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Calculating the ‘real’ cost of apple production: integrating environmental impacts using life cycle analysis into economic data

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The environmental impact of apple cultivation practices in Belgium is evaluated based on FADN data from 2010-2012 for 64 farms. The study evaluates integrated production, the most common practice, and it compares this production method with conventional production and a small number of organic producers. A life cycle approach was used to assess the environmental impacts of these farms. Impacts related to the categories ‘acidification’, ‘eutrophication’ and ‘global warming potential’ were monetized based on the shadow price method in order to obtain external costs. External costs increase the production costs at least with 5 percent, both when they are expressed per kilogram and per hectare. No significant improvement in environmental costs was found for integrated farms compared to conventional farms. The findings showed however a large variability in costs per farm. Farm specific practices have therefore an important influence on the total environmental cost rather than production group specific practices.

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1. Introduction

Products are no longer only evaluated on price and quality only, but an extensive list of economic, external and environmental dimensions are increasingly taken into account by consumers (Esnouf et al., 2011; Pollan, 2006; Spaargaren et al., 2013; Kirwan et al., 2010). However, more scientific research related to these dimensions is needed in order to support actors in their decision making process. Therefore, this study provides new insights on the environmental dimension of the agricultural stage of the food chain.

Previous research on environmental impacts of agricultural practices has been carried out in particular based on the life cycle analysis (LCA) method (e.g. Roy et al., 2008; De Vries et al., 2010). Apples were often used in these LCA studies as a study case (Mila i canals et al., 2006; Cerutti et al., 2011; Mouron et al., 2006; Alaphilippe et al., 2013; Reganold et al., 2001; Blanke and Burdick, 2005). Most of these studies were limited to a small number of observations, often defined as ‘best practices’ (e.g., Mila i Canals et al. 2006, for New Zealand apple production). Other studies were based on an experimental set up (e.g., Alaphilippe et al., 2013, for French apple production systems). One of the main reasons for this is that data gathering is consuming a lot of time and money given the wide range of different inputs and techniques that agricultural systems use. There is however a wide experience in economic data gathering in Europe through the farm accountancy network (FADN). Data on inputs, costs and revenues is gathered from commercial agricultural companies across the member states in order to evaluate the impact of the common agricultural policy. Recently, several member states have also started to collect environmental data through FADN providing the unique opportunity to carry out a full-fledge economic-environmental evaluation, such as done recently by Thomassen et al. (2009) for Dutch dairy farms, Dolman et al. (2012) for Dutch pig fatting farms and Jan et al. (2012) for Swiss dairy farms. In this study we investigate to what extend FADN can be used to perform an environmental impact assessment of a larger number of farms in order to evaluate current practices in a specific geographical context. We argue that decision makers should not only receive information on how different types of agricultural systems could perform (as happens in studies in which they are being assessed based on experimental set ups or ‘best practices), but knowledge should also be provided on how agricultural companies are currently performing.

Once environmental impacts are calculated they can be converted into monetary units. A way of converting impacts calculated by LCA is the shadow price method elaborated by De Bruyn et al. (2010). The shadow price approach is a method that estimates the opportunity costs of environmental impacts, either through 'damage cost' or 'abatement cost' methods. Applications of the shadow price method to agriculture include the calculation of the external costs of UK agriculture (Pretty et al., 2000) and the calculation of the full cost of the UK weekly food basket (Pretty et al., 2005). These studies start from the observation that market prices send wrong or at least incomplete signals regarding a product's real cost to decision makers (consumers, policy makers, market actors,..). Therefore, an attempt is made to calculate a product's 'real' costs which incorporate private as well as societal (i.e. external) costs in order to allow actors make better informed decisions.

The purpose of this paper is to calculate and to compare environmental impacts and costs of current apple production practices, based on FADN data. The study focuses on a specific geographical context, that is Flanders, a region in the north of Belgium. Impacts will be converted in costs in order to calculate the 'real' cost of production. Impacts and costs will further be compared between conventional, integrated and organic producers. The paper investigates in particular whether the switch to integrated apple production is an improvement in terms of environmental impacts compared to conventional production.

The paper is structured as follows. In the next section we will describe the geographical context of the research. Afterwards we describe the materials and methods that were used to conduct the study. Section three will present the results. In the fourth section we will discuss the findings in relation to the here above described objectives. The last section will present the main conclusions of the study.

2. The geographical context of the research

The fruit production sector in Flanders covers approximately 16000 hectares (ADSEI, 2011). This is one percent of the total area of Flanders and 2.5 percent of the agricultural area. The extent of this area has remained constant since the end of the nineties. Around 40 percent of the area is allocated to apple production in open air (ADSEI, 2011). The remaining area is mainly used for the cultivation of pears in open air and strawberries in greenhouses. Like most agricultural sectors in Flanders, the sector is labour and land intensive, because of the scarcity of these resources in the region. According to official statistics apple farms generated an added value of 110 million euro's on this limited area in 2010 (ADSEI, 2011).

Most apple farms are located in the south-east of Flanders, a region around the city Sint-Truiden called ‘Haspengauw’. Up to 30 percent of the agricultural area in that region is allocated to apple production (De Meyer et al. 2014). The companies are mainly cultivating apples, sometimes in combination with pears. They cultivate different apple cultivars. The ‘Jonagold’ cultivar is the most common one. Plantations with Jonagold apples and Jonagold mutants are covering more than 60 % of the total area on which apples are being produced (ADSEI, 2011). Other important cultivars are ‘Golden delicious’, ‘boskoop’, and ‘Elstar’. Most farms are run by the owner, possibly supported by one or more family members. There is however a lot of seasonal work on the farms, especially during the harvest period in September and October.

The largest number of apple farms are using integrated production techniques. Integrated production is defined as "an economically responsible production of quality fruit, where preference is given to cultivation methods that are more environmentally friendly, with a minimal use of chemical substances, and where the undesirable side effects are limited in order to protect the environment and human health" (Flemish Government, 2004). It was stimulated in the beginning of the nineties by the international organization for biological control (Dickler E. and Schäfermeyer S., 1991). The first official code of practice for integrated fruit production was established by the regional government in 1996. The goal of this code was to reduce the use of chemical substances in fruit farms during field operations and to enhance the environmental quality. Certified producers were and are today still restricted to use a list of permitted products drawn up by the government for suppressing weeds and for killing insects and fungi. They are being controlled annually by an independent organization which is licensed by the regional government. In addition to this governmental initiative new codes of practices were established by retail groups in subsequent years. Integrated apple farms were obliged to follow these codes of practices in order to obtain quality labels and in order to sell their products to these retailers.

A limited number of apple companies went a step further then integrated production and converted to organic production. They are selling mainly under the European organic label. They do not use herbicides and they limit the use of inorganic fertilizer. This is however a very small sector, covering 170 hectares, which is less than 3 % of the area allocated to apple production in Flanders.

3. Materials and methods

3.1. Data

The farm accountancy data network is an instrument of the European commission for evaluating the income of agricultural companies and the impact of the common agricultural policy (DG Agri,2010). Data from representative samples of the different agricultural sectors is being gathered in the member states of the Union. The network gathers both economic data (costs and revenues) and physical data on inputs and resource use. We received data on inputs and resource use for a sample of 79 commercial apple farms via the department of fisheries and agriculture of the regional government of Flanders.

From the dataset we only selected farms that were cultivating the Jonagold cultivar or Jonagold mutants. This was done to exclude the impact that cultivar type can have on the results (Alaphilippe et al., 2013). The Jonagold cultivar was chosen because it is the most produced apple in the region (Demeyer, 2013).

In addition we only selected farms with adult plantations, that is, having trees between 4 and 15 years old. This selection was made because there’s a significant difference in impact between young plantations and adult plantations that are in full production (Cerutti, 2011).

The final sample consisted of 64 farms, including 50 integrated farms, 11 conventional farms and 3 organic farms. The classification in integrated or conventional production was done by the regional FADN monitoring unit on the basis of how the farmer profiled himself. In other words, the farmer declared to the monitoring unit if he was using integrated or conventional techniques. The farms are classified as organic if they are organically certified according to European regulations. As several plantations per farm were sampled, data were available for 97 integrated plantations, 17 conventional plantations and 5 organic plantations. For each farm and each plantation we analyzed data related to the three most recent growing seasons (2010-2012).

3.2. Life cycle analysis (LCA)

For each plantation from each farm and for each growing season we conducted a life cycle analysis. This analysis was performed according to the ISO 14044 framework (ISO,2006). The typical LCA steps are described below. They include (1) goal and scope of the study, (2) life cycle inventory, and (3) impact assessment. The fourth step, being the interpretation of the results, can be found in the *Results* section. In addition, we also discuss the assessment of the toxicity caused by pesticide use and how impacts can be aggregated using shadow prices.

3.2.1. Goal and scope

The goal of the LCA study was to quantify the environmental impacts associated with the production of apples in integrated farm systems in Flanders and to compare the results with organic and conventional production systems in the same region.

Two functional units were defined, one mass-based and one surface-based. The mass-based functional unit was defined as ‘1 kg of harvested Jonagold apples’ and the surface-based unit as ‘one hectare’. Both units have been used in previous LCA studies on apples (Blanke and Burdick, 2005; Mouron et al., 2006; Mila i Canals et al., 2006; Alaphilippe et al., 2013).

The focus of this study is on the production stage so other stages of the supply chain like storing, cooling and retail are not included. The study concentrated mainly on the field operations during one growing season when an orchard is in full production, while field operations during the nursery phase of the orchards are not considered. On the other hand, indirect impacts related to the production and transportation of fertilizers, pesticides and fuels were included.

3.2.2. Inventory

We made for each plantation an inventory of the inputs that were used during one specific growing season. The inputs that were taken into account include fertilizers (total amount of inorganic and organic nitrogen, potassium and phosphorous), pesticides (total amount of herbicides, insecticides, fungicides) and fuels (total amount of diesel and other fuels for tractors and machinery). Direct emissions related to the use of these inputs were calculated based on models from Nemecek et al. (2007) and the intergovernmental panel on climate change (IPCC) (2006). Indirect emissions and indirect energy use from fertilizers, pesticides and fuel use were calculated based on the ecoinvent 3.0 database.

3.2.3. Impact assessment

The inventory enabled the assessment of four impact categories: Global warming potential (GWP) for 100 years, Non renewable energy use, acidification potential and eutrophication potential. These impacts are usually considered in other LCA studies on apples (e.g. Mila i Canals et al., 2006; Mouron et al., 2006; Blanke and Burdick, 2006).

The impact category 'Global warming potential' presents the contribution to global warming of the greenhouse gasses emitted during the production process. Emissions were converted in CO_2 equivalents according to Houghton et al. (1995).

Non renewable energy use, expressed in mega joules, includes the direct energy used for the machinery during field operations and the indirect energy used for the production of fertilizers, pesticides and fuels. The amount of direct energy consumed per energy carrier (diesel fuel, gasoline, LPG,...) was converted in mega joules by using the lower heating value.

Terrestrial acidification potential is mainly caused by emissions of sulphur oxides and nitrogen oxide related to machinery use and ammonia emissions related to fertilizer use. Emissions were converted in SO_2 equivalents according to Heijungs et al. (1992).

Aquatic eutrophication potential is calculated in PO_4^{3-}equivalents. Aquatic eutrophication is the water system response to increased levels of nutriënts (suffocation of the environment). It mainly stems from emissions related to fertilizer use (losses of phosphorus and leaching and volatilization of nitrogen). The impact was calculated based on Heijungs et al (1992).

3.3. Assessment of the toxicity caused by pesticide use

The toxicity impact on the environment related to pesticide use was not assessed with the LCA method but following another approach in order to perform a more detailed assessment. To characterise the toxicity of the active ingredients of the products that were used we based ourselves on Kovach et al. (1992). This approach was suggested by Mila i canals (2007) and turned out to be feasible based on the FADN data.

Toxic characterisation factors are constructed in the study of Kovach et al. (1992) based on the toxicity that active ingredients cause on farm workers, consumers and the local ecosystem. They are expressed in 'environmental impact quotient'. This toxicity quotient can only be used for relative comparisons. The absolute values do not have useful meaning. In our case study it is useful to use them to compare integrated, conventional and organic practices.

We have related each active ingredient to their specific toxicity quotient. The sum of the toxicity quotients of all active ingredients could then be compared between plantations. The methodology turned out to be more practical for analysing a large dataset with many different active ingredients per farm.

3.4. Shadow prices

The results of three impact categories were monetized based on the shadow price method (De Bruyn et al., 2010) in order to have insights on additional external costs besides private production costs. The three impact categories for which this was done are global warming potential, acidification potential and eutrophication potential. The cost for non renewable energy depletion is already included in the private costs calculation. The cost for pesticide hazard was not included because this impact category was not expressed in absolute values and it was therefore also not possible to convert it into a monetary value.

The shadow prices that were taken from the study of De Bruyn et al. (2010) are based on ‘damage costs’ related to emissions in the European Union. Impacts of these emissions on both human health and ecosystems health are considered for the determination of the prices. The shadow prices calculated by De Bruyn et al. (2010) for global warming (expressed in Euro per emission of CO_2 equivalents), acidification (expressed in Euro per emission of SO_2 equivalents) and eutrophication (expressed in Euro per emission of kilogram $P0_4^{3-}$ equivalents) were discounted to values for 2010 based on inflation rates related to the consumer price index of Belgium. The final set of shadow prices used in this study are presented in table 1.

INSERT TABLE 1 HERE

4. Results

4.1. Input use and outputs

The amount of inputs that were used in the integrated, conventional and organic production groups are presented in table 2. The mean value is interpreted together with the coefficient of variance and the minimum and maximum values in order to better understand how input use is distributed among the plantations in each production group. This approach is based on insights from Mouron et al. (2006).

INSERT TABLE 2 HERE

Conventional farmers are using on average the highest amount of nitrogen and potassium. The three organic farmers on the other hand were using on average the highest amount of phosphor. The integrated production system has intermediate results. There is however a large variation in fertilizer use on the plantations of the same production group, as shown by the coefficient of variance which is at least 50 % for nitrogen, phosphor and potassium use in the three production groups. The ratio between minimum and maximum values is also very high, especially for phosphor and potassium use in the integrated and conventional production group. It is for example possible that an integrated farmer uses 4 times more phosphor and 3,5 times more potassium than the average but another farmer can use at the same time an amount of phosphor and potassium 100 times smaller than the average.

The results for pesticide use show that the integrated farmers are using on average a very small amount of insecticides compared to the other two production groups. This makes sense because they are using integrated pest management techniques to manage pests and harmful insects. However, they are using on average the highest amount of fungicides and herbicides compared to the conventional and organic groups. The three organic farms on the other hand are not permitted to use herbicides on their plantations, which is also reflected in the results, but they used on average 5 times more insecticides than the conventional producers and 9 times more insecticides than the integrated producers. This might seem awkward at first, but organic farmers are allowed to use certain types of insecticides. When we look at the conventional farmers we see intermediate values. This is surprising, we expected them to use the largest amount of pesticides because they don't have the same environmental restrictions as the integrated and organic producers. There is however again a large variation in pesticide use, indicated by coefficients of variance above 40 %. We see especially a large variation in insecticide use (a CV of more than 80% for the three production groups).

The results for fuel use indicate that the integrated producers were using more fuel than the conventional ones, but the highest average fuel consumption was found for the 3 organic farms. The conventional producers were consuming on average 13 gigajoule per hectare, while the integrated producers used on average 17 GJ and the organic producers 21.7 GJ.

Yields are also presented in table 2. The integrated farmers have an average the highest yield. They harvest 48 tonnes per hectare compared to a yield of 41 tonnes for the conventional producers and 37 tonnes for the organic producers.

4.2. Impacts per hectare

The environmental impact expressed per hectare is presented in table 3. The results show no significant differences between the integrated group and the organic production group (based on the Kolmogorov-Smirnov test). There was only a significant difference between the conventional and integrated group for the categories acidification, pesticide hazard and non renewable energy use. The expected impact of these three categories is always significantly lower for the conventional group compared to the integrated group. This is mainly due to significantly higher amounts of direct energy use and the use of pesticides by the integrated group (cfr. Table 2). The integrated group emits on average 102.2 kg SO_2 equivalents per hectare compared to 89.6 kg SO_2 equivalents by the conventional group. It has a non renewable energy consumption of 56.9 GJ per hectare compared to 47.0 GJ for the conventional group. The pesticide hazard equals 10.6 EIQ, which is slightly but significantly higher than the 10.5 value for the conventional group.

INSERT TABLE 3 HERE

The expected impacts of the integrated group are within the range of previous LCA studies (Mouron et al., 2006; Alaphilippe et al., 2013). The integrated group is for example emitting on average 2,5 tonnes of CO_2 equivalents per hectare which is very close to what Mouron et al. (2006) found in a study on Swiss apple companies (he found an average value of 2,6 tonnes per hectare). The results of Alaphilippe (2013) in France ranged between 1 and 1,3 tonnes per hectare, which is lower than our results. This study of Alaphilippe was based on an experimental set up, which could indicate that in practice GHG emissions are higher compared to an experimental setup which often represents ‘the best practice’. However, this study was performed in a different geographical context and on different cultivars which can also explain the differences.

The results show also a larger variability for most impacts of the integrated group compared to the impacts of the other two groups. This is represented by a coefficient of variance between 47.8 and 54.5%. The skewness of the distribution of the impacts for the integrated group was, except for global warming potential, always positive. This indicates that on a larger number of plantations the impacts were higher than the average.

The minimum and maximum values of the impacts are presented in table 4. In this table we find bigger differences between minimum and maximum values in the case of the integrated production group compared to the conventional group. For the integrated production group the maximum pesticide hazard is for example 245 times larger than the minimum hazard, while only 25,5 for the conventional group. This can be due to the fact that the integrated group is larger. Another reason can be that conventional farmers are following more standard practices, while integrated farmers are more experimenting with new products and practices.

INSERT TABLE 4 HERE

4.3. Impacts per kilogram

The impacts expressed per kilogram show higher expected impacts for the organic production group compared to the other two groups. The organic production group is in other words less impact efficient. The main reason for this are lower yields (cfr. table 2). The impacts of the conventional production group on the other hand are not significantly different from the integrated production group when expressed per kilogram. The conventional production group has on average lower yields than the integrated production group (cfr. Table 1). Hence, impacts that were significantly lower per hectare for the conventional system aren't significantly different anymore.

INSERT TABLE 5 HERE

4.4. Internalizing external costs

External cost are calculated global warming, acidification and eutrophication. We find a total external cost of 1044.7 euro per hectare for integrated farm practices (table 6). If we add this external cost to the average private cost for growing Jonagold apples in Flanders (18,627 euro per hectare according to FADN in 2010 for integrated farm practices) we obtain a real cost of 19671.7 euro per hectare. In other words, the production cost increases with 5 percent. The same occurs when the real cost is calculated per kilogram of apples. The real cost (private plus external costs) expressed per kilogram is 0.38 Euro. FADN calculated a private cost of 0.36 Euro so also in this case the production cost increases with 5 percent when external costs are added to the private costs. The largest contribution to external costs is coming from global warming. This is because the long term effects of greenhouse gasses are included in the cost calculation(De Bruyn et al. 2010).

INSERT TABLE 6 HERE

5. Discussion

The study demonstrated the possibility to perform an environmental impact assessment of agricultural farms and sectors based on FADN Data. In this way current practices could be evaluated for a large number of observations. Data on input use (pesticides, fertilizers and fuels), land use, planting density and yields were accessible through FADN and could be integrated in the study. Data on buildings and machines were less detailed and could therefore not be integrated. The accessibility of data will however be different in other regions or member states because much freedom is given to the monitoring units in each state on how to gather data.

Calculated impacts related to global warming, acidification and eutrophication could be converted into monetary units in order to calculate the external cost. The study finds that private costs per kilogram and per hectare should at least increase with 5 percent in order to reflect the real cost to society. As such, this study provides the minimum cost that should be added (e.g. through taxation) to private costs to reach an equilibrium more in line with the socially desired optimum. Other costs, like environmental and health costs related to toxicity (in particular from pesticides) could not be included and as such the external costs might even be higher. In addition, issues like carbon sequestration in the soil, biodiversity or landscape effects are also not considered and might also affect the magnitude of the external cost linked to apple production. However, the approach enabled the evaluation and comparison of the most relevant costs and in addition it demonstrated the feasibility of assessing external costs based on accountings of the EU.

The study further investigated whether integrated apple production in Flanders is an improvement in terms of environmental impact compared to conventional production. The switch towards integrated fruit production has started in the nineties, stimulated by the regional government and retailers. The codes of practices developed by these actors were aiming at lower negative impacts on the environment. In particular, they included a list of pesticides to use in order to lower the toxic effects on the environment. Our findings show that integrated producers in Flanders are indeed using today on average less insecticides per hectare, however, the overall average pesticide hazard on the environment was significantly higher for integrated than for conventional producers. This is due to the fact that integrated producers are still using a significant amount of fungicides and herbicides. Integrated producers were also on average depleting significantly more non renewable energy sources and were significantly more contributing to terrestrial acidification. The major reason for these two latter impacts is that integrated producers were using a larger amount of fuels during field operations. The conventional producers were on the other hand using more fertilizers than the integrated group. Consequently, there are no significant differences between the two groups in contribution to global warming and eutrophication. From these findings we can’t conclude that integrated fruit production is an improvement compared to conventional production. For none of the impact categories the integrated producers showed significantly better results compared to the conventional producers. A possible explanation for this is that integrated fruit producers are today producing the best quality fruit, sold under the best quality labels, hence farmers are more intensively ‘taking care’ of their plantations, and by consequence they still spread a lot of fungicides and herbicides and they use a large amount of fossil fuels, resulting in a significant impact on the environment.

Another interesting result is that both the ratio between maximum and minimum values and the variability in impact were higher for the integrated group compared to the conventional group. Integrated producers seem to experiment with new codes of practices (depending on the retailer and the quality label) and hence there’s a wider range of inputs and techniques that they use compared to the conventional producers which follow more standard practices. This results in larger differences in environmental impacts. The findings showed also that the skewness of the impact of the integrated producers was mainly positive, indicating that a number of agricultural companies were having a much higher impact compared to the expected impact. There’s hence an important risk that ‘within the restrictions’ of the codes of practices an integrated producer still has a high impact. For the above reasons we recommend policy makers and market actors to work together and to combine the environmental strengths of each code of practice into one harmonized code in order to have a standard code of practice.

Our findings are also showing that commercial organic apple companies are not per se performing better in terms of environmental impact compared to integrated and conventional practices. The three organic agricultural companies that we have been analyzing showed very different results. Although they are certified with the European organic label and hence they were not using herbicides, their use of fungicides and insecticides can still be high and hence they can still have high toxic effects on the environment. The impacts of the organic group were only significantly different from the integrated group when expressed per kilogram due to lower yields. This is different from the study of Alaphillipe et al. (2013). Alaphillipe et al.

concluded based on experimental set ups that organic practices have lower environmental impacts per hectare compared to low-input practices. Our findings show that the difference in reality is not that straightforward.

6. Conclusion

We conclude that the total cost of producing apples in Flanders increases at least with 5 percent when environmental costs are added to the private costs. We also conclude that the switch to integrated fruit production is not always an improvement in terms of environmental impact compared to conventional production and this in contrast to findings of other studies that rely on experimental (i.e. best-practice) set-ups. Differences in environmental costs and impacts between production groups turned out to be not that straightforward. The study didn't show lower average impacts for the integrated production group compared to the conventional group. In contrary, they showed significantly higher average impacts per hectare for the categories acidification, pesticide hazard and non renewable energy use. The organic farmers showed higher impacts per kilogram due to lower yields. The distribution of the different impacts related to the three production groups demonstrated however large differences between farms of the same production group. Farm specific practices have therefore an important influence on the total environmental impact rather than production group specific practices.

References

Algemene Directie Statistiek en Economische informatie (ADSEI), 2011. Definitieve resultaten van de landbouwtelling van mei 2010.

Alaphilippe A., Simon S., Brun L., Hayer F., Gaillard G., 2013. Life cycle analysis reveals higher agroecological benefits of organic and low-input apple production. Agronomy for sustainable development 33, 581-592.

Blanke M., Burdick B., 2005. Food (miles) for thought- energy balances for locally–grown versus imported fruits. Environmental Science and Pollution Research (ESPR) 12, 125-127.

Cerutti A. K., Bruun S., Donno D., Beccaro G. L., Bounous G., 2013. Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production, *52*, 245 - 252.

Cerutti A. K., Galizia D., Bruun S., Mellano G. M., Beccaro G. L., Bounous G., 2011. Assessing environmental sustainability of different apple supply chains in Northern Italy. In M. Finkbeiner (Ed.), Towards Life Cycle Sustainability Management (pp. 341 - 348). Springer, Netherlands.

Demeyer R., De Baets T., de Schaetzen C., D'hooghe J., Keulemans W., Marchand F., Wustenberghs H., 2012. Duurzame fruitbedrijven: bepalende factoren – indicatoren – hot issues. Vlaamse overheid, Departement Landbouw- en Visserij, afdeling Monitoring en Studie, Brussel.

De Bruyn S., Korteland M., Markowsha A., Davidson M., de Jong F., Bles M., Sevenster M., 2010. Shadow Prices Handbook : Valuation and weighting of emissions and environmental impacts. CE Delft, Netherlands.

De Vries M., De Boer I.J.M., 2010. Comparing environmental impacts for livestock products: A review of life. Livestock Science 128, 1–11.

Dickler E., Schäfermeyer S., 1991. General principles, guidelines and standards for integrated production of pome fruit in Europe. IOBC-WPRS Bulletin 14 (3): 67 p.

Dolman M.A., Vrolijk H.C.J., de Boer I.J.M., 2012. Exploring variation in economic, environmental and societal performance among Dutch fattening pig farms. Livestock Science 149(1-2): 143-154.

Esnouf C., Russel M., Bricas N., 2011. Pour une alimentation durable: Reflexion stratégique duALIne. Editions Quae, Paris, France.

Flemish Government, 2004. Order of the Flemish Government of 24 March 2004 to recognition of the integrated production method for pit fruit and of the producers who cultivate according to this method. 10.06.2004: 43848. Moniteur belge/Belgisch staatsblad.

Intergovermental Panel on Climate Change (IPCC), 2006. IPCC guidelines for national greenhouse gas inventories (Vol. 4 - Agriculture, forestry and other land use). IGES, Japan.

Heijungs R., Guinee J.B., Huppes G., Lankreijer R.M., Udo de Haes H.A., Wegener Sleeswijk A., 1992. Environmental life cycle assessment of products. Guide. Leiden.

Houghton J.T., Meira Filho L.G., Callander B.A., Harris H., Kattenberg, A., Maskell, A., 1995. Climate change. In: The Science of Climate Change. Cambridge University Press, United Kingdom.

Intergovermental Panel on Climate Change (IPCC), 2006. IPCC guidelines for national greenhouse gas inventories (Vol. 4 - Agriculture, forestry and other land use). IGES, Japan.

International Organiszation for Standardization (ISO), 2006. International Standard 14044:2006 Environmental Management - Life Cycle Assessment –Requirements and Guidelines.

Jan P., Dux D., Lips M., Alig M., Dumondel M., 2012. On the link between economic and environmental performance of Swiss dairy farms of the alpine area. International Journal of Life Cycle Assessment 17(6), 706-719.

Jensen A. A., Hoffman L., Moller B. T., Schmidt A., Christiansen K., Elkington K., Van Dijk F., 1997. Life cycle assessment, a guide to approaches, experiences and information sources.

Kovach J., Petzoldt C., Degni J., Tette J., 1992. A method to measure the environmental impact of pesticides. New York's food and life sciences bulletin, 139, 1 - 8.

Kirwan J., 2004. Alternative Strategies in the UK Agro-Food System: Interrogating the alterity of farmers' markets. Sociologia Ruralis, 44, Nr 4.

Mila i canals L., Burnip G.M., Cowell S.J., 2006. Evaluation of the environmental impacts of apple production using Life cycle assessment (LCA): case study in New Zealand. Agriculture, Ecosystems and Environment 114, 226-238.

Mouron P., Scholz R. W., Nemecek T., Weber O., 2006. Life cycle management on Swiss fruit farms: Relating environmental and income indicators for apple-growing. Ecological Economics, 58, 561 – 578.

Mouron P., Scholz R. W., Nemecek T., Weber O., 2006. Management influence on environmental impacts in an apple production system on Swiss fruit farms: Combining life cycle assessment with statistical risk assessment. Agriculture, ecosystems and environment, 114, 311-322.

Nemecek T., Kagl T., 2007. Life cycle inventories of Swiss and European Agricultural Production Systems. Final report ecoinvent V2.0. NO.15A. Agroscope Reckenholz-Taenikon Research Station ART, Swiss Centre for Life Cycle inventories, Zurich and Dübendorf, Switserland.

Pollan M. , 2006. The omnivore's dillema: a natural history of four meals. Penguin books, USA.

Pretty J.N., Brett C., Gee D., Hine R.E., Mason C.F., Morison J.I.L., Raven H., Rayment M.D., Van der Bijl G., 2000. An assessment of the total external costs of UK agriculture. Agricultural Systems 65, 113-136.

Pretty J., Ball A.S., Lang T., Morison J., 2005. Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. Food Policy, 30, 1-19.

Reganold J. P., Glover J. D., Andrews P. K., Hinman H. R., 2001. Sustainability of three apple production systems. Nature, 410, 926 - 930.

Poritosh R., Daisuke N., Takahiro O., Qingyi X., Hiroshi O., Nobutaka N., Takeo S. A review of life cycle assessment (LCA) on some food products. Journal of Food Engineering, 90, 1–10.

Spaargaren G., Oosterveer P., Loeber A., 2013. Food practices in transition: changing food consumption, retail and production in the age of reflexive modernity. Routledge studies in sustainability transitions.

Thomassen M.A., Dolman M.A., van Calker K.J., De boer I.J.M., 2009. Relating life cycle assessment indicators to gross value added for Dutch dairy farms. Ecological Economics 68(8-9), 2278-2284.

Van Broekhoven E., Somers L., Tacquenier B., 2012. Overzicht van de boekhoudkundige resultaten van 749 land- en tuinbouwbedrijven Boekjaar 2010. Landbouwmonitoringsnetwerk, Beleidsdomein Landbouw en Visserij, afdeling Monitoring en Studie, Brussel.

TABLES

Table 1: Shadow prices for global warming potential, acidification potential and eutrophication potential.

Impact category	Shadow price
Global warming potential	0,402 €/ kg $C0_2$ equivalents
Acidification potential	0,237 €/ kg $S0_2$ equivalents
Eutrophication potential	0,60 €/ kg PO_4^{3-}equivalents

Source: own calculations based on De Bruyn et al. (2010)

Table 2: Use of inputs and outputs per hectare in the three production groups

	Conventional				Integrated				Organic			
	Mean	CV (%)	Min	Max	Mean	CV(%)	Min	Max	Mean	CV (%)	Min	Max
INPUT												
Fertilizers (kg)												
• **Nitrogen**	72.3	70.7	3.5	206.5	71.2	56.8	3.0	191.2	64.9	61.2	2.6	118.9
• **Phosphor**	12.7	93.9	0.02	43.8	11.9	81.8	0.3	47.3	15.8	67.1	3.6	26.9
• **Potassium**	60.5	81.2	0.1	195.2	41.1	85.3	0.3	145.8	33.6	83.8	3.0	75.5
Pesticides (kg active matter)												
• **Insecticide**	3.1	91.6	0.2	11.6	1.9	84.5	0.2	8.3	17.5	88.7	0.8	51.3
• **Fungicides**	25.9	41.2	2.0	52.5	26.4	40.2	2.1	62.0	20.8	61.3	1.2	37.1
• **Herbicides**	4.0	63.1	0.7	9.7	5.1	50.7	0.4	12.6	0.0	0.0	0.0	0.0
Fuel (GJ)	12.7	33.6	3.2	24.8	17.0	45.4	2.1	47.6	21.7	34.5	14.7	36.6
OUTPUT												
Yield (t)	41.2	47.9	3.5	82.3	47.7	40.1	2.8	100.3	36.7	70.2	8.1	90.2

Table 3: Environmental impacts per hectare of the three production groups

	Conventional			Integrated			Organic		
	Mean	CV (%)	Skew	Mean	CV (%)	Skew	Mean	CV (%)	Skew
Global warming (t CO2 eq.)	2.6	33.8	0.5	2.5	47.8	-0.1	3.0	30.9	1.2
Acidification (kg SO2eq.)	89.6*/**	28.0	-1.0	102.2	50.3	0.1	130.4	18.7	0.3
Eutrophication (kg PO4eq.)	27.7	42.5	0.6	25.9	54.1	0.3	32.3	27.9	- 0.1
Pesticide hazard (EIQ)	10.5*/**	21.2	0.1	10.6	54.5	0.2	12.4	59.7	- 0.4
Non renewable Energy use (GJ)	47.0*/**	24.7	- 0.9	56.9	53.0	0.4	65.7	18.7	0.2

*significantly different from the integrated group (p<0.01) (based on Kolmogorov-Smirnov test)

** significantly different from the organic group (p<0.01) (based on Kolmogorov-Smirnov test)

Table 4: The environmental impact per hectare represented by the minimum and maximum values for the integrated and conventional production groups.

	Conventional			Integrated		
	Mean	Min	Max	Mean	Min	Max
Global warming (t CO2 eq.)	2.6	1.1	4.4	2.5	0.1	5.1
Acidification (kg SO2eq.)	89.6*	6.3	125.6	102.2	5.2	226.3
Eutrophication (kg PO4eq.)	27.7*	7.2	56.0	25.9	0.8	61.8
Pesticide hazard (EIQ)	10.5*	0.6	15.3	10.6	0.1	24.5
Non renewable Energy use (GJ)	47.0*	14.8	65.7	56.9	3.6	138.3

*significantly different from the integrated group (p<0.01) (based on Kolmogorov-Smirnov test)

Table 5: Environmental impacts per kilogram of the three production groups

	Conventional			Integrated			Organic		
	Mean	CV (%)	Skew	Mean	CV (%)	Skew	Mean	CV (%)	Skew
Global warming (g CO2 eq.)	64.3	51.1	0.8	54.1	58.9	0.4	152.4*/**	58.2	0.4
Acidification(g SO2eq.)	2.2	46.2	0.6	2.2	60.4	0.5	5.2*/**	54.8	0.5
Eutrophication (g PO4eq.)	0.5	40.6	0.4	0.5	63.2	0.5	1.0*/**	57.6	0.8
Pesticide hazard (EIQ)	26.3	50.9	0.6	26.1	64.8	0.6	34.9*/**	66.7	0.8
Non renewable Energy use (MJ)	1.2	47.4	0.9	1.2	59.3	0.5	3.2*/**	62.3	0.8

*significantly different from the integrated group (p<0.01) (based on Kolmogorov-Smirnov test)

** significantly different from the conventional group (p<0.01) (based on Kolmogorov-Smirnov test)

Table 6: external costs per hectare and per kilogram related to the expected global warming, acidification and eutrophication impacts of the three production groups

	Conventional	Integrated	Organic
Costs per hectare			
Global warming (€/ha)	1045.2	1005.0	1206.0
Acidification (€/ha)	21.2*/**	24.2	30.9
Eutrophication (€/ha)	16.6	15.5	19.4
Total external cost (€/ha)	1083.0	1044.7	1256.3
Costs per kilogram			
Global warming (0.01€/kg)	2.6	2.2	6.1*/**
Acidification (0.01€/kg)	0.1	0.1	0.1*/**
Eutrophication (0.01€/kg)	0.03	0.03	0.1*/**
Total external cost (0.01€/kg)	2.7	2.3	6.3*/**

*significantly different from the integrated group (p<0.01) (based on Kolmogorov-Smirnov test)

** significantly different from the organic group (p<0.01) (based on Kolmogorov-Smirnov test)