PARALLEL SESSIONS 2

2C / Environmental, economic and societal assessments in LCA

Environmental and economic assessment of protected crops in four European scenarios

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ABSTRACT
In this study we analysed the environmental and economic profile of greenhouse crops in Europe using four scenarios of current agricultural practices in warm and cold climates. The methodologies selected for the study were Life Cycle Assessment for the environmental analysis and cost-benefit analysis for the economic assessment. The main environmental burdens were energy consumption, structure and fertilizers. Environmental impacts due to energy consumption can be reduced by using co-generation or geothermal water in glasshouses. Structure contribution can decrease with the use of recycled materials. Adjustment of fertilizers doses and closed irrigation systems are recommended in Spain and Hungary. The best economic perspectives to reduce inputs are energy savings in glasshouses and reduction of fertilizers in Spain and Hungary.

Keywords: Life Cycle Assessment, horticulture, reduction of inputs, cost-benefit analysis, greenhouse

1. Introduction

Population increase has meant greater food demand, leading to an increase in intensive agricultural practices. Different climate and market conditions in Europe have had a strong influence on the technological and economic development of protected crops. With the mild winters in southern Europe, thin plastic film is used to cover practically all the greenhouse area, and most greenhouses are unheated and use simple technology. In contrast, in northern, cold-winter climates, the majority of greenhouses are covered with glass, and efficient heating and high technology is needed for high productivity.

The EUPHOROS (2008-2012) project was set up in response to the concern about sustainability of food production. The aim of this research project is to develop sustainable protected crops with a reduction in external inputs yet with high productivity and resource-use efficiency also as priorities.

The objective of the study is to assess the current situation of protected crops in Europe and identify the main environmental and economic loads of horticultural production in different kinds of greenhouse production systems. The results of the assessments will help to evaluate the most efficient solutions to improve sustainability of agricultural practices.

2. Materials and methods

Four scenarios, representative of the present situation of protected horticultural and ornamental crops in Europe were analysed: 1) tomato crop in a multi-tunnel greenhouse in Spain;

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2) tomato crop in a Venlo greenhouse in Hungary; 3) tomato crop in a Venlo greenhouse in the Netherlands; and 4) rose crop in a Venlo greenhouse in the Netherlands.

The environmental analysis was conducted using Life Cycle Assessment methodology (LCA), following the ISO 14040 standard (ISO-14040, 2006). The inventory phase included the inputs and outputs of the processes in the greenhouse production systems.

The technical and economic data for the tomato greenhouse in Spain were provided by the Cajamar Experimental Station in Almeria and from the literature (Fundación_Cajamar, 2008; Mesa *et al.*, 2004). The data for a commercial tomato greenhouse farm in Hungary was supplied by Mórakert, a vegetable and fruit producers and sales cooperative. For the Dutch situation, data on tomato and rose greenhouse farms were according to the Quantitative Information for the Greenhouse Horticulture (Vermeulen, 2008) and the Farm Accountancy Data Network of the AERI (Anonymous, 2008). Secondary data for the environmental analysis were obtained from the Ecoinvent database (Frischknecht *et al.*, 2007).

The functional unit (FU) defines the quantification of the primary function of the system, providing a reference to which the inputs and outputs are related. Systems in this study delivered a single product, and mass FU was selected for each: 1 ton tomato for tomato crops in scenarios 1, 2 and 3; and 1000 stems for the rose crop in scenario 4.

The system boundary was considered from raw materials extraction to farm gate. Material disposal was also included but not recycling processes or transport to recycling plants, following the cut-off allocation procedure of Ekvall and Tilman (1997). The processes and flows included in the inventory were structured in several stages to facilitate assessment: infrastructure, climate control system, auxiliary equipment, fertilizers, pesticides and waste management.

The SimaPro program version 7.1 (PRéConsultants, 2008) was used for the environmental assessment, only performing the obligatory phases of classification and characterization.

The indicators and impact categories selected for the impact assessment were: one energy flow indicator (cumulative energy demand) and five midpoint impact categories defined by the CML2001 method v.2.04 (Guinée *et al.*, 2002): abiotic depletion (kg Sb eq), acidification (kg SO_2 eq), eutrophication (kg PO_4^{-3}eq), global warming (kg CO_2 eq) and photochemical oxidation (kg C_2H_4 eq).

The manufacture of equipment and greenhouse elements included materials and manufacturing processes. Depending on the scenario, the systems for climate control could include heating, co-generation, natural ventilation, thermal water, CO_2 enrichment and crop lighting. A co-generation system was used in the Dutch scenarios for the production of thermal energy for heating the greenhouse and electricity. The electricity produced was considered as being discharged to the public electricity grid, entailing both environmental and economic benefits. Electricity consumption for greenhouse operations was included and emissions released were calculated on the basis of the electricity production of each country. Irrigation installation included recirculation of drain water for the crops in the Netherlands. The fertilizers stage included emissions due to their manufacture and application to the crop. In scenarios 1 and 2 there was no recirculation of drain water and nitrate emissions (NO_3^-) to groundwater were taken into account. Transport processes to or from the greenhouse included vehicle and road manufacture, maintenance and diesel consumption. Waste management considered transport of waste materials to landfill or incinerator and emissions released in these treatments; and transport of green biomass to the compost plant.

For the economic assessment, all costs and benefits of the reference greenhouse production systems were taken into account to ensure the economic soundness (profitability) of the tools developed in the course of the EUPHOROS project. The inventory included costs for greenhouse equipment, plant material, energy sources, electricity, fertilizers, crop protection and labour (employers and employees).

The life span of the four greenhouses was fifteen years. This was the time period considered for the environmental analysis of the frame materials (metal, glass, and concrete and polycarbonate walls in multi-tunnel greenhouses) and the economic depreciation of the greenhouse. The average life spans in agricultural practices were considered for the remaining materials, e.g. three years for plastic film covering and substrates.

3. Results

Both the environmental and economic assessments gave an insight into which components made the highest contributions to the greenhouse production systems (Figure 1). Results for each of the four scenarios were:

1. Tomato production in the multi-tunnel greenhouse in Spain:

Structure was the main contributor to most impact categories, due to the large amount of steel in the frame and plastics for the covering and floor. Auxiliary equipment and fertilizers had the second or third major impact depending on the category. Manufacture of substrate and electricity consumption for the irrigation system were the main burdens of auxiliary equipment. The major contribution of fertilizers was a result of their manufacture, with their application also causing high impacts. The high contribution to eutrophication was due to nitrate leaching since the irrigation system was an open-loop system.

In the economic assessment, tangible assets (depreciation and maintenance) and labour were responsible for almost 60% of total costs. The cost associated with the structure of the greenhouse and other equipment amounted to a third of the costs. Fertilizer costs amounted to 7% of the total costs. The variable costs of crop protection and energy were low.

2. Tomato production in the Venlo greenhouse in Hungary.

Climate control system and structure were major contributors to abiotic depletion and cumulative energy demand since thermal water was used for the greenhouse heating system, and with very similar contributions. In this case, the electricity consumption of greenhouse operations was the main burden of the climate control system. If natural gas was used for heating the greenhouse, the climate control system was the main burden to abiotic depletion and cumulative energy demand and natural gas became the main load in this stage, in these two categories. The relevant contribution of structure was due to the large amount of metal in the frame. This frame included additional reinforcements to support the possible weight of snow. Fertilizers represented a major burden to all impact categories as the quantity of fertilizer applied was visibly higher than fertilizers used on other tomato crops with similar yields.

In this scenario, more economic components had a substantial effect on total costs: tangible assets, labour, fertilizers and energy. They contributed 75% of total costs. The high contribution of the costs of fertilizers was noticeable, while the cost of crop protection was limited.

3. Tomato production in the Venlo greenhouse in the Netherlands.

The LCA results for tomato production in the Netherlands using a co-generation system need additional explanation. The co-generation system produced a large amount of electricity that exceeded the greenhouse consumption. As the surplus electricity was transferred to the public grid, there was an environmental benefit. One may reach the paradoxical conclusion that the more natural gas is used by the co-generation system the better for the environment. Since the generation of electricity was not the main function of the greenhouse and in order to better understand the contribution of all the stages in tomato production, it was decided to conduct the LCIA without considering the environmental benefits of the co-generation system, but calculating the difference in contribution with and without using co-generation. Using co-generation, the potential environmental impacts for the total tomato production system were reduced by 53% in the abiotic depletion category, and by 57% in the cumulative energy demand impact category. The reduction for the remaining impact categories was between three and eight-fold.

The results for this scenario without co-generation showed that the climate control system was the main burden for most impact categories. Natural gas was the reason for the burden on abiotic depletion and cumulative energy demand, whilst electricity consumption for greenhouse operations was the cause of the major contributions to the remaining impact categories. Structure was also a major contributor in the impact categories, primarily due to the metal frame and secondly because of the amount of glass in the covering and walls.

Total costs mainly depended on natural gas consumption, tangible assets and labour. The costs attributable to fertilizers and crop protection were relatively minor.

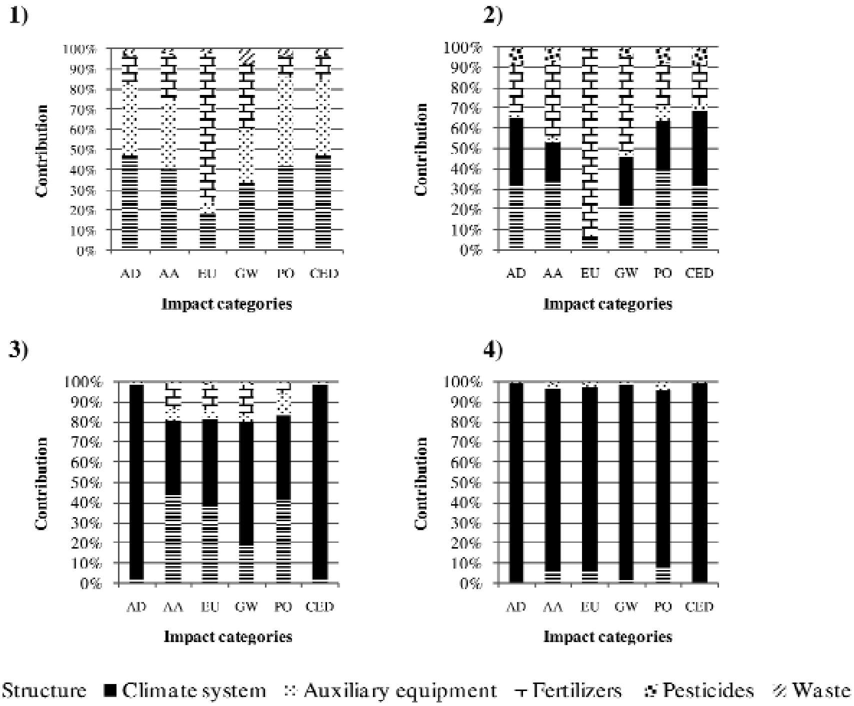

Figure 1: Stage contribution to impact categories for: 1) scenario 1; 2) scenario 2; 3) scenario 3, without co-generation; and 4) scenario 4, with co-generation. Impact categories AD, abiotic depletion; AA, air acidification; EU, eutrophication; GW, global warming; PO, photochemical oxidation; CED, cumulative energy demand

4. Rose production in the Venlo greenhouse in the Netherlands.

Clearly, the climate control system stage, even including co-generation, accounted for the highest contribution to all the impact categories. The contribution to abiotic depletion and cumulative demand was due to the natural gas consumption for heating the greenhouse. The consumption of electricity, mainly for providing light for the crop, was the cause of the contribution to the rest of the impact categories. Co-generation only helped to mitigate the environmental impacts; it was not able to completely prevent them. Furthermore, co-generation could not supply all the electricity needed for rose production, so a large amount of electricity had to be bought from the national grid.

Results for the assessment of structure, in particular, were as for the structure of the tomato greenhouse in the Netherlands, i.e. metal as the first burden and glass the second.

In this scenario, the main cost components were energy, tangible assets and labour. A large volume of fossil energy (natural gas) was used, not only for heating but also for lighting. The cost of fertilizers and crop protection agents were less significant.

The environmental assessment showed that auxiliary equipment represented a lower burden in Venlo greenhouse assessments. A detailed analysis showed that the manufacture of substrate and plastic elements were the main loads for this stage. There was also a high contribution from the polystyrene layers to support substrates bags, in the photochemical oxidation impact category, due to pentane emissions to air from the foaming expansion during manufacture. Waste management and pesticides gave low environmental impacts in all four scenarios studied.

4. Interpretation

In terms of the environmental assessment, LCA proved to be a very useful tool to identify the main bottlenecks in the four scenarios.

Energy saving is a priority in glasshouses in cold climates. Fossil energy consumption for heating and electricity could be reduced by alternatives such as co-generation systems, use of geothermal water, new developments in cover materials, management of energy storage systems and use of renewable energy resources. The benefits of co-generation were considerable. Unfortunately, the use of thermal water is not widely spread in Hungarian greenhouses because of the large initial economic investment necessary for installation. Electricity consumption should also be reduced and its impacts could be decreased if more renewable energies were used in the electricity production mix.

The contribution of structural materials could be decreased by the use of recycled materials, advances in greenhouse design and an increase in the life span of the greenhouse.

Fertilizers had a large environmental contribution because of emissions in their manufacture and application. Improvements focus particularly on Spain and Hungary in order to reduce doses, adjust the fertilizers-water balance and implement closed-loop irrigation systems. These results and recommendations are similar to those observed in a previous LCA for tomato production (Antón *et al.*, 2005), although the scenario for the study was not the same. With regard to the risk of eutrophication, it should be noted that the methodologies currently used to assess the amount of fertilizer reaching the aquifers are only approximate.

Due to the high energy demand for the manufacture of substrates, these had a major environmental impact in all four scenarios. Recycling of substrate and reducing the volume applied per plant are both strongly encouraged.

Future technological improvements should be developed to increase yields and thereby directly reduce the environmental burdens per unit of produce. Scenario 1 showed that there exists a high potential for increasing yields in greenhouses in southern Spain.

Although waste management was a minor burden in the production system, material disposal should advance towards recycling and reuse of materials, especially for green biomass.

In terms of the economic assessment, cost-benefit analysis gave an insight into the current situation of protected horticulture and which cost inputs contributed most to the net financial results. The cost of the components was used to calculate the investment capacity in order to give an indication of the economic possibilities of alternative options to reduce inputs. Among the four scenarios, greenhouse systems were more capital intensive in the Netherlands than in Hungary and Spain. The best economic perspectives to reduce resource use seem to be in energy saving options in glasshouse production. Fertilizer cost was high in

Hungary and relatively significant in Spain. Nevertheless, the investment in reduction of fertilizers would be more effective in Spain since there is not much scope for energy savings. Equipment and labour costs made a substantial contribution to total costs in all four scenarios. These costs could be reduced by extension of the life span. Crop protection was not a major cost factor in any of the scenarios and the high risk of loss of yield hinders the economic possibilities of pesticide reduction. Although the costs of fertilizers and crop protection were relatively low in most scenarios, their environmental impacts should still be reduced in order to advance towards more environment-friendly and healthy production.

The environmental and economic assessments on the product systems showed the importance of including both aspects in sustainability studies. Furthermore, the inclusion of both assessments is useful as a measure of the relevance between environmental improvements and their economic consequences.

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Explaining relations between economic and life cycle assessment indicators for Dutch pig fattening farms

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ABSTRACT

Economic and environmental indicators were quantified for 29 specialized fattening pig farms in 2007, based on data from the Dutch FADN (Farm Accountancy Data Network). Economic indicators used were: gross value added (GVA) expressed per 100 kg slaughter weight (SW) or per annual working unit. Environmental indicators used were deduced from a "cradle-to-farm-gate" life cycle assessment, and were: land occupation, non-renewable energy use, global warming potential, eutrophication potential and acidification potential, each expressed per 100 kg SW. Results on economic and environmental indicators are within the range of results in literature. Variation among farms was larger for economic than for environmental indicators. A high GVA on a pig fattening farm was associated with a low acidification and eutrophication potential. From partial least squares regression analysis, it was concluded that this relation was affected by farm characteristics related to scale or to type of feed used.

Keywords: pig fattening, explanatory variables, FADN, economic performance, environmental performance

1. Introduction

Pork production is an important sector in the Netherlands. Over the last decades, sustainable production of food is becoming increasingly important (Anonymous, 2009a). Sustainable production of pork requires farms that are economically viable, ecologically sound and socially acceptable, both now and in the future. Important sustainability issues with respect to Dutch pork production are animal welfare, ammonia emission and farm income (Boone and Dolman, 2010). To improve sustainability of pig farms, variation in, for example, their environmental performance can be used to identify promising mitigation options (Thomassen *et al.*, 2009). Deduction of mitigation options from variation in performances among farms, however, requires a relatively large number of farms and insight in multiple environmental issues. To quantify the environmental performance of a farm, a life cycle assessment (LCA) can be used. In the recent past, multiple LCA studies are performed to quantify environmental performance of pork production. These studies, however, often focused on input-output figures only, used one or a small number of farms, or were based on scenarios (Cederberg and Darelius, 2002; Zhu and Van Ierland, 2004; Basset-Mens and Van der Werf, 2005; Williams *et al.*, 2006; Blonk *et al.*, 2008). The impact per kg of meat widely differed among studies (De Vries and De Boer, 2010), which implies, next to differences is modelling, variation in performance among farms or scenarios. To our knowledge, no scientific publication exists that analysed LCA results on a large number of fattening pigs farms. Moreover, when LCA results were computed at farm level, their relation with the economic performance was not investigated. Therefore, the main objective of this study is to quantify the economic and environmental performance on a large number of specialized fattening pig

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farms and to identify and explain relations among economic and environmental performance indicators. Data of the Farm Accountancy Data Network (FADN) were used to meet above mentioned objectives (Vrolijk *et al.*, 2009).

2. Materials and methods

2.1. Data

The economic and environmental performance of specialized national FADN fattening pig farms were analyzed for 2007. The Agricultural Economics Research Institute continuously collects technical and environmental data for an randomly selected stratified sample of fattening pig farms. These data include information on quantity and type of feed used, quantity of energy and water used, and detailed information on housing facilities. Because this study focused on specialized fattening pig farms, farms were selected from this stratified sample only when at least 67% of the gross margin originated from fattening pigs (Poppe, 2003), and no other animals were present. In total 29 farms were analyzed. On each farm, all feed required for pork production was purchased. Possible on-farm activities related to crop production, such as purchase of fuel, artificial fertilizers and crop revenues were therefore excluded from the analysis.

2.2. Economic performance

The economic performance of 29 farms was assessed by computing the gross value added (GVA). GVA is an economic measure for reimbursement of labour, capital and land, and is computed by subtracting the non-factor cost from farm revenues, whereby depreciation is excluded (Barry *et al.*, 2000). Non-factor costs include all costs except costs related to land-lease, labour and interest. To correct for differences in farm size, GVA was expressed in euro per annual working unit[1], or per 100 kg of SW.

2.3. Environmental performance

The environmental performance of 29 farms was quantified using a life cycle assessment (LCA). LCA is a method that evaluates the environmental impact of all stages in the life cycle of an activity, in this case pork production. The stages of the pork production cycle included up to the moment that fattening pigs leave the farm (i.e. "cradle-farm-gate" LCA) were: production of feed (including production and use of fertilizer, pesticides and energy required for cultivation, processing and transport), production of piglets and fattening of pigs. The functional unit was 100 kg of slaughter weight (SW) leaving the farm gate. We performed an attributional LCA. Whenever a multifunctional process occurred, economic allocation was used. Impact categories (and corresponding indicators) included were: land occupation (m^2 per year/kg SW, non-renewable energy use (MJ/kg SW), global warming potential (GWP in kg CO_2-eq/kg SW), eutrophication potential (EP in kg NO_3^--eq/kg SW) and acidification potential (AP in kg SO_2-eq/kg SW). Characterization factors for EP and AP were based on Heijungs *et al.* (1992), whereas for GWP they were based on IPCC (2006).

[1] Regularly employed labour is converted into Annual Work Units (AWU). One AWU is equivalent to one person working full-time on the holding. A single person cannot exceed 1 AWU equivalent, even if his actual working time exceeds the norm for the region and type of holding (EC, 2005).

Production of feed and piglets

For each farm, detailed information on the type of feed was known, i.e. exact quantity used, and dry matter (DM), N and P content. Three feed types were distinguished: two dry feed groups (compound and singular concentrates), and one group with other feed products (mainly wet by-products from the food processing industry). The average composition of compound concentrates (i.e. main feed type) was based on monthly publications of Nevedi (2008). Main ingredients were tapioca (30%), wheat expeller (11%), soy cake (8%), wheat (8%), maize (6%) and rapeseed cake (5%). For each feed ingredient used, the environmental impact of crop cultivation, processing and transport were based on Thomassen *et al.* (2009) and additional empirical data, literature or expertise from feed processing companies. Moreover, impact of production of compound concentrates was included. On 10 farms, pigs were fed other feed products (i.e., whey, potato steam rinds) in addition to concentrates. Similar to compound concentrates, impact related to crop cultivation, processing and transport were included.

Production of piglets

The environmental impact of the production of piglets included the impact from housing and feeding of farrowing sows, and the impact from feed used to rear piglets up to 25 kg. The environmental impact from housing and feeding of sows was expressed per piglet, based on average figures of specialized pig rearing farms in FADN. The impact from use of feed for piglet rearing was computed based on data of an average pig rearing farm in FADN, and expressed per kg live weight, since the live weight of purchased piglets was known for each fattening pig farm analyzed (Deusings, 2008).

Stable balance and gaseous losses

For each farm, excretion of N and P in manure was computed specifically. Since 2006, Dutch pig farms are obliged to verify their NP excretion in manure using a stable balance (Anonymous, 2008). In such a balance, gross NP excretion is computed by subtracting the amount of N and P in meat sold, from the total amount of N and P in purchased inputs, such as feed and piglets. NP inputs or outputs resulting from stock changes are included (Groenesteijn *et al.*, 2008). Subsequently, for each farm gaseous N losses were computed. Emission of NO_x and N_2O was computed as 0.01 kg and 0.001 kg per kg of N excreted in manure (Oenema, 2000). Emission of NH_3 was assumed to depend on stable type and floor area per animal place. We distinguished traditional housing and low-emission housing, either with an air-brusher or with an adapted floor system. For farms with < 0.8 m^2 per animal place, NH_3 emission was assumed at 2.5 kg/place/yr for traditional housing and 0.8 and 1.2 kg/place/yr for low-emission housing, either with an air-brusher or with an adapted floor system. In case of > 0.8 m^2 per animal place, these values were 3.5, 1.1 and 1.5 kg/place/yr NH_3 respectively (Anonymous, 2009).

2.4. Relating economic and environmental performance

Relations between economic and environmental indicators were quantified by a correlation analysis. Pearson's rank correlation was used in case of normality, whereas Spearman's rho correlation was used in case of non-normality. To further explain relations, partial least squares (PLS) regression was performed. PLS regression yielded the main orthogonal factors underlying a relation, and quantified the loading value (-1 until 1) of 16 farm characteristics on each orthogonal factor. A farm characteristic with a loading value above 0.3 was considered important for the relation found.

3. Results

3.1. Descriptive

On average, 1,927 fattening pigs were present per farm (table 1). Piglets were purchased with an average live weight of 25.2 kg. Fattening pigs were sold with an average SW of 90.9 kg. Fattening pigs were fed 285 kg DM per 100 kg SW, of which 75% originated from dry concentrates. Expressed per 100 kg SW, gross nutrient excretion in manure was on average 4.7 kg N and 1.8 kg P in 2007.

Table 1: Weighted mean and standard deviation (st.dev) of farm characteristics for 29 specialized pig fattening farms (FADN 2007).

Farm characteristic	Unit	mean	st.dev
Average no. fattening pigs	Number	1,927	1,481
Traditional animal places	number	1,088	829
Low-emission animal places	number	1,028	1,370
Labour	AWU	1.0	0.5
Average piglet weight	kg per piglet	25.2	1.3
Average slaughter weight (SW)	kg per fattening pig	90.9	2.2
Slaughter weight delivered	kg per year	505,426	365,244
Dry feed intake	kg DM per 100 kg SW	188.7	68.5
Other feed intake	kg DM per 100 kg SW	66.1	72.1
Gross N excretion	kg N per 100 SW	4.7	0.5
P excretion	kg P per 100 SW	1.8	0.3

3.2. Economic and environmental performance

The average GVA per 100 kg SW was €5.1 per 100 kg SW, and €26,150 per AWU. Coefficient of variation was 151% for GVA per 100 kg SW and 173% for GVA per AWU (table 2).

Table 2: Mean and standard deviation (st.dev) of the economic and life cycle assessment indicators for 29 specialized pig fattening farms in 2007.

Indicator	unit	Total mean	Total st.dev	On-farm (mean)	Off-farm (mean)
Land occupation	m^2 per 100 kg SW	937	105	2	935
Non-renewable energy use	MJ per 100 kg SW	1,995	227	169	1,826
Global warming potential	kg CO_2 eq per 100 kg SW	530	56	38	492
Acidification potential	kg SO_2 eq per 100 kg SW	9.3	1.9	1.9	7.4
Eutrophication potential	kg NO_3^- eq per 100 kg SW	85.9	8.7	3.7	82.2
Gross value added	€ per 100 kg SW	5.1	7.7		
Labour productivity	€ per AWU	26,150	45,140		

Total AP was 9.3 kg SO_2-eq per 100 kg SW, of which 45% was from emission of NH_3, 40% from emission of NO_x and 9% from SO_2. Total climate change was 530 kg CO_2-eq per 100 kg SW, of which 24% was from emission of CO_2, 9% from CH_4, and 68% from N_2O. Total EP was 85.9 kg NO_3^--eq per 100 kg SW, of which 49% was from leaching of nitrate and 34% from phosphate. Total land occupation was 937 m^2 per year, where total energy use was 1,995 MJ per 100 kg SW. For each impact category, the majority (ranging from 79-99%) of the environmental impact occurred off-farm, i.e. during production and transport of required farm inputs. The major part of this off-farm impact resulted from cultivation and transport of dry feed (components). This stage of dry feed production contributed 41% to the total non-renewable energy use, 55% to total AP. The coefficient of variation was smaller for environmental indicators (i.e. 10-20%) than for economic indicators.

3.3. Relations among economic and environmental performance

A correlation was found between GVA and total AP and EP. For GVA per 100 kg SW, as well as for labour productivity this relation was similar. The relation between labour productivity and AP per 100 kg SW of -0.53 was strongest. Such a negative relation implies that farms with a better economic performance produce pork with a relative low AP. With PLS regression, one orthogonal factor was found which explained 54% of the variation of both dependent variables. Farm characteristics that loaded high one this factor (value between brackets) were related to scale (i.e., the average number of fattening pigs (0.4), the total amount of labour (0.4) or the number of low-emission animal places (0.4)), or to the type of feed used (i.e., dry feed intake per 100 kg SW (-0.3) and other feed intake per 100 kg SW (0.3)).

4. Discussion and conclusion

Results on economic and environmental indicators are within the range of results in literature (De Vries and De Boer, 2010; Hoste and Puister, 2009). Variation among farms was larger for economic than for environmental indicators. This was because the environmental performance was determined mainly by cultivation and transport of one average compound feed. Economic performance, however, was highly affected by variation in production cost (Hoste and Puister, 2009). Furthermore, a high GVA on a pig fattening farm was associated with a low AP or EP. Farm characteristics that influence this relation were related to scale or type of feed used. Increasing the amount of "other feed" in the diet, for example, reduced feed costs and AP or EP per kg SW, because "other feed products" were cheaper than the dry feed, and had a lower EP and AP from cultivation and transport.

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Innovative olive-growing models: an economic and environmental assessment

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ABSTRACT

The Italian olive-growing sector has to face both the growing competition on the international olive oil market and the shift of the common agricultural policy (CAP) from market and price policies towards direct aids decoupled from production. In addition the olive growers, as other farmers, have to comply with stricter obligations to manage their farms in sustainable ways (cross compliance). In this scenario the sector needs new competitive strategies to address these new challenges. In this paper we assess if innovative olive-growing models, like the high trees density orchards, are able to reduce production costs without worsening environmental sustainability. Indeed the intensive olive systems produce higher yields within a few years of planting and allow a higher level of mechanization (pruning and harvesting) but they could generate higher environmental impacts. In this study we perform an economic and environmental comparison between two olive growing systems: the "high density" and the "super high density". The analysis integrates the Life Cycle Assessment (LCA) and the Life Cycle Costing (LCC) methods by using a common database.

Keywords: olive-growing models, innovation, super high density plantation, LCA, LCC

1. Introduction

In recent years the Italian olive-growing sector has to face deep changes in the economic and institutional framework. The emerging scenario is characterized by the internationalization of the olive oil market, increasingly dominated by the strategies of multinational industrial bottling companies and those of modern retailer firms that becomes the key player in the olive oil supply chains. Nowadays the Italian olive farming sector is mainly composed by small and medium-scale farms (the average farm size is less than 1 UAA) and the traditional olive orchards (with less than 200 trees/ha) still cover a high quota of olive area, even in the most suitable olive-growing areas. The productivity of traditional olive system is relatively low as the level of mechanization of the harvesting and pruning operations. As a result the production costs at farm level are significantly higher than in other producing countries, both in non-EU Mediterranean country with higher availability of labor force and lower salary as in the "new producing countries" (Argentina, Australia, Chile, Mexico, New Zealand, South Africa and the United States of America) with better structural conditions. On the institutional level the common agricultural policy has shifted from market and price policies to income support policies decoupled from production (Single Payment Scheme). This policy change is accompanied by stricter obligations on farmers to manage their farms in sustainable ways that links direct payments to farmers to their respect of environmental and other requirements set at EU and national levels (cross-compliance).

A possible strategy to address this high competitive scenario could be the renewal of olive groves through the adoption of innovative olive-growing models able to reduce production costs without worsening environmental sustainability. In the last 30 years, several authors from Spain and Italy have recommended the use of more intensive olive orchards, designed

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for mechanical harvesting and associated with higher yields and lower production costs (Fontanazza, 2000). There are essentially two kind of intensive olive models: the "high density" (with over 200 trees/ha) and the "super high density" (with over 1,500 trees/ha) (Tous et al., 2007). While the first model is largely widespread in the traditional olive producing countries and in the new olive-growing countries, the second one appeared in Catalonia at the beginning of the 1990s and later it was introduced into other Spanish regions (Aragon, Andalusia, etc.) and other olive producing countries (Tunisia, Morocco, California, Australia, Portugal, France, Chile, Argentina, Italy, etc.). This olive model seems to be very promising because it could guarantee high yields within a few years of planting and the full mechanization. Therefore the analyses so far conducted in Italy about the super high density model are based on few years experimental data and are mainly focused on agronomic aspects and the cost reduction of harvesting, neglecting the overall life cycle costs and the environmental impacts.

In this paper we perform an integrated economic and environmental comparison between the two innovative olive models. We apply the Life Cycle Assessment (LCA) (ISO 14040, 2006) and the Life Cycle Costing (LCC) (White et al., 1996) methods. The integration of the two methods is based on the adoption of a common database. This approach has the undoubted benefit of offering consistent and fully comparable results between the examined systems.

2. The two olive growing systems

In this analysis we considered two innovative olive models: the "high density" (HDO) and the "super high density" (SHDO) olive orchards. In both models, the selection of varieties is fundamental to achieving the appropriate shape of the canopy in order to obtain the maximum productivity and quality of oil and, of course, adaptation for full mechanization (Fontanazza, 2000). The first model, already tested and adopted in the Italian context, is based on the exploitation of traditional cultivars. The second one is based almost exclusively on few low vigor cultivars (Arbequina, Arbosana, Koroneiki) compatible with the straddle harvesting machines. This olive model, that still has little presence in Italy (some hundreds hectares), requires special technical conditions such as relatively flat land and irrigation.

To perform our analysis we build up the technical database making some basic assumptions (table 1) based on information coming from the agronomic literature (Tous et al., 2006; Pastor et al., 2006; Camposeo and Godini, 2009). The data were collected assuming as reference area the northern zone of the province of Bari, in Apulia region, that is one of the most suitable Italian olive area (De Gennaro et al., 2010). The reference period of the analysis was set at 48 years, equal to the supposed economic life of the HDO and three time that of the SHDO. The economic and environmental evaluation are both based on 1 hectare olive orchard. From the environmental point of view, goal of the LCA is to build up the environmental profile of the two systems, in order to compare them and to identify their hot spots. The functional unit chosen is 1 t olives in the reference period of 48 years; the analysis covers the life cycle phases, starting from the production of the inputs used in the agricultural phase (fertilizers and pesticides) until the production of olives; distribution and consumption are not included because they are in common between the two systems. The background data are taken from the LCA databases (most of them from Ecoinvent). The emissions of N_2O, NH_3, NO_3-, due to the use of nitrogen fertilizers have been modelled respectively following Houghton (1997), ECETOC (1994) and Brentrup et al. (2000) methodologies. The emissions of pesticides during their use have been assessed following the model developed by Hauschild (2000). The inventory results expressed in physical units have been assessed by the CML 2000 assessment method (Guinèe et al., 2002). The assessment method has been stopped to the characterization, without going through the normalization and weighting steps.

Table 1: Main features of two olive models

PARAMETER	HDO	SHDO
Cultivar	Coratina	Arbequina
Planting density (orchard layout)	400 trees/ha (6 m x 4 m)	1,667 trees/ha (4 m x 1.5 m)
Plants quality	Grafted trees (over 80 cm)	Rooted Cuttings (40-50 cm)
Training system	Free vase and central leader	Central leader
Pruning	Manual, annual	Mechanical and manual, annual
Irrigation system	Drip irrigation and fertilization	Drip irrigation and fertilization
Weed control	Mechanical tillage and herbicides	Mechanical tillage and herbicides
Disease control	Conventional technique	Conventional technique
Harvest method	Shakers with a collecting umbrella	Straddle harvester
Yield (FP)	11,0	9,0
Fruit quality	Normal size and oil content	Smaller size but normal oil content
Economic life:	48 years	16 years
– *Young phase (YP)*	*1st – 2nd year (2 years)*	*1st – 2nd year (2 years)*
– *Growing production phase (GP)*	*3rd – 8th year (6 years)*	*3rd – 5th year (3 years)*
– *Full production phase (FP)*	*9th - 48th year (40 years)*	*6th - 16th year (11 years)*
Number of productive cycles	1	3

On the base of literature and with the help of olive-growing experts we set-up the cultivation techniques for each phase of the two olive models, from which we derive the inputs and outputs matrix for the entire reference period (table 2).

Table 2: Inputs and outputs of two olive models during the reference period (48 years)

	Short description	HDO	SHDO
INPUTS:			
Water (m3/ha)	Water for irrigation	87,360.00	86,700.00
Fertilizers (t/ha)	Nitrogen	12.01	12.06
	Phosphorus	3.45	3.51
	Potassium	6.28	6.54
Pesticides (t/ha) (as active principle)	Glyphosate	0.00671	0.00958
	Glufosinate	0.00667	0.00952
	Copper sulphate	0.139	0.191
	Copper ion (Cu++)	0.259	0.339
	Phosmet	0.122	0.164
	Dimethoate	0.06764	0.09063
	White paraffin oil	1.728	1.944
Inputs of machineries (t/ha)	Diesel fuel	37.057	37.666
	Lube oil	4.289	4.359
OUTPUTS:			
Olives (t/ha)	Olives for oil production	476.84	387.00
Wood (t/ha)	Pruning wood	165.20	196.50
	Explantation wood	180.00	150.00

3. Cash flow analysis

To assess the economic profitability of the two analyzed olive models we applied the Cash Flow Analysis. The criteria utilized to compare the alternative investments are: the Net Present Value (NPV) and the Internal Rate of Return (IRR). The analysis is based on the following assumption:

- the discount rate (r) was initially set equal to 2%;

- the costs were assessed considering the current hourly wage of workers for the manual operations and current tariffs charged by agricultural services provider for the mechanical operations;
- the annual total revenues include the revenue from selling the olives production and the revenue from selling the explantation wood at the end of the orchard economic life, but exclude the CAP direct aids;
- the olives revenues were calculated considering the same olives price for the both models that was initially set equal to the price observed on the marketplace of Bari during the last harvesting campaign (350 €/t) (ISMEA, 2010).

The first step of the analysis was to estimate the initial investment (plantation costs) and the flows of operating costs and revenues of the two models over the entire reference period.

The initial investment is higher in the SHDO, reflecting the higher costs for planting and for the irrigation system installation, despite the lower cost of plants (Table 3).

The operating costs are heavily influenced by the degree of mechanization of the olive orchard. In fact, despite the higher use of inputs (fertilizer and pesticides), the SHDO show lower operating costs respect to the HDO in all production phases, excluded the young phase, due to lower costs of pruning and harvesting operations (Tables 4 - 5).

Table 3: Comparison of plantation costs (€/ha)

Cost items	HDO	SHDO
Soil preparation	1,430.00	1,430.00
Pre-planting fertilization	1,911.00	1,911.00
Plants	2,600.00	2,500.50
Plants support system	600.00	1,198.49
Trees plantation and support system installation	381.10	1,543.35
Drip irrigation system	3,550.00	4,000.00
Total plantation costs	**10,472.10**	**12,583.34**

Table 4: Comparison of operating costs and revenues in each stage of the life cycle (€/ha*year)

	HDO		SHDO	
	Operating costs	**Revenues**	**Operating costs**	**Revenues**
Young phase	1,014.05	0.00	1,025.95	0.00
Growing production phase	3,075.75	2,149.00	2,785.31	3,500.00
Full production phase	4,485.70	3,850.00	3,543.55	3,150.00

Table 5: Comparison of operating costs in FP (€/ha)

Cultivation operations	HDO	SHDO
	€/ha	**€/ha**
Soil tillage	250.00	250.00
Fertilization	621.54	617.52
Irrigation	339.96	348.96
Weed and diseases control	1,251.13	1,454.15
Pruning	877.50	406.25
Harvesting	1,145.58	466.67
Total operating costs	**4.485,70**	**3.543,55**

The second step of the analysis was to calculate annual net cash flow and to measure the criteria of economic profitability (NPV and IRR). At the current olive price (350€/t) both olive models show negative NPV, equal to -32,249.48 € for the HDO and to -34,622.54 € for the SDHO. This means that for both models there is not economic profitability to invest.

As a final step we calculate the NPV and IRR as functions of the selling price of olives (Figures 1 - 2). As for the first criterion the HDO show a better performance than the SHDO for each price level (Figure 1). The IRR criterion is rather better for the HDO up to a certain price level (approximately 580 €/t), above which the performance SHDO exceeds that of

HDO (Figure 2). The economic analysis show the investment in innovative systems is not economically convenient at the current market conditions (olives price equal to 350 €/t). Assuming a discount rate of 2%, the olives price must grow up to 461 €/t for the HDO and to 493 €/t for the SHDO to obtain a positive NPV.

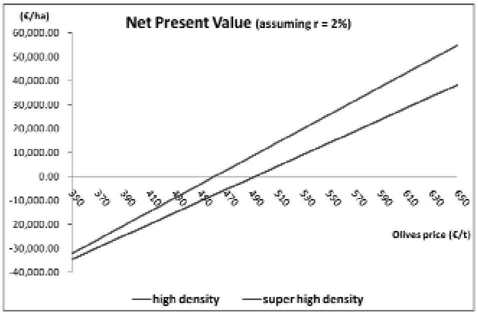

Figure 1: Trends of the Net Present Value (NPV) as a function of olive price for the high density and super high density orchard

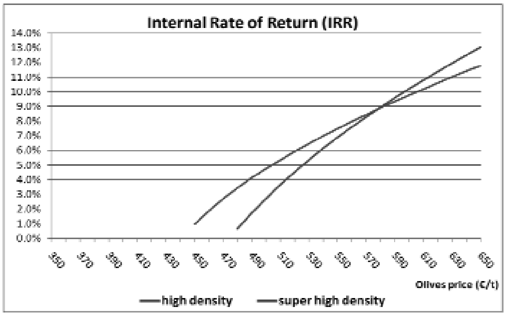

Figure 2: Trends of the Internal Rate of Return (IRR) as a function of olive price for the high density and super high density orchard

4. Environmental impact assessment

In Figure 3 the results coming from the characterisation phase of the two systems are shown. It can be easily found out that the HDO system scores better than the SHDO one in all the environmental impact categories with a percentage from 21% to 37%. The full production phase represents in both the systems the major impact (more than 75% of the whole impact in all the impact categories in HDO, between 50% and 75% in SHDO). As example, in Figure 4 the characterization of the full production phase of HDO system is shown, shared between fuels and lubricants for the agricultural operations, fertilizers and pesticides. It can be noted that, as expected and in line with other LCA of agriculture, fuels impact more on the categories linked to the energy supply and use (ADP, GWP, ODP, HTP); fertilizers impact more on AP and NP due to the emissions of nitrogen and phosphorous compounds; pesticides impact more on the toxicity categories (FAETP, MAETP, HTP) and on POCP; TETP is shared in almost the same way between the three items. Going through the uncertainty analysis, it can be noted the low values of the coefficient of variation (CV) for most of the impact categories (range 3.7 – 6.3%) with the exception of HTP with a CV of 18.9%.

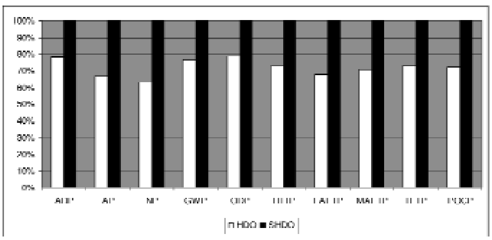

Figure 3: Characterization of the two systems

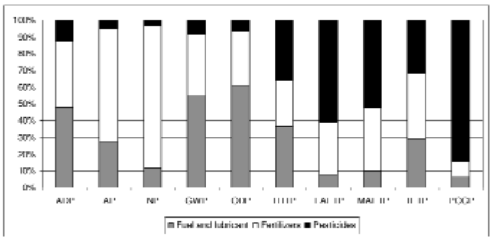

Figure 4: Characterization of the Full production phase in the HDO system

5. Concluding remarks

The analysis has shown the economic and the environmental profile of two innovative olive-growing models, the high density and the super-high density olive orchards, during their life cycle. From an economic point of view the HDO could be considered more convenient than the SHDO: in fact, despite the lower operating costs of the latter due to the complete mechanization of pruning and harvesting operations, these costs are counterbalanced by higher initial investment costs that the company has to charge three times than the HDO system. The total result is that the Net Present Value is better for the HDO for each olive price level. The environmental analysis carried out through LCA has also shown a better performance of the HDO system for all the impact categories, due to a lower use of energy and chemical inputs and to higher olive yields. This study shows that, when innovative systems are compared, the analysis must consider the whole life cycle, because, by pointing out the advantages offered by a unique operation could lead to misleading results.

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Application of a costing model consistent with LCA to the production of pasta in a small-sized firm

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ABSTRACT

In this note the production of fresh pasta in a small-sized firm has been chosen as an illustrative example in order to apply a costing model which is consistent with LCA, because it shares a similar Input-Output computational structure. The first section provides some methodological background and motivation. Section 2.1 briefly describes the food production system, points out what kind of data is required, and how it should be arranged using matrices, assuming in particular that complex information systems are not in place. Section 2.2 discusses the outcomes that are relevant for the firm's management and that can be obtained by calculating the resources consumption, the environmental aspects and the manufacturing costs associated with a typical food production system, using one procedure. Section 2.3 outlines a possible integration and combination of the obtained information with LCA. Finally, Section 3 provides some concluding remarks.

Keywords: Pasta; Life Cycle Costing; Input-Output Accounting; Food industry operations

1. Background and motivation of the study

The economic counterpart of LCA is generally addressed as Environmental Life Cycle Costing (LCC). It is of increasing concern for LCA practitioners and it has been discussed widely since the mid-90s (Hunkeler *et al.*, 2008; Huppes *et al.*, 2004). Just like LCA, LCC may concern also food products. Yet, the literature provides only a few applications of LCC to nondurable products, in general. As to food products, in particular, the approaches adopted vary significantly within the available LCC studies (Settanni *et al.*, 2010a). Unlike the LCA they are combined with, the approaches to LCC are seldom discussed in sufficient details. This heavily depends on the little emphasis that they usually place on modelling transparently the relevant physical flows within and across the manufacturing processes. Apparently, the applications of LCC to food products pose no major methodological questions, so far as LCC is understood only as a discounted cash-flows analysis. However, doing a cash-flow analysis for such non durable goods as food products makes sense only if an investment in a new production plant is to be assessed. LCA, on the contrary, can be applied to both durable and non-durable goods, and to both existing and new production processes, using the same computational principles. From a theoretical perspective, this evidently gives raise to consistency issues as one tries to combine or integrate LCA and LCC to some extent (Settanni, 2008). A model of LCC based on Input-Output Analysis (IOA) is consistent with LCA, sharing a similar computational structure (Settanni *et al.*, 2010b). Here we apply such model in order to represent accurately the technology and operations of the fresh pasta production system in a small-sized firm from-gate-to-gate. Not only this provides the physical information necessary to build part of the Life Cycle Inventory (LCI); it also turns into cost flows the physical flows associated to any production choice, actual or prospective, made by the firm's management, thus providing real support for decision making.

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2. Modelling technology and costs for each production stage

IOA is widely applied in the realm of LCA. It is mainly used for modelling the LCI and carrying out further computations (Heijungs and Suh, 2002). However, this is usually not highlighted within the ISO-type LCAs of pasta (see *e.g.* Bevilacqua *et al.*, 2007). Moreover, it is used for hybrid LCA, based on the intersectoral tables of national economies. The latter has been successfully carried out for the improvement of the pasta life cycle inventory (Notarnicola *et al.*, 2004). Here IOA is used in order to model the actual production technology of fresh pasta from-gate-to-gate in a plant that already exists and operates, consistently with the LCA's computational structure so that the assessment of production costs at each stage depends on how such production technology has been modelled.

2.1. Production system description

The model applies to an existing small-sized firm, where complex information systems are not in place. Data about one specific configuration of the multi-stage, multi-product product system of fresh pasta have been collected on-site and arranged using matrices. Six main processes operate along one production line: A) Kneading; B) Moulding; C) Pasteurization; D) Pre-drying; E) Chilling; F) Modified atmosphere packaging (MAP). Processes A and F operate in batch mode, whereas the other processes operate in continuous mode during one shift. There are no work-in-process inventories. Finally, there is a dedicated auxiliary process, G, the production of overheated steam. The relevant environmental aspects include on-site interventions such as CO_2 emissions from steam generation, wasted intermediate products from C and E, and packaged final products returned by the retailers. It should be noted that no treatment or recycling process takes place internally.

All the relevant physical flows are collected for each process separately. This is shown in Table 1a. Literature has been used when direct observations were not available, *e.g.* for calculating the material balances of pasteurization and drying processes (Valentas *et al.*, 1998) and for the empirical determination of the specific heat of pasta (Gönül Kaletunç, 2007). Also, personal communications with producers of specific equipment have been used.

Processes A-F have been further specified according to the product types that they produce during the period of time chosen as reference for the analysis – one working day (8 hours). For example A(1) in Table 1a denotes process A producing intermediate product (dough) type 1. It can be seen from Table 1a that the starting point is not an overall (*e.g.* daily) physical "balance" of the production system. Rather, such balance is the final outcome of the model.

Moreover, the proposed model keeps separated records concerning the "fixed" amount of resources associated to processes, the levels of activity of which do not influence, and are not influenced by, the other processes and the product types produced. This is shown in Table 1b Examples include fixed overheads (the generation of pressurized air, the daily cleaning of the production line, the storage of finished products in a refrigerated warehouse, and setups – which depend on product changes rather than on production volumes). However, also such processes as C, D, E and G are characterized by partly fixed resources use, *e.g.* electric energy or fuel consumption.

2.2. From material flows to cost flows

A computational procedure for LCC based on IOA is described in Settanni *et al.* (2010b) and it is applied here in order to turn the material flows collected in Table 1 into cost flows.

Table 1a: Processes (material flows not balanced - ref.: one process run)

	unit	A		B			C			D			E			F			G	Cost Coeffi-cients (€/unit)
		A(1)	A(2)	B(1)	B(2)	B(3)	C(1)	C(2)	C(3)	D(1)	D(2)	D(3)	E(1)	E(2)	E(3)	F(1)	F(2)	F(3)		
Dough type 1	kg	70.0	0	-3.0	0	-3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	p_1
Dough type 2	kg	0	73.0	0	-2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	p_2
Formed pasta type 1	kg	0	0	3.0	0	0	-9.0	0	0	0	0	0	0	0	0	0	0	0	0	p_3
Formed pasta type 2	kg	0	0	0	2.6	0	0	-7.80	0	0	0	0	0	0	0	0	0	0	0	p_4
Formed pasta type 3	kg	0	0	0	0	3.0	0	0	-9.0	0	0	0	0	0	0	0	0	0	0	p_5
Pasteurized pasta type 1	kg	0	0	0	0	0	8.9	0	0	-5.99	0	0	0	0	0	0	0	0	0	p_6
Pasteurized pasta type 2	kg	0	0	0	0	0	0	7.79	0	0	-5.19	0	0	0	0	0	0	0	0	p_7
Pasteurized pasta type 3	kg	0	0	0	0	0	0	0	8.9	0	0	-5.51	0	0	0	0	0	0	0	p_8
Pre-dried pasta type 1	kg	0	0	0	0	0	0	0	0	5.78	0	0	-46.9	0	0	0	0	0	0	p_9
Pre-dried pasta type 2	kg	0	0	0	0	0	0	0	0	0	5.00	0	0	-40.7	0	0	0	0	0	p_{10}
Pre-dried pasta type 3	kg	0	0	0	0	0	0	0	0	0	0	5.32	0	0	-43.2	0	0	0	0	p_{11}
Cooled pasta type 1	kg	0	0	0	0	0	0	0	0	0	0	0	46.9	0	0	-5.0	0	0	0	p_{12}
Cooled pasta type 2	kg	0	0	0	0	0	0	0	0	0	0	0	0	40.6	0	0	-5.0	0	0	p_{13}
Cooled pasta type 3	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	43.16	0	0	-5.0	0	p_{14}
Packaged pasta type 1	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	p_{15}
Packaged pasta type 2	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	p_{16}
Packaged pasta type 3	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	p_{17}
Overheated steam	kg	0	0	0	0	0	0.2	0.25	0.2	0	0	0	0	0	0	0	0	0	50	p_{18}
Semolina type 1	kg	-52.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.36000
Semolina type 2	kg	0	-52.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.30000
Water (var.)	L	-18.0	-21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.00112
Electric energy (var.)	kWh	-1.7	-1.9	-0.2	-0.2	-0.2	0	0	0	0	0	0	0	0	0	-4.2E-3	-4.2E-3	-4.2E-3	0	-0.00731
Nitrogen	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-26.7	-22.9	-25.4	0	-0.00099
Carbon dioxide	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8.9	-7.6	-8.5	0	-0.00234
PE film	cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-22.0	-19.0	-21.0	0	-0.00113
Cardboard	pieces	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.0	-1.0	-1.0	0	-0.18500
Crude scrap stage C	kg	0	0	0	0	0	4E-3	3E-3	4E-3	0	0	0	0	0	0	0	0	0	0	0
Crude scrap stage E	kg	0	0	0	0	0	0	0	0	0	0	0	0.05	0.04	0.043	0	0	0	0	0
Moisture losses	kg	0	0	0	0	0	0	0	0	0.21	0.19	0.19	0	0	0	0	0	0	0	0
Carbon dioxide	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Returned final items	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead time A	min	-20.0	-21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.0034
Lead time B	min	0	0	-1.0	-1.0	-1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.0816
Lead time C	min	0	0	0	0	0	-3.0	-3.0	-3.0	0	0	0	0	0	0	0	0	0	0	-0.0243
Lead time D	min	0	0	0	0	0	0	0	0	-2.0	-2.0	-2.0	0	0	0	0	0	0	0	-0.0182
Lead time E	min	0	0	0	0	0	0	0	0	0	0	0	-16.0	-16.0	-16.0	0	0	0	0	-0.0221
Lead time F	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.0	-1.0	-1.0		-0.0312
Lead time G	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-60	0

Table 1b: Fixed cost overheads (ref.: one shift)

Electric energy (fix.)	kWh	0	0	-29.7	-1.6	-1.5	-21.5	-6.2	-5.8	-26.8	-7.8	-7.3	-25.1	-7.2	-6.8	-28.9	-7.2	-7.2	-3.3	-0.16410
Natural Gas	MJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-45.1	-0.01172
Water (incl. line cln.)	m^3	-25	-25	-25	-25	-25	-50	-50	-50	-50	-50	-50	-50	-50	-50	0	0	0	-61.5	-0.00115
Labour (incl. setups)	min	-484.2	-244.0	0	-10.0	-3.0	0	0.0	0.0	0.0	0	0	0	0	0	-80.0	-20.0	-20.0	0.0	-0.12773
Fixed emissions CO_2	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88.7	0

First, a production plan establishes the final deliveries for a given time period – one working day (8 hrs): 800 kg of packaged pasta type 1, 200 kg of type 2, and 200 kg of type 3. All the flows in Table 1a are to be balanced according to such plan. The presence of by-products/scrap recycling and/or treatment would have increased the complexity of the procedure. The balanced material flows and the fixed cost drivers in Table 1b must be considered in order to calculate the direct cost at each production stage. The known firm-specific economic variables are shown in Tables 1a and 1b as well: 1) the prices of the inputs purchased externally, 2) the overhead cost rates that are applied according to each process' lead time, and 3) the costs that are fixed with reference to the processes' level of activity during the planning period. Such direct costs can be turned into 1) the direct process cost, and 2) the unit product costs for each life-cycle stage, as shown in Settanni *et al.* (2010b). All the necessary matrix operations can be carried out by means of an MS-Excel spreadsheet. The outcomes are shown in Table 2.

In order to make a non-deterministic analysis, uncertainty has been attached to the main technical-economical parameters of the proposed model. In absence of historical data, the uncertainty has been modelled as triangularly-shaped distributions. A numerical simulation (Monte Carlo Method) has been performed by means of Oracle Crystal Ball. As a result, the deterministic unit costs of the finished product types shown in Table 2 are turned into calculated probability distributions. An example for one product model is shown in Figure 1.

An additional step is to determine the cost of the inefficiencies produced at different stages (Settanni *et al.*, 2010b), an additional information that is useful for the management of the firm. The computational procedure is very similar to the allocation on mass basis in LCA, since a process is split into two processes: one process producing only the valuable output, and a fictitious process producing only the inefficiency. The inefficiency which is of interest here is the scrap of intermediate and final product, shown in Table 1a. An additional process, called "scrap collection" is introduced. Such process actually does not use any physical resource. It only accounts for the cost, say €20, of collecting and disposing of externally a certain amount of waste, say 50kg. This analysis is carried out with reference to the final product type 2, considered at various stages of production. It is shown that: 1) the cost of a scrap produced at the pasteurization stage costs less than a scrap produced at the chilling stage and at the packaging stage (respectively: 0.75€/kg, 0.79€/kg, and €0.91€/kg), since scraps generated at downstream stages are produced using more resources, including the upstream intermediate products; 2) The cost of producing a scrap is greater than the cost of producing the main product on unit basis shown in Table 2, since the model assigns entirely to the fictitious processes generating the scrap the cost of collecting/treating it.

2.3. Integration and combination with LCA

The fresh pasta manufacturing stage previously described in detail for cost management purposes must be turned into an aggregated "black box" process that can be integrated within an LCA, as part of the LCI. Starting from the overall physical balance previously obtained, just one final product is chosen among the possible product models – say, "pasta type 1". The balance is re-scaled according to a new reference amount for such product – say 0.5 kg, corresponding to a single package of finished product. Then, the inventory for the aggregate unit process producing "pasta type 1", now called "Production of fresh pasta", is obtained by summing the relevant rows. For the illustrative purposes, a from-cradle-to-gate LCA of 1kg of "Fresh pasta", the output of the aggregated process "Production of fresh pasta", has been carried out by using CMLCA (5.1). The upstream processes "semolina production" has been taken from the literature (Notarnicola *et al.*, 2004). The relevant background processes are taken from Ecoinvent (ver. 2.1). The chosen impact assessment method is CML 2001.

Table 2: Production costs (relative to the production plan)

	$A(1)$	$A(2)$	$B(1)$	$B(2)$	$B(3)$	$C(1)$	$C(2)$	$C(3)$	$D(1)$	$D(2)$	$D(3)$	$E(1)$	$E(2)$	$E(3)$	$F(1)$	$F(2)$	$F(3)$	G
Direct process costs (€)	290.65	122.95	28.20	8.33	7.00	10.44	3.06	2.88	9.62	2.82	2.66	10.35	3.03	2.85	96.44	22.44	23.52	6.54
	p_1 Dough type 1	p_2 Dough type 2	p_3 Formed pasta type 1	p_4 Formed pasta type 2	p_5 Formed pasta type 3	p_6 Pasteuri-zed pasta type 1	p_7 Pasteuri-zed pasta type 2	p_8 Pasteuri-zed pasta type 3	p_9 Pre-dried pasta type 1	p_{10} Pre-dried pasta type 2	p_{11} Pre-dried pasta type 3	p_{12} Cooled pasta type 1	p_{13} Cooled pasta type 2	p_{14} Cooled pasta type 3	p_{15} Pack-aged pasta type 1	p_{16} Pack-aged pasta type 2	p_{17} Pack-aged pasta type 3	p_{18} Over-heated steam
Unit product costs (€/kg)	0.34	0.29	0.38	0.33	0.32	0.39	0.35	0.34	0.42	0.38	0.37	0.43	0.39	0.38	0.56	0.51	0.507	0.05

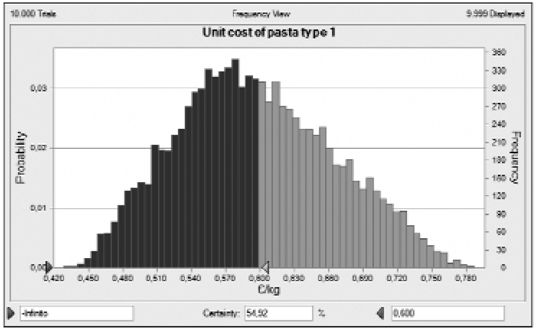

Figure 1: Uncertainty distribution of the unit production cost of the final products - Packaged pasta type 1

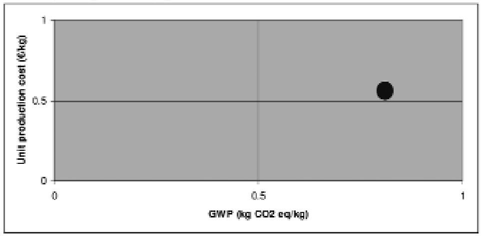

Figure 3: Combination of cost and environmental coordinates for 1kg of fresh pasta.

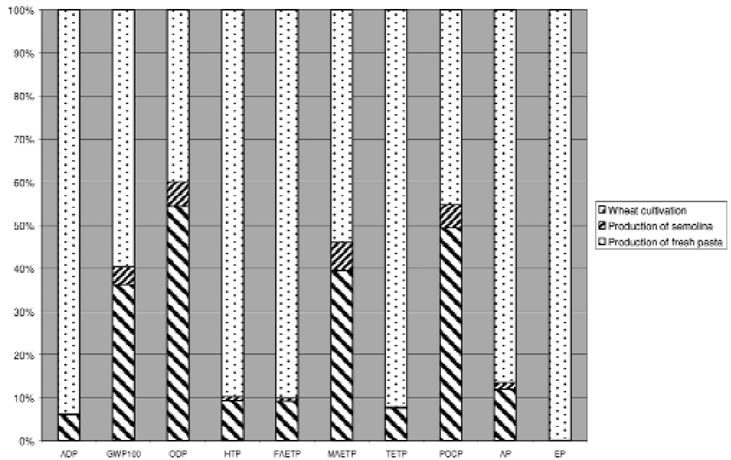

Figure 2: Contribution to the impact categories of the life-cycle stages. ADP: Abiotic depletion (elements); GWP 100: global warming; ODP: ozone layer depletion (steady state); HTTP: human toxicity; FAETP: Freshwater aquatic ecotoxicity; MAETP: Marine aquatic ecotoxicity; TETP: Terrestrial ecotoxicity; POCP: photochemical oxidation potential; AP: acidification potential; EP: eutrophication potential

The contribution analysis of each life cycle stage to each impact category, with reference to 1kg of "Fresh pasta", is shown in Figure 2. Besides this detailed analysis, the LCA provides the environmental measures that can be combined with the unit production cost. Such environmental measure can be either an aggregated environmental indicator, or one specific impact category, *e.g.* GWP, as in the case discussed here. For the illustrative purpose, this is shown in Figure 3 for one product only, but the same approach applies to each product type.

3. Conclusive remarks

In this paper an application of a costing method consistent with the computational structure of LCA to the production of fresh pasta in a small-sized firm has been discussed. Contrary to the well—established concept of LCC in management accounting, the method proposed here applies to such nondurable commodities as food products. This paper has illustrated how to proceed to the cost assessment on the basis of the material flows that have been also used for building part of the Life Cycle Inventory, as well as the other cost drivers. Then, the outcomes of the detailed costing procedure have been combined with those of a traditional LCA, so that the economic and environmental outcomes have been taken into account simultaneously. Further research should address in detail the complexities arising within the economics of the agricultural stage, which might include subsidies, production quotas and high uncertainty. Moreover, it should be taken into account that the actual profitability of the agricultural stage also depends on the management of complex supply chains, which often gives rise to aspects that are relevant for a Societal LCA, as well.

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Reporting the social indicators to the functional unit for food product. Theoretical contribution regarding the collection of relevant data.

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ABSTRACT

Several conceptions of social LCA lend on two often implicit hypothesis i) the source of impacts, the stressor would be either from technical origin, either from social one. It stems from it that relating the quantity of impacts to the quantity of functional unit has to be done through the unit processes, as it is done in ELCA. ii) companies are singly and freely choosing their practice, and even imposing social behaviour. We expect pointing out that we may build another representation. The values of the social indicators may be related proportionally to the functional units, if we handle them at the relevant level. Suggestions about the potential levels for picking up the data will conclude this proposal.

Warning: In the social LCA field, all the authors agree that the conceptual framework (e.g. UNEP, 2009) is far from being comprehensive. Moreover, no one claim that there is a unique or even consensual framework (epistemological, theoretical), to date. So, **this paper is not a case study**. This paper is a modest contribution towards building a conceptual framework for social LCA. It doesn't provide a list of indicators, it doesn't address the choice of indicators. Because we consider that these steps can't be performed before setting a strong theory of "what really count" among the social impacts of products. And this theory is not available today. However, we can build together parts of the foundations for the social LCA of tomorrow. The modest objectives of this paper are: 1) Discussing two implicit hypothesis underpinning many social LCA case studies 2) Showing that using different hypothesis, we may relate the social indicators (even if we don't provide a list) to the functional unit. Here are the prudent objectives of this paper. We expect it to be seen like a small part of the foundations we claim for.

1. Introduction

Within the conceptual framework of the Life Cycle Assessment (Jolliet et al., 2004), it is worth the indications provided about the impacts to be related to the functional unit. This property means that- up to a point- the quantities of impacts will vary in the same direction and proportionately with the quantities of functional unit. The issue is as critical for the so-called social impacts as it is for the environmental ones. The users need to choose ex-ante between different scenarios able to provide equivalent goods. They therefore require results formulated in proportion with the functional unit. But Reap et al . (2008) underpin that most impacts on people are independent of the physical processes that make the product, and more dependent on company behaviour and as such the «relation of the impacts to the product [-] is no longer straightforward » (Dreyer et al., 2006). About this critical issue, Kruse et al. (2009) have made the distinction between two kinds of inventory indicators, the additive ones and the descriptive ones. The first ones relate to the functional unit (e.g. labour costs). The second may be assessed at each point of the chain, but the authors explain that they cannot be related to the functional unit (e.g. use of child labour). Norris (2006) has came up the same difficulty thanks to the « life cycle attribute assessment ». One indicator

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only amongst the additive ones proposed by Kruse is chosen. It could be the number of work hours spent by each company involved in the product life cycle. The features that Kruse would call "descriptive indicators" are becoming attributes in the new approach. Doing so, researchers can calculate the rate of work hours from local origin involved in one industry providing greenhouse tomatoes in Canada (Andrews et al., 2009).

Both conceptions lend on two often implicit hypothesis, worthy to be discussed: i) The source of impacts, the stressor (the element of pressure) would be either from technical origin, either from social one (Parent et al., 2010). It stems from it that relating the quantity of impacts to the quantity of functional unit has to be done through the unit processes, as it is done in ELCA. ii) Companies are singly and freely choosing their practices, like being observant of codes of ethics or not, and even imposing social behaviours.

Our objective is pointing out other hypothesis. Doing so, the values of the social indicators may be related proportionally to the functional units, if we handle them at the relevant scale. Suggestions about the different potential levels for collect will conclude this proposal.

2. Social impacts are not stemming from unit processes

Stressors causing the social or other impacts are all stemming from social origin. They are depending from numerous social factors, some of them offering drivers to policy-makers. The average life expectancy is influenced by drivers on the nationwide scale, like the health policy. Industry may or may not implement policies, embedded in the state policies, for preventing occupational injuries. Companies and moreover groups of companies (March et Simon, 1999) have chosen organisational and technological (Kloepffer, 2003) configurations, the unit processes of today as a result. The unit process is the LCA term to assign one composite body, a layout of diverse resources: human, material and symbolic, gathering people, objects, space, machines, documents, and given the responsibility of doing a particular task (Girin, 1995). In ELCA, the relevant unit processes are special composite bodies. The non-technical parts seem to be cancelled out by the Fordist standardisation, performed in order to secure the return on the machines. The unit processes are time and space stabilized enough for us to build data bases delivering how much X substance is released by the process Y per functional unit. In appearance, everything works as if the machine alone was creating the impacts! But modify the tuning, and the outputs will shift. The machines are not the cause of the social impacts. When Boje (2009) recounts a fatal injury, it is clear that the killer-machine is only one tiny part of the explanation: « social here refers to poverty that would prompt 14-year old Liu pan to work 72 hour weeks on an unsafe machine, at 60% of China's legal minimum wage, to the point of exhaustion »(page 3).

In general, we get only fuzzy ideas about the pathways between the set up of one milk container in one *brazilian assentamento* (homestead), and the literacy gain which seem to be its output. We feel that many others elements but the milk container itself, take place. The human component of the composite body is re-established. These pathways are neither standardized, nor brought in general use. « It is very difficult to find any consistent differences between different technologies or production routes involved in the production of any given product, simply because the social impacts are so site specific that the variation between sites exceed the variation between technologies or production routes » (Weidema, 2002). By « site specific », we understand "linked with human behaviour". The social impacts are not linkable with each process unit because they are dependent on non standardized human behaviours. Indeed, very numerous human decisions affect the pathway between the unit process and the result. The whole constitutes a "complex system integrating human actors", where the human being's attendance introduces specific types of complexity (Girin, 2000). This entails that the future social impact is unpredictable from the unit process state.

Moreover, it is logical to focus on stressors at the level which holds the drivers. Sometimes, the company is not the best relevant level.

3. Companies comply with institutional isomorphism

Companies are embedded within the social fabric. They create disruptive fields (Emery and Trist, 1965) which bend the fabric, while complying with it, in a common cultural milieu. It is the so-called phenomenon of institutional isomorphism (Di Maggio and Powell, 1983). It means that all the companies belonging to one industry tend to become similar along the time, even to borrow the same or complementary strategies. About 20 developed countries, Maria Gjoldberg (2009) highlights that differences in political-economic background will be reflected in differences in Corporate Social Responsibility (CSR) performance. The countries with the most developed strong CSR practices belong to two groups. The first ones (Switzerland, UK, ND) welcome a high rate of globalized companies, more exposed to the spotlight of watchdogs from NGOs and the media. The seconds ones (Nordic countries) are characterised by close, cooperative and consensual relations between state, business and labour, as well as long-standing tradition for involving civil society in policy making. Her paper concludes by pointing out the need to acknowledge the fundamental interdependence between traditional, "hard" government- corporatist regulation of business responsibilities and "soft" civil regulation of corporate responsibilities." (Gjolberg, 2009).

Dreyer et al (2010) implicitly acknowledge the influence of more macroscopic levels than the company's one, and the institutional isomorphism phenomenon, because they underpin that the labour rights violation risk depends on the contextual factors surrounding the company. Indeed, they include in those factors the « (1) existence and enforcement of national legislation concerning the issue, and social, cultural, economic and political practices at the location, and (2) the practices of members of the industry ». As an outcome, the number of child labour hours involved in the making of rice in China doesn't depend on the company choice and behaviour, but on the national cultural agreement about it. Even if a Chinese company makes advertisement on its website as being "child labour" free, it can't merely be true if child labour is the rule in the rest of the society (Boje, 2009).

4. What is the relevant level for picking up data?

Because the social impacts don't stem from the unit processes level, and because of the institutional isomorphism of companies, we speak in favour of assessing the social impact at the sector or industry's levels. The idea is accounting for the evolution of the average practices of the companies making the product in one given country, and not to focus upon the specific unit processes from the company X. At the sector or industry level, one may find a value for the inventory indicators that we may relate to the quantities of functional units. So, the number of hours of child labour by functional unit of the rice sold by the company under scrutiny, and its national suppliers as a whole, may be collected at the industry level. If available, the two indicators values to collect are: 1) the number of children working into the rice industry ; 2) The quantity of rice processed in the country. You may calculate so a national indicator year 2010 of the number of child labour hours per functional unit of rice. Of course, it is a rough assessment, but not so bad, and including all the national companies involved in the chain under scrutiny. Weidema (2002) advices to filling any data gaps with default data, based on input-output tables extended with social parameters. We argue that these data will be more accurate than data drawn from auditing one company. Jorgensen (2008) too emphasizes how the generic data may be worthwhile « the quality of site-specific data is very dependent on the auditing approach and, therefore, not necessarily of high accuracy, and [-] generic data might be designed to take into account the location, sector, size and maybe ownership of a company, and thereby in some cases, give a reasonable impression of the social impacts that can be expected from the company performing the assessed process." Indeed, getting those values don't provide the pathways describing the impacts.

In theory, we are able to calculate the number of hours provided by children for each process unit in the world (for instance for each fruits drying rack) from real world data. All we have to do is to draw up a typology of « drying racks in their social context » (it means taking into account the technique, the place, time, and other social relevant items). And yet, these so precious data will turn out to be very instable along the time, while no one could explain ex-ante the causes of the variations. And so, the final impact measures would be so error-prone, that they would become unusable (Lenzen, 2006). Indeed, the alternate conversions from former outputs into impact measures are linked with characterisation factors matched with incertitude slot. The longer the chain between the first event (here it is the dryer rank functioning) and the final impact is, the larger the incertitude slot becomes.

The more the data will be picked up at macroscopic level, the more the data will be stable along the time. They will provide a final impact measure as accurate (with narrow incertitude slot) as the causality chain (between the driver and the end-point) will be shorter. Despite they advice us to pick up data at the level of the « companies in which the processes occur », Dreyer et al. (2010) acknowledge the role of more macroscopic levels : « the translation from performance score [within the company] to risk involves the assessment of the context of the company in terms of geographical location and industry and of the typical level of social impacts that these entail, and interpretation of the company's management effort in the light of this context » (page 247).

If data are lacking at the sector level, it is worth getting them from the immediately inferior level, which is from the industry level or from a group of companies. As one goes along down till the unit processes, data become more and more unstable, because the phenomenon whose data account for, is less and less dependent on these inferior level (the drivers belong to upper levels). However, this idealistic scheme assumes that the drivers are really triggered at each level, initiating with the upper and more general one. National State is assumed to spread its health policy in order to improve the inhabitants' life expectancy, the sectors are assumed to implement their occupational injuries prevention programmes and so on. In case of deficiency from upper levels, the first decision level triggering the drivers will be the relevant one to perform the collect of inventory data.

The table 1 highlights the different levels for picking up the inventory data in the food products field. We provide two examples often quoted in the literature: changes in life expectancy at birth and using child labour. From the bottom of the table (unit processes) it is clear that the company level is the first one where some decisions take place, for instance about the work organisation, which could influence the corresponding impacts. But the stability of the data along the time is worst than at any upper level. So, choosing the relevant level for data picking is a compromise between data availability, the best stability along time as possible, and the smallest incertitude slot about the final impacts.

It is worthy of note to set aside efforts in order gathering data of great worth for making up data basis reusable by other researchers.

Table 1: Stability of collected data and existence of drivers, according to the level of the collect, within the agri food field.

Level for collecting data	Time stability	Example 1: Where are the drivers for moving the life expectancy of workers in rice industry?	Example 2: Where are the drivers for using or not child labour?
State level	Very stable	The average life expectancy at birth depends on drivers handled at the Nation level.	It is a cultural issue, so if drivers exist, they are handled at the Nation level.
Agri food sector level	Stable	Some features of the sector (e.g. often outdoors working conditions) entail differences around the average. Some drivers are handled at this level.	Some features of the sector (e.g. low qualification level needed) entail differences. Some drivers are handled at this level.
Rice industry level (companies processing rice)	Stable	Some features of the industry (e.g. localisation of the rice industry in remote areas) entail differences around the former average. Some drivers are handled at this level. .	Some features of the industry (e.g. localisation of the rice industry in remote areas) entail differences around the former average. Some drivers are handled by this level.
Group of companies level within the rice industry	Average stability (depends on the size of the group compared with the industry size)	Depends on the size of the group within the industry	Depends on the size of the group within the industry
Company level (e.g. packaging plant)	Between weak and average stability	When the former drivers are not triggered, a company alone may handle drivers, depending on the type of company.	There may be huge differences according to the type of company (e.g. globalized versus local company) if the former drivers are not triggered.
Agricultural itinerary	weak	No relationship	No relationship
Unit processes level	weak	No relationship	No relationship

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Measuring sustainability in the agri-food sector: BASF's Eco-Efficiency and SEEBALANCE Analysis

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ABSTRACT

BASF has pioneered the assessment of the sustainability of chemical products and production processes through the development and use of Eco-Efficiency Analysis as well as SEEBALANCE Analysis. The tools are used to assist strategic decision-making, facilitate the identification of product and process improvements, enhance product differentiation as well as to support the dialogue with opinion makers, NGOs and politicians. Both Eco-Efficiency and SEEBALANCE Analysis are comparative methods; the advantages and disadvantages of several alternatives are assessed according to a predefined customer benefit. The analysis uses a Life Cycle Assessment approach– from cradle to grave – being considered. Next to the environmental impact, which is assessed based on ISO 14040 and ISO 14044, all economic factors are taken into account. Examples of the application of Eco-Efficiency and SEEBALANCE Analysis in the agri-food sector such as in the production of vitamin B2 as well as fruit and vegetable retailing will be presented. The new developed method, the AgBalance goes beyond these introduced and well known tools. It considers specific agro-related evaluation factors additionally. In the focus there are evaluation systems for biodiversity and soil. Furthermore specific social factors were developed to integrate them in an overall sustainability evaluation system.

Keywords: Eco-Efficiency, SEEBALANCE Agro, Sustainability evaluation, Life cycle Calculations,

1. General information

The Eco-Efficiency Analysis compares the economic and environmental pros and cons of alternatives that fulfil a specific customer benefit over the whole life-cycle. Thus, eco-efficient solutions are those which provide a specific customer benefit more effectively than others from the financial and environmental point of view. Over 400 Eco-Efficiency Analyses have been conducted at BASF and their results have been used to support strategic decision-making in different applications. It is also applied in co-operations with customers or external parties along the whole supply chain. Eco-Efficiency Analysis, as one important strategy and success factor in Sustainable Development will continue to be a very strong operational tool at BASF.

Eco-Efficiency Analyses is useful for:

- Supporting strategic decision-making
- Marketing: communicating with external customers
- Prioritizing R & D activities
- Activities in the field of stakeholder dialog and political decision-making processes

The purpose of Eco-Efficiency Analysis is to harmonize economy and ecology. Eco-Efficiency Analysis is applied in order to use as few materials and energy as possible in producing our products and to keep emissions as low as possible. At the same time, sustainable products can help to conserve resources.

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The main outline of the Eco-Efficiency Analysis method of BASF is provided next, while a more detailed discussion is available in literature (Saling 2002), (Landsiedel 2002).

Every Eco-Efficiency Analysis passes through several key stages. This ensures consistent quality and the comparability of different studies. Environmental impacts are determined by the method of life-cycle assessment (LCA) and economic data are calculated using the usual business or, in some instances, national economical models.

The basic preconditions in Eco-Efficiency Analysis are:

- Products or processes studied have to meet the same defined customer benefit.
- The entire life-cycle is considered.
- Both an environmental and an economic assessment are carried out.

The Eco-Efficiency Analysis is worked out by following specific and defined ways of calculations:

- Calculation of total cost from the customer viewpoint.
- Preparation of a specific life-cycle analysis for all investigated products or processes according to the rules of ISO 14040 and 14044. A defined set of environmental data are assessed.
- Determination of impacts on the health, safety and risks to people, assessing use of area over the whole life-cycle.
- Calculation of relevance and calculation factors for specific weighting.
- Weighting of life-cycle analysis factors with societal factors.
- Determination of relative importance of ecology *versus* economy.
- Creation of an Eco-Efficiency portfolio.
- Analyses of weaknesses, scenarios, sensitivities, and business options.

The major elements of the environmental assessment include energy consumption, resource consumption, emissions to all media, toxicity potential, risk potential and land use. The relevance of each environmental category and also of economic *versus* environmental impacts is evaluated using national emissions and economic data (Saling *et al.* 2009). They will be summarized to an environmental fingerprint in the first step. In the second step they are aggregated to an environment axis positioning the alternative with the highest and the lowest burden relatively on a summary axis (Figure 1).

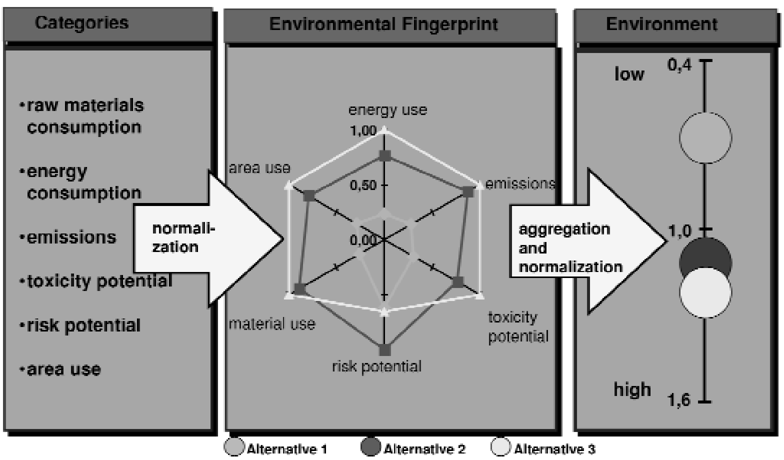

Figure 1: Generating the Environmental fingerprint and the summarized environment positions

2. More sustainability in products dedicated for the agri sector with Eco-Efficiency Analysis

Vitamin B_2 is produced by BASF's Agricultural Products & Nutrition segment for use as a vitamin for human and animal nutrition. As a component of animal feed, it is vital to ensure the animals' health and fitness; vitamin B_2 deficiency leads to slower growth and poor feed conversion.

Eco-Efficiency demonstrated which vitamin B_2 production process is the most eco-efficient. Three "bio-technological" and one "chemical" process were evaluated for the production of 100 kg of vitamin B_2 for use in animal feed pre-mix. All of the processes include renewable resources such as plant oil or glucose as a raw material. The bio-technological processes use fermentation, while the chemical process starts with a bio-technological precursor like glucose or soybean oil and uses afterwards traditional chemistry to produce the vitamin B_2 (Shonnard *et al.* 2003).

One of the Biotech processes under evaluation was the most eco-efficient alternative. It had the least overall environmental impact, and was one of the lowest cost alternatives. Another Biotech process compare to the most eco-efficient one, had noticeably higher environmental impact and higher costs. In this case the Chemical process alternative had the highest cost and greater environmental impact than the Biotech processes, resulting in the lowest Eco-Efficiency. BASF produces Vitamin B_2 via one-step fermentation from vegetable oil by using the fungus Ashbya gossypii. BASF pioneered the shift from chemical to biotechnological vitamin B_2 production on industrial scale and is running a production facility in Korea. It is an excellent example of industrial-scale production using the most eco-efficient technology currently available (Figure 2). The upper right corner of the Eco-Efficiency Portfolio is the desired position showing a good cost performance linked with a good environmental performance. There the most eco-efficient alternatives are located. Relatively, all other alternatives are ordered in the Eco-Efficiency Portfolio. This method gives the reader of a study in short times a clear picture of the result. In strategic discussions it helps to get an easy to understand summary of a life cycle-based and often complex calculation process.

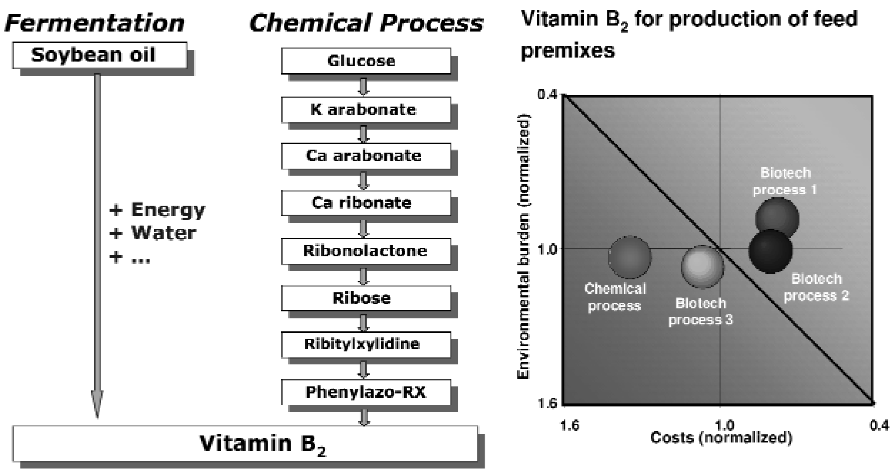

Figure 2: Reaction steps and results in the Eco-Efficiency Analysis for Vitamin B2

3. More sustainability in fruit and vegetable retailing with BASF Eco-Efficiency Analysis

Is it ecologically responsible to buy an apple from overseas? Shouldn't people as a rule choose fruit from national or local producers? Such questions play an every greater role in consumers' buying decisions. Yet our gut feelings can be misleading. Approaches, such as BASF's Eco-Efficiency Analysis, make it possible to carry out an objective assessment.

BASF is increasingly applying Eco-Efficiency Analysis to measure sustainability in the agri-food sector. An example of our work is the comparison of organic with conventional production of apples. As most people would have expected, the production cost of organic apples is significantly higher than for conventionally grown ones. But it takes more land and more trips with the tractor over the field to grow the same 1,000 kilograms of organic apples. As a result, conventional produce actually has a slightly better environmental footprint than organic. It turns out that yield is the key factor for a more sustainable production.

BASF's Eco-Efficiency Analysis for fruit and vegetables: REWE Group and BASF Crop Protection determine the governing factors for sustainability in apple growing and trading.

Examined and evaluated were apples of the Braeburn variety in November and April from the growing regions of Germany, Italy, New Zealand, Chile and Argentina.

The entire life-cycle of the apple from the tree to the shelf in a German supermarket, including all the resources and materials required for this, was evaluated in terms of environmental impact and costs. A holistic approach was especially important for this. Along with the energy and resource consumption, emissions into the air, water and soil, the acreage requirement and the potential for toxicity and risk were included for the first time in such an Analysis.

The results were surprising and expected in equal measure: It makes no difference in Eco-Efficiency whether the apples come from Germany or Italy. But Braeburn apples purchased from overseas in April can perform better than their European counterparts in terms of their environmental impact. The reason: less energy is converted in shipping the apple from overseas then by placing the European apple in cold storage. The targeted use of fertilizer and crop protection products improves the Eco-Efficiency: Higher yields reduce the acreage requirement and the burden on the environment. Actions for improving the process in terms of cost and ecology can be derived from the Eco-Efficiency Analysis (Figure 3). Beyond that, it facilitates strategic decisions in purchasing.

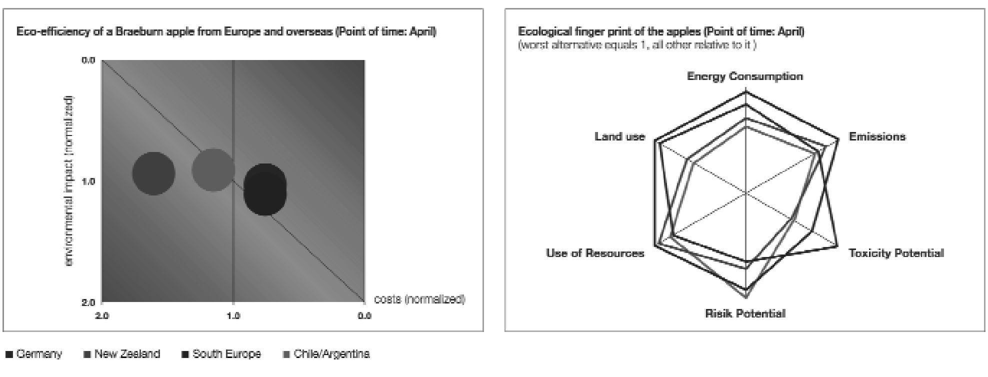

Figure 3: The Eco-Efficiency Portfolio and the Environmental fingerprint

The decisive adjustments for improving the sustainability of a product along the value chain have been identified with the Eco-Efficiency Analysis. All participants along the purchasing chain are involved in the improvement process with this analysis. Similar products or processes can be compared with the help of the Eco-Efficiency Analysis.

The decisive adjustments for improving the sustainability of a product along the value chain

4. Outlook

The **SEEBALANCE®**, an instrument that includes an assessment of a product's social impacts in addition to the economic and environmental ones, is currently being developed (Schmidt, I. *et al.* 2004).

It is an innovative tool which not only provides an assessment of the environmental impact and costs of products and processes, but also of the societal impact. The aim is to unify and quantify the performance of all three pillars of sustainability with one integrated tool for product assessment. The societal impact is represented by several evaluation categories. Assessed are indicators such as the number of jobs and the number of working accidents occurring during production. Special advantages or risks during the application of the products are also taken into account. The societal indicators are summarized in a societal fingerprint, similar to the ecological indicators (Kölsch, D. *et al.* 2008).

For the Agro Sector specific requirements are under further development. For example, new categories such as biodiversity, soil parameters or water usage that will be included into the methodology. Specific agricultural evaluations are under development and had been presented on a press conference this year in Chicago. The methodology, the new AgBalance also implements social aspects of farming activities. It was shown that the new modules of the methodology supporting decision-making processes especially in the Agro-sector very effectively. A more detailed outlook of these developments will be given in the presentation.

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