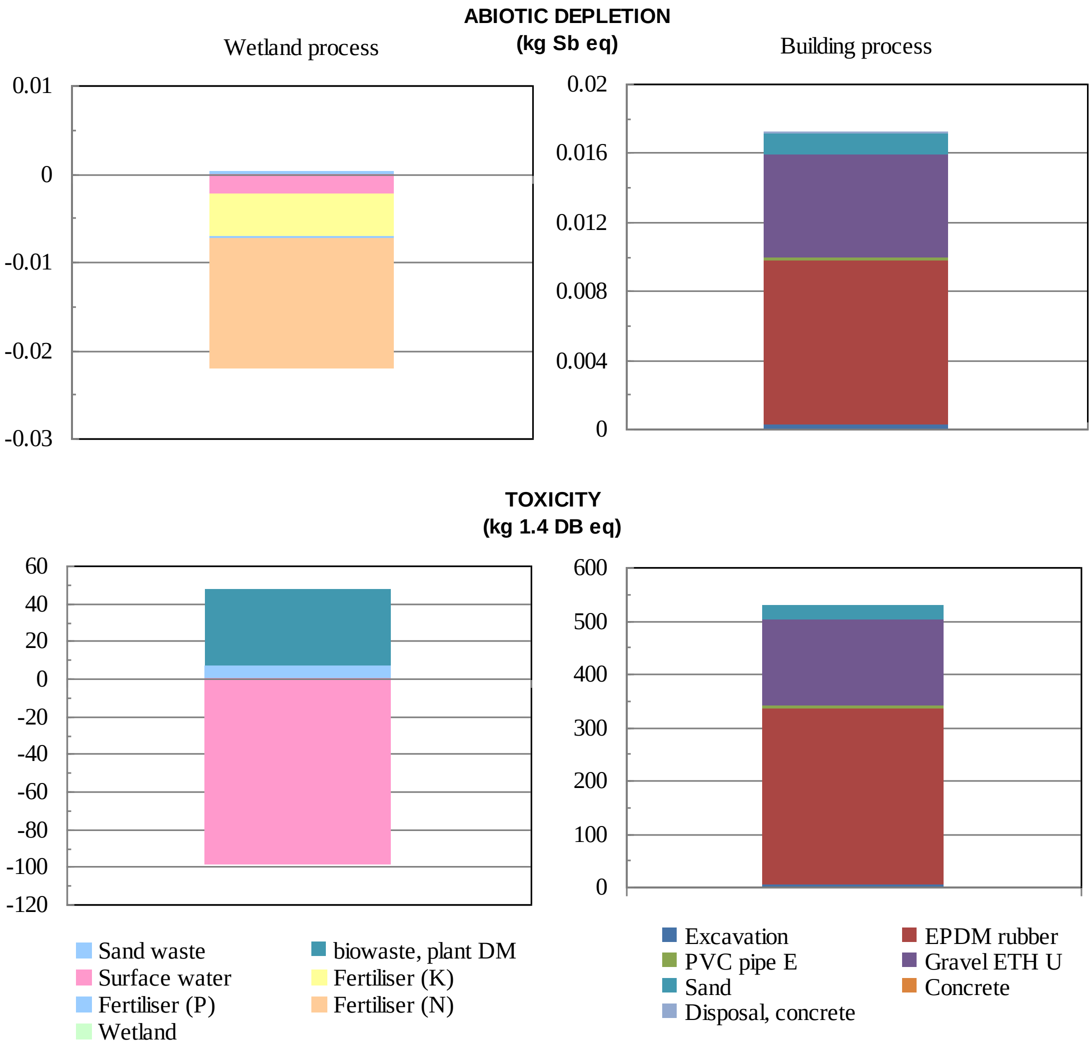

Fig. 4. Contribution of the different component of wetland process and wetland building to abiotic depletion and toxicity impact categories expressed per m^3 of treated slurry.

Conclusions

As we have seen, the use of environmental impact predictive tools, such as life cycle assessment, allowed us to characterize the impact categories, in products and processes, of slurry management.

In this paper, the use of natural wetlands for final slurry treatment has been studied in order to assess the impacts on the treatment process and construction. The impacts associated to wetland process proved to be higher than those of the construction, except for the category of toxicity and abiotic depletion. The quantitatively biggest impacts were due to emission gases in the process, reflected in the categories of acidification and global warming. The high environmental benefit obtained with the reincorporation of the purified slurry to the ground and the consequent saving of mineral fertilizer caused that degradation of the waterproof plastic and building materials to be offset in the overall balance, particularly reflected in the toxicity and abiotic depletion impact categories. For the wetland construction, the biggest impact was for the toxicity impact category, and it was associated with the waste generated (EPDM rubber, gravel and sand) as well as transport for its manufacture and recycling.

5.2 Study case 2. Life cycle assessment of the use of pig slurry as fertilizer

The slurry average composition, with a high content of nitrogen and about 95% moisture, gives it an added value for agriculture. Agronomic application of manure is one of the most respectable practices for the environment, if it does not imply a pollution problem. There are many management systems for slurry treatments; i.e. the direct use of slurry in the fertilization of soils (agricultural valorization), mechanical separation of phases to reduce volume and subsequent land application as amendment (phase solid) or the irrigation system (liquid phase), biological treatment (anaerobic or aerobic digestion), composting or cogeneration plants (Gonzalez, 2003).

One of the most economic and interesting choices is the agricultural valorization, by its direct application to the field. However, this alternative is feasible as long as enough useful agricultural surfaces and a controlled application be considered (Daudén and Quilez, 2003). This control implies not exceeding the limits set by the European Council Directive 91/676/EEC of 12 December 1991, translated into Spain as Real Decreto 26/1996, to prevent water pollution by the effect of nitrates from agricultural activities.

From an environmental point of view, the management of a by-product should be always a beneficial option and it should pursue the sustainability of the system. In this sense, one of the best environmental predictive tools is life cycle assessment (LCA). The study of production, management and disposal alternatives for a product or a by-product by LCA allows choosing the most suitable option, thus generating the smallest environmental impacts. Some researchers have already used this environmental tool for slurry treatment (López-Ridaura, 2009; Gómez-López et al., 2010a and 2010b), as well as for agricultural and food processes (Roy et al., 2009; De Vries et al., 2010).

This example deals with the use of pig slurry as organic fertilizer, taking into account different strategies to optimize the relationship between the quality of the manure and nutrient uptake by crops. The use of LCA has allowed us to present an environmental point of view for this process, by means of the study of inputs and outputs to the system.

The use of pig slurry as a fertilizer

The use of pig slurry has been proposed as a field amendment due to its high mineral content, taking always into account the limits imposed by current legislation. The link established between breeder and farmer has been studied: breeder keeps the slurry pig into a reservoir, being later transferred to fields for its direct spreading.

As it is well recognized, only a proportion of applied elements by fertilization are taken up by the crop, the remainder being dissipated in the atmosphere or leached into water. According to different authors, field absorption figures would be 60% for N (Langevin et al., 2010), 100% for P and K (Nguyen et al., 2010), 90% for Ca and 25% for Mg (Llona, 2005).

Table 5 shows the elemental composition and characteristics of pig slurry for different housing, i.e., fattening pig, closed cycle and maternity (both gestating and nursing sows). These values have been estimated for each hosing system, according to a field contribution with the maximum allowed level of N (170 kg ·ha^{-1}).

Table 5. Total (t) and available (a) fertilizer elements from different pig slurries (kg ·ha^{-1})

Pig manure	Dosage L/ha	N(t)	N(a)	P(a)	K(a)	C(t)	C(a)	Mg(t)	Mg(a)
Fattening	34,000	168.30	94.85	5.75	185.45	19.76	18.02	16.42	3.98
Closed cycle	64,000	169.60	107.74	5.90	216.76	7.67	6.99	5.74	1.39
Maternity	77,000	169.40	111.92	9.79	372.64	14.95	13.63	5.46	1.32

Due to the variability of the composition for different pig slurries according to the housing system, and also the different crop requirements (Table 6), a strategy for breeder-farmer association is proposed for lettuce, broccoli and artichoke growing, with a minimization of leaching nutrients and air pollution.

Table 6. Extraction of fertilizer elements from different crops

Crop	Duration (days)	N (kg ·ha^{-1})	P (kg ·ha^{-1})	K (kg ·ha^{-1})	Ca (kg ·ha^{-1})	Mg (kg ·ha^{-1})
Letucce[1]	120	100	25	204	45	15
Broccoli[2]	87	244	29	240	221	23
Artichoke[3]	222	400	59	625	132	48

[1] Rincón et al, (1996); [2] Rincón et al, (1999b); [3] Rincón et al, (1999a)

LCA applied to fertilization was developed using fattening pigs because its highest production (about 80%). The functional unit was 1 m3 pig slurry, and the system limits were established from the pond for slurry accumulation in the farm up to field application. All these considerations are included in Figure 5.

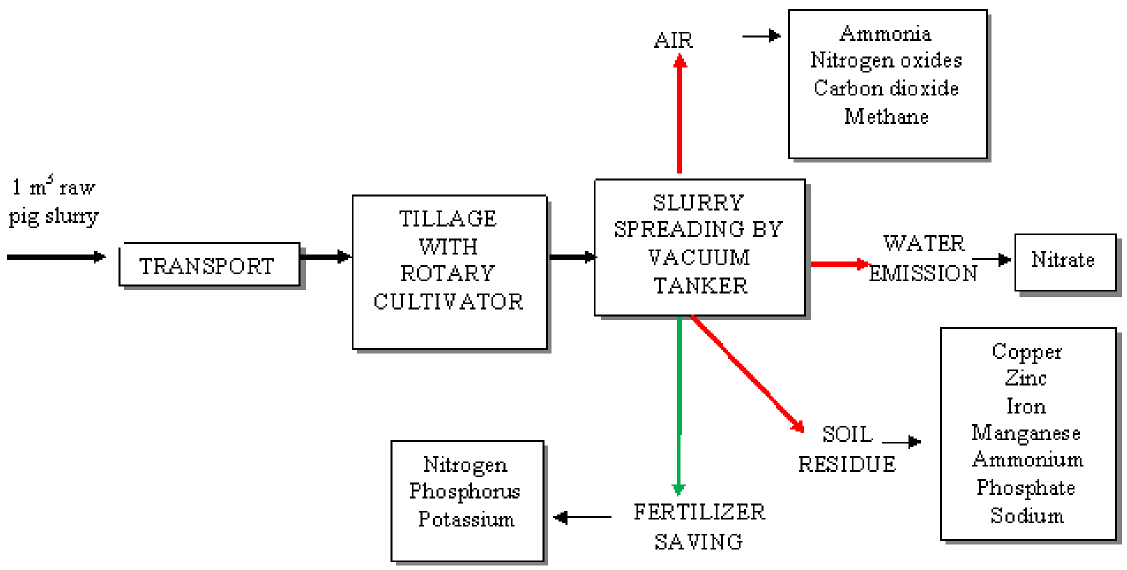

Figure 5. Flow chart related to pig slurry cycle

Fertilization strategies

As shown in Tables 5 and 6, different recommendations can be included according to the origin of the pig slurry and the crop to be applied. For lettuce, the more suitable alternative would be the use of pig slurry from closed cycle, because of a minor N and K extraction. The needs would be completed with 60,000 L·ha^{-1} of pig slurry, having to be complemented with P, Ca, and Mg. As the main origin of pig slurry was from closed cycle, 34,000 L·ha^{-1} of pig slurry would provide almost all N needs, being similar the P contributions. The supplementation with Ca and Mg would be lower, but it would be necessary to include a K supplement.

Broccoli is one of the crops where this practice is being used. As for lettuce, the best choice is pig slurry from closed cycle, due to a similar supplement of N and a higher amount of added K (216 kg·ha^{-1} versus 185 kg·ha^{-1}). In both cases, N should be added.

Artichoke appears to be a highly demanding crop for N and K, being the pig slurry selection would also determined by the legislative imposition of no more than 170 kg·ha^{-1} of N. Regardless of the pig slurry selected, the addition of mineral elements would be necessary, always in a lower amount for maternity pig slurry, specially for K. This kind of slurry has two main disadvantages: low availability and a high dose (77,000 L·ha^{-1}). A mixture of different pig manures would also be possible, with a previous analysis of its composition.

Life cycle assessment

Table 4 depicts the inputs and outputs of the system, as well as the avoided products. The inputs to the system have been experimentally obtained; the methodology can be consulted in Gómez et al. (2009). Data referred to nitrogen dynamics have been calculated from model proposed by Langevin et al. (2010). Emission data for the other elements were estimated from Loyon et al. (2007). Finally, the avoided products were also considered; i.e. the fertilizer used for the crop and not to be chemically synthesized.

Once the Life Cycle Assessment was carried out, environmental impacts due to fattening pig slurry application can be observed in Figure 6, both grouped by effects and damage categories. As it can be observed, the highest effects were for respiratory inorganics, climate change, and ecotoxicity, all of them due to the full process. The reason of this result can be explained by the chemical compounds emitted to the atmosphere, water, and soil, and not absorbed by the plant.

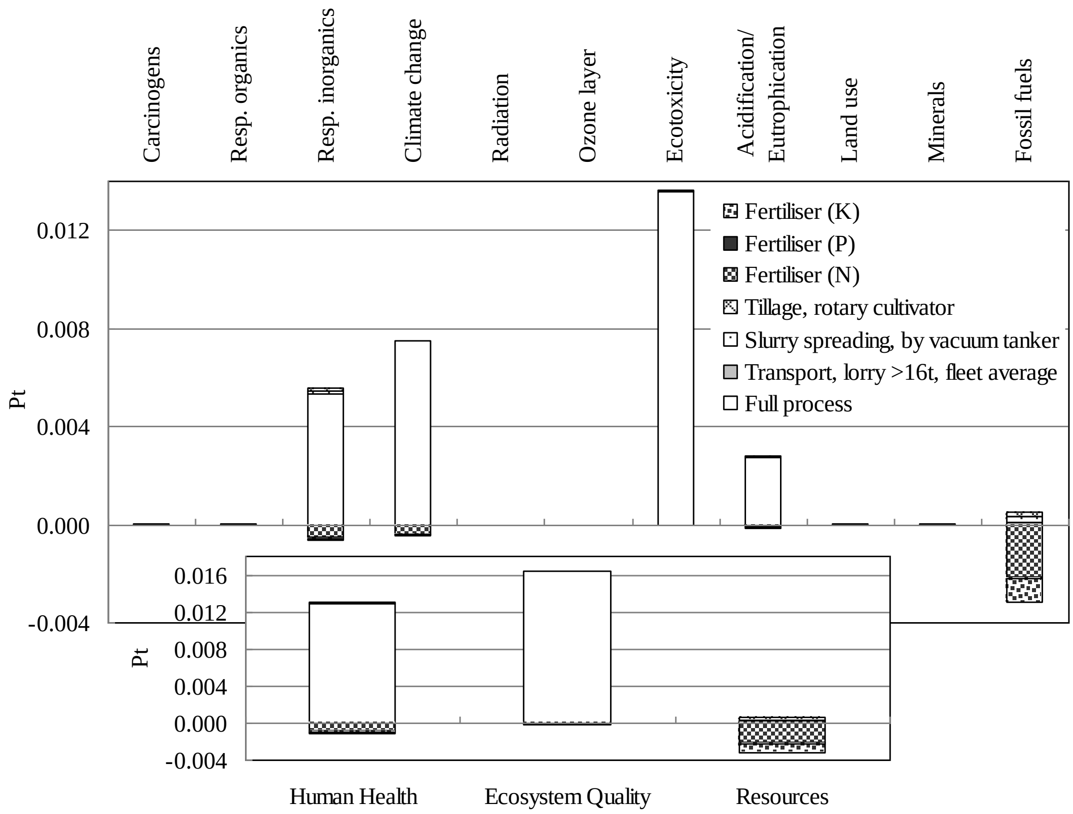

Figure 6. Contribution of the different stages to the impact factors per m³ of pig slurry

It is interesting to remark the negative values obtained by avoided products, such as N and K, and also P although in a lesser extent. These results are reflected in the fossil resources, respiratory inorganic, and climate change impacts, making the final balance more positive than it was expected. Similar results were found by López-Ridaura et al. (2009) for slurry treatment.

Table 7. Inventory data for the considered system (1 m³ fattening pig slurry)

INPUTS	
Composition and physicochemical parameters	
Mg (mg·L^{-1})	482.80
Ca (mg·L^{-1})	581.30
K (mg·L^{-1})	5454.45
Na (mg·L^{-1})	2564.95
Fe (mg·L^{-1})	9.00
Mn (mg·L^{-1})	1.80
Total Nitrogen (mg·L^{-1})	4950.00
NH_3-N (mg·L^{-1})	3950.00
Zn (mg·L^{-1})	21.90

Cu (mg·L^{-1})	2.95
PO_4^{3-} (mg·L^{-1})	550.00
P (mg·L^{-1})	169.00
Conductivity (dS/m)	26.00
pH	7.45
Humidity (%)	91.60
Density (g·mL^{-1})	1.01
Dry matter (g·L^{-1})	25.50
Transport and manure spreading	
Transport from breeder to farmer (km)	2.50*
Field application (m^3)	1.00
Farming by rotovator (m^2)	126.20*
OUTPUTS	
Emissions to water	
NO_3^- (kg·m^{-3})	1.20
Emissions to air	
NH_3 (kg·m^{-3})	0.88**
N_2O (kg·m^{-3})	0.08**
CH_4 (kg·m^{-3})	23.71***
CO_2 (kg·m^{-3})	51.01***
AVOIDED PRODUCTS	
N (kg·m^{-3})	2.79
K (kg·m^{-3})	3.25
P (kg·m^{-3})	0.06
Ca (kg·m^{-3})	0.53
Mg (kg·m^{-3})	0.12

*average value; **according to Langevin et al. (2010); ***according to Loyon et al. (2007)

In addition, the high equivalence factor for ammonia emissions within the acidification impact category (Huijbregts, 1999) resulted in a high impact for the full process. The same occurs with eutrophication category, where increased concentrations of nitrates and phosphates in water body can encourage an excessive algae growth, depleting the oxygen concentration and so damaging the ecosystem.

The same conclusion can be drawn for climate change, with a high impact due to carbon dioxide and methane generated during the application process, and considered important factors for global warming characterization (Council Directive 2008/1/EEC, 2008). The most important substances contributing to ecotoxicity were heavy metals released from the full processes, with similar results reported by Suh et al (2001). There are also two more contributions to this impact category: methane gas from the landfill and effluent gases from the transport vehicles. Figure 6 shows that the major contribution to this effect is the full process and the metal leaching involve in it, taking into account an average distance farmer-breeder of 2.5 km.

Conclusions

The legislative imposition of no more than 170 kg·ha-1 of N conditions the use of fattening pig slurry in no more than 34,000 L·ha-1. This paper presents some considerations and recommendations for different crops, being the best options: (i) pig manure from closed cycle at 60,000 L·ha^{-1} for lettuce; (ii) pig manure from closed cycle at 64,000 L·ha^{-1} for broccoli; and (iii) maternity pig slurry at 77,000 L·ha^{-1} for artichoke.

Life cycle assessment for pig slurry application as a fertilizer has shown the highest effect on the environment is due to the soil deposition of heavy metals, causing a high ecotoxicity. Also gases with global warming effect, ammonia on acidification and nitrates and phosphates on eutrophication can be mentioned as important effects. The decrease in the synthesis of inorganic fertilizer can be pointed out as a positive aspect in this project, both from an economic and environmental point of view. In addition, following the fertilizing recommendations, it is possible to reduce the environmental effects by decreasing the leaching processes, i.e., nitrates in the pig slurry.

Finally, it can be concluded that an alternative pig manure treatment which minimizes gaseous and water emissions, together with a metal-elimination system would improve the environmental behavior of this sub-product.

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