Environmental impacts of imported versus locally-grown fruits for the French market as part of the AGRIBALYSE® program

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ABSTRACT

As part of the AGRIBALYSE® project, apple and peach from France, small citrus from Morocco and mango from Brazil were evaluated. Representative systems for each fruit were designed relying mostly on expert knowledge for apple, peach and small citrus and on a detailed survey of 8 commercial orchards for mango from the Rio San Francisco Valley in Brazil. For most impact categories, apple showed the least impacts, small citrus the greatest. Beyond the classical yield effect, this was mostly linked to lower fertilizer rates for apple and to fossil energy share in the electricity. For marine eutrophication, mango and small-citrus had the least impact, followed by apple and peach far above. For ecotoxicity, mango had the least impact followed by apple, peach and small citrus far above. Ecotoxicity results revealed the most uncertain due to the difficulty to determine representative crop protection practices for perennial crops. Complementary research is needed to better model crop protection practices, field emissions and water use impacts.

Keywords: Fruits; environmental impacts; crop protection practices; uncertainty; representative systems

1. Introduction

As all other food products traded globally, fruits are under growing scrutiny regarding their environmental impacts. In France, the Agribalyse® program was launched by the French environment agency (ADEME) in 2009 to support environmental labeling as planned by the "Grenelle de l'environnement" roundtables. Based on the life cycle assessment (LCA) methodology, the objective of Agribalyse® was the development of a homogenous and consensual LCI database for French agricultural products and a few imported products. In France, 50% of fruits are produced locally and 50% are imported often from distant and warm countries. As part of the Agribalyse® program, two locally-produced fruits: apple and peach, and two imported from overseas: small citrus from Morocco and mango from Brazil were evaluated. The evaluation of fruits with LCA is quite recent, the most studied fruits being citrus (Sanjuan et al. 2005; Beccali et al. 2009; Trydeman Knudsen et al. 2011; Pergola et al. 2013; Lo Giudice et al. 2013) and apple (Mila i Canals et al. 2006; Mouron et al. 2006; Alaphilippe et al. 2013). Ingwersen (2012) recently published a full LCA study on pineapple from Costa-Rica, but tropical fruits have been seldom studied with complete LCA studies. The application of LCA to fruit cropping systems has revealed specific challenges related mostly to their variable and perennial cropping systems, frequent pesticide treatments and use of irrigation water (Mouron et al. 2006; Bessou et al., 2012; Cerutti et al., 2011 and 2013). Although most LCA studies do not account for the perennial cycle of fruit cropping systems, certain authors have recommended the inclusion of all phases of fruit orchards in the LCA modeling of fruits including nursery, orchard installation, growing of trees, full production phase and possibly decreasing-yield phase and dismantling of plantation (Mila i Canals et al. 2006; Cerutti et al. 2011; Bessou et al. 2012; Cerutti et al. 2013). Bessou et al. (2012) proposed a formalization of the different possibilities to account for the perennial cropping systems depending on the objective of the study and data availability. One can either use a spatial assessment, a chronological assessment or a modular assessment, presented as the minimum requirement to account for the perennial cropping cycle. A modular assessment in which each phase is modeled independently with different sources of data can be used when neither complete spatial data nor chronological data are available on the studied system. Bessou et al. (2012) also highlighted the inadequacy of usual methods for estimating field emissions for perennial cropping systems especially under tropical, sub-tropical or semi-arid conditions. For instance, tropical and sub-tropical systems remain clearly underrepresented in IPCC Tier 1 data sets. Bessou et al. (2012) concluded on the need for producing specific data sets on perennial cropping systems to improve existing operational models and the prediction of their field emissions. Finally, several authors also raised the issue of the choice of functional unit and allocation procedures for fruit products, insisting on the various qualities of fruits including their edible content. Ingwersen (2012) used the serving of fruit (165 g fresh fruit according to USDA 2009 definition) to express his results and compare with other LCA studies. Cerutti et al. (2013) recommended indicating the edible content of fruits when a mass-based functional unit is chosen. Regarding the comparison of imported fruits with locally-grown equivalent, the question of allocation may be crucial since the fruits exported correspond to the highest quality fruits, the lower quality fruits being usually sold locally.

In a context of recent application of LCA to the fruit sector, the objective of the Agribalyse® program was not to develop new research but to properly apply the consensual and up-to-date methodology for all agricultural products including fruits.

The objectives of this paper are:

- To present the methods and data used to design and assess fruit cropping systems in each situation
- To present and discuss the LCA results for the 4 fruits in relation to existing literature, methodological choices, data availability and studied function
- To identify some margins of improvement and research perspectives

2. Materials and methods

2.1. Goal and scope

The main objectives of this study were:

- Comparing a panel of major fruits produced with conventional rules and consumed in France, two locally-grown: apple and peach and two imported: mango from Brazil and small citrus from Morocco.
- Applying the consensual methodology of the AGRIBALYSE® project (Koch and Salou, 2013).
- Designing most representative systems as possible for each situation given the data availability.

In line with the Agribalyse® method, the functional unit used was 1 kg of fruit at farm-gate. Representative systems for each fruit were designed relying mostly on expert knowledge for apple, peach and small citrus and on a detailed survey of 8 commercial orchards for mango from the Rio San Francisco Valley in Brazil. The reference period defined in the Agribalyse® report is 5 years from 2005 to 2009 but must reach 10 years for strongly alternating productions such as fruits. This was formally possible for mango where data were collected over more than 20 years on real orchards but relied on expert advice for other fruits supposed to include seasonal and regional variability over the orchards' life. For crop protection practices, data were based on a large sample survey (349 field surveys) for apple, on expert advice for peach and small citrus and on average data for the 8 surveyed orchards for mango. For all fruits, the full orchards' life was modeled according to recent practice (2000-2010) as presented in section 2.2.1 using either real data or expert advice.

2.2. Studied systems

In agreement with the AGRIBALYSE® method, the system boundaries were set from cradle-to-farm-gate including the production, transport and use on the farm of all inputs except very minor tools and inputs, e.g. pruners, and non-agricultural buildings (Figure 1).

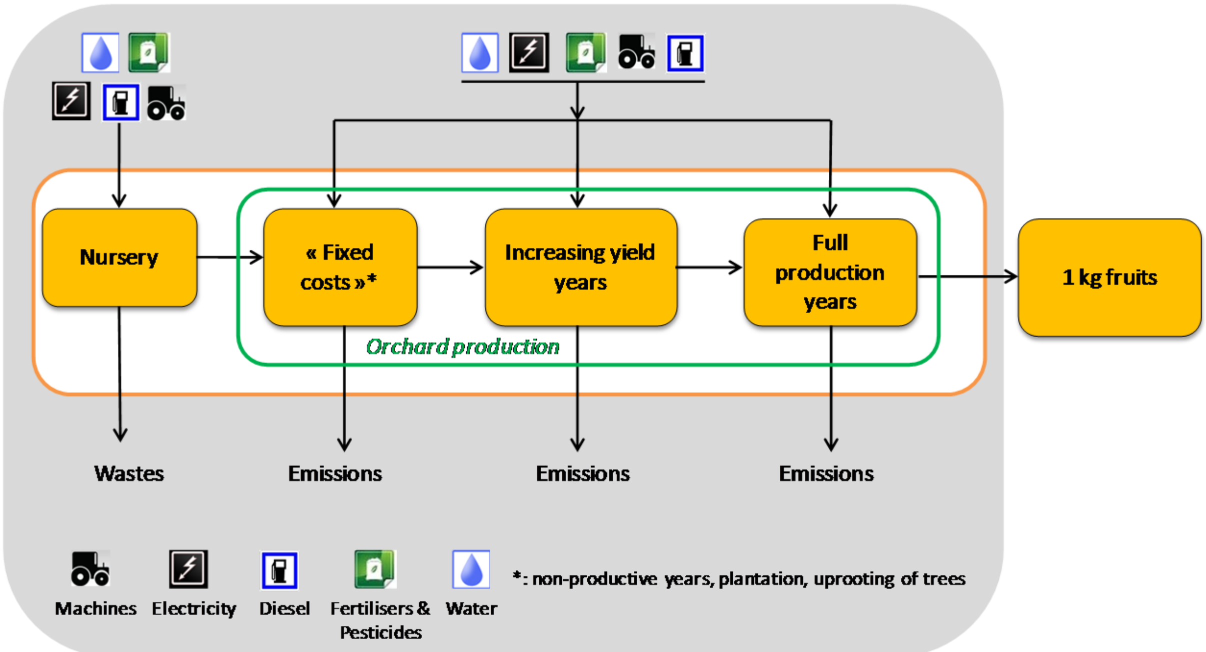

Figure 1. Cradle-to-farm-gate fruit systems for apple and peach from France, mango from Brazil and small citrus from Morocco

2.2.1. Modelling of perennial cropping systems

According to the AGRIBALYSE® methodology, the perennial cropping system was modeled in four phases: nursery (or plant production), fixed costs (including plantation, non-productive years and uprooting of trees at the end of the orchard life), increasing yield years and full production years. This implied to collect or estimate representative data for all four phases in terms of agronomic practices and duration. An important assumption for perennial cropping systems is the life time of the orchard. It was assumed to be 20 years for apple, 15 for peach, and 25 years for mango and small citrus.

2.2.2. Apple from France

Apple is mainly produced in the South-East, the South-West and the Loire Valley regions in France, according to 38%, 31% and 23% surface-wise, respectively (Agreste, 2008). In each region, experts of apple production from technical extension services and farmers' associations participated in the design of most representative apple production systems for the recent period. The average conventional system was a combination of non-scab and scab resistant (or tolerant) varieties across all regions weighted by their respective share. Crop protection practices were based on a survey from a large sample of orchards (349 field surveys) for the period 2005-2008. These data for the full production phase (years 5 to 20) were extrapolated to the entire life cycle of the orchard ignoring the constant evolution of active molecules certification. For the first (non-productive) years, crop protection practices were assumed to be one third of that for full production years while they were assumed to be two thirds for increasing yield years (from 2 to 4). Only the most common molecules were selected from the survey. Data for the nursery phase was based on the survey of two nurseries, one in the Loire Valley region the other in the South-East region. Key agronomic data for the full production phase of apple production and other fruits are presented in Table 1.

2.2.3. Peach from France

The production of peach is mainly located in the South of France. Similarly to the apple inventory, experts of peach production from technical extension services and farmers' associations were involved in the design of the most representative peach production systems for France for the recent period. Based on national statistics from Agreste (2008), the national average system was the weighted (surface-wise) combination of early, median and late productions, influencing the yield, mechanization requirements, crop protection and irrigation practices (see table 1 for full production phase). Two commercial nurseries representing more than 25% of the production of peach scions and grafted plants were surveyed to design the nursery phase. Crop protection practices were based on expert knowledge for the full production phase (years 5 to 15) and extrapolated to other phases of the orchard assuming one third of pesticide inputs from the full production was applied for the first non-productive years (years 1 and 2) and two thirds for increasing yield years (years 3 and 4).

Table 1. Main agronomic data for the full production phase of apple (France), peach (France), mango (Brazil) and small citrus (Morocco). Values are given per annum.

Intervention	Unit	Apple	Peach	Mango	Small citrus
Country		France	France	Brazil	Morocco
Orchard age	Years	20	15	25	25
Density	Trees/ha	1730	640	280	500
Yield	t/ha	53,7	28	33	28
Fertilisation					
N	kg/ha	50	110	165	180
P_2O_5	kg/ha	30	100	100	45
K_2O	kg/ha	125	220	273	180
Irrigation					
Water	m^3/ha	2767	7000	7999	8000
Energy	MJ/ha	2,988	7,560	2,946	22,830
Plant protection products					
Total herbicides	kg/ha	3.4	4.4	0	10.2
Total insecticides	kg/ha	5.1	0.7	0.301	9.58
Total fongicides	kg/ha	38.4	24.2	5.66	16.5
TOTAL pesticides	kg/ha	48.9	29.3	5.961	36.3
Growth regulators	kg/ha	0.2	0	4.03	0.02
Petroleum oils	kg/ha	12.3	16.3	0	0

2.2.4. Mango from Brazil

Brazil is the leading supplier of fresh mangoes to the EU. In the Rio San Francisco Valley which concentrates more than 90% of Brazilian mango exports, modern and intensive production systems have developed. These systems feature year-round production thanks to well-controlled floral induction and abundant dam water access. In this region, a sample of eight contrasted Kent and Tommy Atkins mango orchards was surveyed in 2012. Data over the complete crop cycle of mango trees was collected, over more than 20 years for elder orchards. Despite this detailed and very time consuming survey, many input and yield data were missing over the 25 years of mango orchards. Annual average for all input and yield data available across the eight orchards were first calculated and aggregated into average data for each phase (see table 1 for full production phase). No nursery was included since grafted plants are produced on farm.

2.2.5. Small citrus from Morocco

In Morocco, small citrus for export to France are produced in two main regions of production: the Souss region and the Oriental region (Berkane area) with, for the 2009-2010 season, 55.6% of small citrus exported and 32.8%, respectively (EACCE, 2010). Until recently in each region, specific varieties and cropping system management were used. In the Oriental region, traditional practices included mainly Clementine varieties such as Cadoux, low density orchards (270 trees.ha^{-1}) and gravity irrigation, while in the Souss region the management was more modern and intensive using mostly the Nour variety, high density orchards (500 trees.ha^{-1}) and drip irrigation. According to local experts, the Oriental system is rapidly evolving toward a more modern management very similar to the Souss system. For this reason, we chose the Souss system using Nour variety, high density orchards and drip irrigation as the most representative for the Moroccan small citrus for export to France.

Key input and yield data for the representative Souss-Nour system were based on expert knowledge of the small citrus production in Morocco for each phase of the citrus orchard (see table 1 for full production phase). Other more specific operations and data were based on a detailed survey over the whole orchards' life of one commercial orchard of small citrus from the Beni Mellal region. Regarding crop protection practices, the main pests were inventoried and the most common practices and active molecules used for each pest defined. Other practices may exist. A detailed survey was conducted in a commercial nursery to design the nursery phase.

2.3. Environmental inventory

2.3.1. Emissions from orchards

To estimate field emissions, the AGRIBALYSE® recommendations were applied (Koch and Salou, 2013). Phosphates and pesticides emissions were calculated according to Nemecek and Kägi (2007), assuming that 100% of the pesticides applied would be emitted to the soil (Nemecek and Kägi 2007). Nitrous oxide, carbon dioxide from urea and lime and nitrate leaching were estimated according to IPCC (2006). Ammonia emissions were based on emission factors from EMEP/CORINAIR 2006 and nitrogen oxides according to EMEP/EEA (2009). According to IPCC (2006), nitrate leaching was considered nil for mango and small citrus because localized irrigation is used and rainfall is reduced in both regions (daily irrigation (or rainfall) volume was constantly below the soil field capacity) while for apple and peach it was assumed to be 30% of the nitrogen inputs. The SALCA-SM method was used for trace elements but only for French products since data was missing for imported fruits (Freiermuth, 2006 and SOGREAH, 2007). For land transformation, the Ecoinvent v2 reference was used (Frischknecht et al., 2007).

2.3.2. Indirect inventory data

Indirect inventory data were based on Ecoinvent Life Cycle Inventories (LCI) database available in the SIMAPRO software and on processes developed specifically for the studied production system and the country.

2.4. Characterization of environmental impacts

The impact assessment was performed using the ReCiPe Midpoint life cycle impact assessment method (Goedkoop et al., 2009), adopting the Hierarchist perspective. The following environmental impact categories were considered: climate change (100 years; kg CO_2eq), terrestrial acidification (g SO_2eq), freshwater and marine eutrophication (g P-eq and g N-eq respectively, based on the nutrient-limiting factor of the aquatic environment), terrestrial and freshwater ecotoxicity (g 1,4-DB-eq: 1,4-dichlorobenzene), agricultural land occupation (m^2.year), fossil depletion (kg oil-eq). The non-renewable energy consumption (fossil and nuclear; MJ-eq) was assessed using the Cumulative Energy Demand method (Hischier et al. 2009). To facilitate comparison with published LCA studies, we also calculated LCIA results using the CML 2001 methodology (Guinée et al., 2002) (see section 2.5).

2.5. Comparison with published LCA studies

We compared our cradle-to-farm-gate LCA results with cradle-to-farm-gate LCA results from 9 published studies on fruits using the CML 2001 methodology (Guinée et al., 2002) (Table 2). Incomplete LCA studies were discarded. Among all studies, GWP and Non-renewable energy demand were the most consistently evaluated and could be systematically reported. Apart from Pergola et al (2013) who evaluated both non-renewable and renewable energy sources based on Namdari et al. (2011), all other authors used different versions of the Ecoinvent method for cumulative energy demand in MJ (Frishknecht et al., 1996; Frishknecht et al., 2003; Hischier et al., 2009). For eutrophication and acidification potentials, most studies used CML 2001 or EDIP97 which are identical for eutrophication and slightly different for acidification (Dreyer et al., 2003). Several studies did not include toxicity impacts due to methodological limitations (Beccali et al., 2009; Trydeman Knudsen et al., 2011; Pergola et al., 2013). In other studies a range of approaches was used for toxicity impacts. We only selected results from studies using the CML methodology: Sanjuan et al. (2005), Alaphilippe et al. (2013).

3. Results

3.1. Cradle-to-farm-gate LCA results for apple, peach, mango and small citrus

Except for marine eutrophication, terrestrial ecotoxicity and freshwater ecotoxicity, apple revealed the least impacting per kg of raw fruit at-farm-gate, followed by mango, peach and small citrus showing the greatest impacts (from twice to four times apple's impacts) (Table 2; Figure 2). This was firstly due to the yield of raw fruits ranging from 54 t/ha at full production for apple, to 33 t/ha for mango and 28 t/ha for peach and small citrus. A second important aspect was the fertilizer rates on orchards increasing from apple, peach, mango and small citrus. Overall, the two imported fruits showed higher fertilizer rates than the French ones. Another reason for this ranking was the share of fossil energy in the mix electric in each country, increasing from France (less than 10%), Brazil (10%) and Morocco (50%).

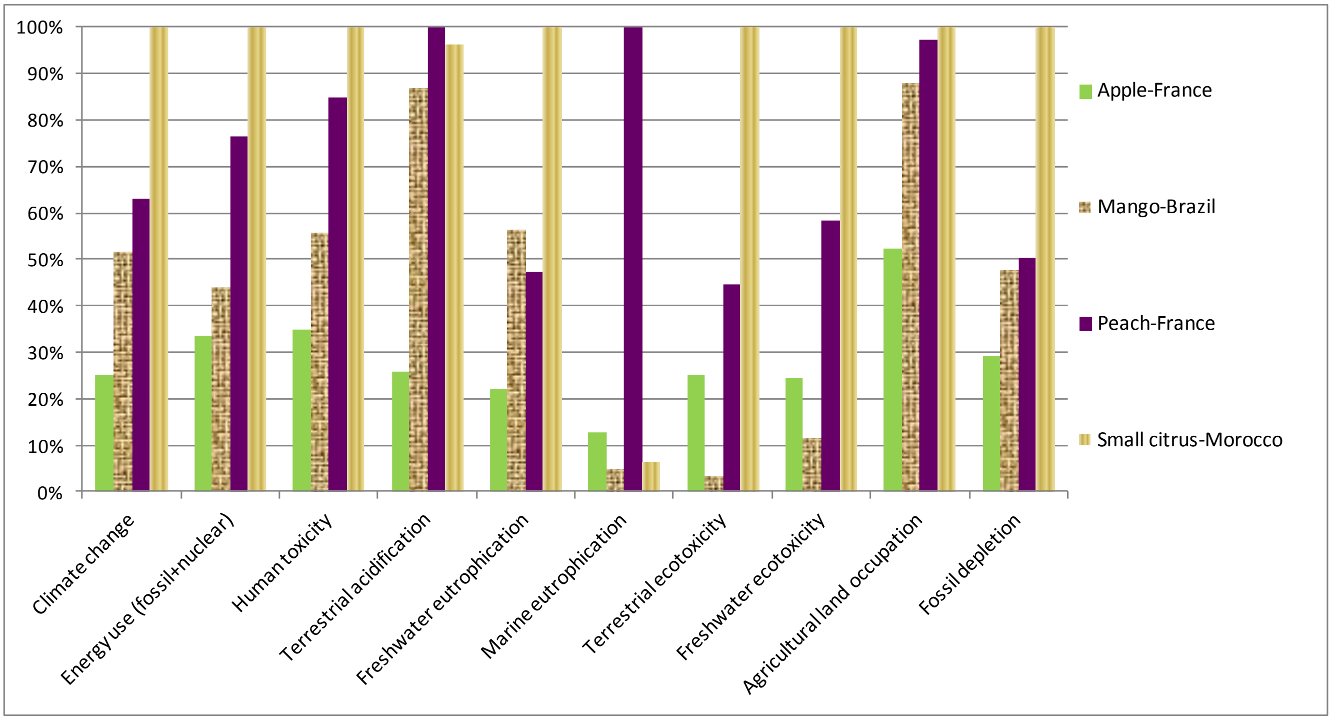

Figure 2. Cradle-to-farm-gate LCA results per kg of raw fruit for a selection of environmental indicators (ReCiPe Midpoint (H)) for apple, mango, peach and small citrus. Results are expressed as a percentage of the greatest result.

Table 2. Cradle-to-farm-gate LCA results per kg of raw fruit for a selection of environmental indicators (ReCiPe Midpoint (H); Cumulative Energy Demand) for apple, mango, peach and small citrus.

	Apple France	Mango Brazil	Peach France	Small citrus Morocco
Climate change (kg CO_2-eq)	0.0678	0.139	0.170	0.269
Non-renewable energy (MJ)	1.12	1.46	2.54	3.32
Human toxicity (kg 1,4 DB-eq)	0.0273	0.0436	0.0664	0.0783
Terrestrial acidification (g SO_2-eq)	0.610	2.05	2.36	2.27
Freshwater eutrophication (g P-eq)	0.0283	0.0715	0.0602	0.127
Marine eutrophication (g N-eq)	0.233	0.0842	1.83	0.116
Terrestrial ecotoxicity (kg 1,4 DB-eq)	0.00177	0.000230	0.00312	0.00699
Freshwater ecotoxicity (kg 1,4 DB-eq)	0.00151	0.00071	0.00359	0.00616
Agricultural land occupation (m^2.a)	0.239	0.402	0.445	0.458
Fossil depletion (kg oil-eq)	0.0195	0.0317	0.0334	0.0667

Mango and small citrus had both lower marine eutrophication (around 0.1 g N-eq), compared to apple (above 0.2) and peach (1.8). This was explained by the use of IPCC nitrate emission factors: being nil under drip-irrigated crops in semi-arid climate as mango from Brazil and small citrus from Morocco but reaching 30% of nitrogen inputs for crops under temperate climate as apple and peach from France.

Regarding terrestrial and freshwater ecotoxicity, mango showed for both the least impact followed by apple and then by peach and finally by small citrus far above. The great ecotoxicty impact for small citrus was essentially due to the use of Chlorpyrifos-ethyl for controlling California red scale in small citrus orchards in Morocco. This molecule has a very high toxicity potential and does not have efficient alternative up-to-date. The low ecotoxicity impact for mango was probably also the most uncertain of all since it relied on a small sample of farms. Furthermore, although the use of highly toxic molecules, such as Cypermethrin, in mango orchards had been orally reported we could not find evidence of such treatment in our sample of farms. This would definitely warrant further confirmation through survey across a wider sample of farms.

3.2. Comparison with published references

We could not find complete LCA studies for peach and mango. For apple and small citrus, our results were in the same range as results from the literature for GWP, Energy use, eutrophication and acidification (Table 3). For toxicity impacts, we only had one reference for each product to compare with. Overall, results were of the same order. Overall, the literature references confirm the least impacts of apple compared to citrus at farm-gate. This can be explained by higher nitrogen inputs and energy use for irrigation in citrus production associated to lower yields compared to apple.

4. Discussion

4.1. Farm-gate environmental impacts for 4 fruits consumed in France calculated with the Agribalyse® methodology

Until recently, fruits consumed in France had never been assessed with the LCA methodology. LCA references were therefore crucially needed to feed the eco-labeling program and debate on food products. Two locally-grown and two imported fruits were evaluated with the LCA methodology following a consensual method as dozens of other French agricultural products. This constituted an important step forward. At farm-gate these studies confirmed the greater impacts of citrus compared to apple mainly due to intensive practices associated to lower yield. It also produced novel references for peach and mango for which no LCA studies could be found worldwide. Contrary to most LCA studies on perennial products, in the Agribalyse® methodology the whole perennial crop cycle was modeled which represented an important and systematic progress. Beyond these important achievements, one should remind that in the Agribalyse® program the system boundaries were set at farm-gate which represents a limitation to properly compare imported with local fruits. The first reason relates to the exclusion of the transport of imported fruits to their final market which can represent important impacts. The second limitation is the non-inclusion at that stage of the quality requirements on fruits for export. From the total yield at farm-gate, only a fraction will have the required quality and should be allocated most of the impacts due to its higher economic value compared to the local quality fruits. Locally-grown (French here) fruits also show different qualities but will all end up on the local market. Moreover, in Agribalyse® the functional unit used was the kg of raw fruit while another important aspect for comparing fruits is the actual number of servings per kilogram of fruits also corresponding to their edible part (Ingwersen 2012; Cerutti et al. 2013). Thus, the rules for a proper comparison of imported versus locally-grown fruits need to be analyzed and formalized. At least the system

Table 3. Global warming Potential, non-renewable energy, eutrophication, acidification and toxicity impacts from different LCA studies for fruits and for this study. Results are expressed per kg of raw fruit at farm-gate.

Reference	Selected Product	Country	GWP (kg CO_2-eq)	Non-renewable energy (MJ)	Eutrophication (g PO_4-eq)	Acidification (g SO_2-eq)	Human toxicity (kg 1,4-DB-eq)	Aquatic freshwater ecotoxicity (kg 1,4-DB-eq)	Terrestrial ecotoxicity (kg 1,4-DB-eq)
Mila i Canals et al. (2006)	Integrated apple	New Zealand	0.04 – 0.095	0.41 - 0.7	n.a.	0.3 – 0.8b	-	-	-
Mouron et al. (2006)	Integrated apple	Switzerland	0.083	1.2	0.134	0.809b	-	-	-
Alaphilippe et al. (2013)	Conventional apple	France	0.032-0.038	0.44 - 0.51	0.23 – 0.33	0.20 – 0.23	0.012 – 0.014	0.005 – 0.010	0.002
Sanjuan et al. (2005)	Integrated orange	Spain	0.22 – 0.28	-	1.95	0.07 – 0.09	0.620	-	0.0043 – 0.0054
Beccali et al. (2009)	Lemon	Italy	0.155	2.33	0.636	0.994	-	-	-
	Orange	Italy	0.217	3.42	0.905	1.387	-	-	-
Trydeman Knudsen et al. (2011)	Conventional orange	Brazil	0.112	1.265	0.99	1.1b	-	-	-
Lo Giudice et al. (2013)	Integrated blood orange	Sicily	0.089	1.932	-	-	-	-	-
Pergola et al. (2013)	Conventional lemon	Sicily	0.12	2.85a	-	-	-	-	-
	Conventional orange	Sicily	0.13	2.87a	-	-	-	-	-
Ingwersen (2012)	Pineapple	Costa Rica	0.155	1.45	-	-	-	-	-
This study	Conventional apple	France	0.068	1.1	0.267	0.547	0.053	0.053	0.0038
	Conventional peach	France	0.168	2.5	1.27	1.83	0.119	0.135	0.0115
	Conventional small citrus	Morocco	0.269	3.3	0.679	2.08	0.107	0.733	0.0176
	Conventional mango	Brazil	0.139	1.5	0.49	1.64	0.079	0.061	0.0068

a: based on Namdari et al (2011), these figures include both renewable and non-renewable energy sources but Pergola et al (2013) explained that the renewable energy share is reduced to 5% in conventional systems. b: presented figures correspond to EDIP97 for Mila i Canals et al. (2006) and Trydeman Knudsen et al (2011) and to Heijungs et al. (1992) for Mouron et al. (2006) being probably overestimated compared to CML 2001 acidification results.

boundaries should be extended beyond the farm-gate to include transportation phases, fruit quality (including edible part) and allocation issues between the different fruit qualities. Regarding the method used for estimating field emissions, the most consensual and up-to-date ones were chosen which represented an important progress. However, the very generic emission factors used (such as IPCC or EMEP-CORINAIR ones) are not particularly valid for perennial crops under semi-arid climate. This represents definitely an important margin of progress and perspective for research. Finally, although water deprivation can represent a key environmental problem for fruit production, this indicator could not be included in the Agribalyse® program and this should be completed in upcoming studies.

4.2. Design of representative systems

One key difficulty of the Agribalyse® objectives was the design of representative systems in terms of technology, time and space. Important discrepancies between situations were faced in terms of data quality and availability. Where statistical average systems could be calculated for some products, others such as fruits were mostly evaluated through expert-based scenarios (apple, peach, small-citrus) or small samples of farms (mango). If expertise can be satisfactory for estimating most inputs and agronomic data, it is insufficient to capture the actual shares of pesticides used across a population. Knowing that certain active molecules have very high toxicity potentials, not having this statistical representation constitutes an important bias in the assessment of an average system. Using a small farm sample for mango proved even weaker in its capacity to capture the diversity of pesticide treatment practices and results for toxicity impact categories for mango should be seen as very uncertain. For French fruits, an additional effect has to be reported. Due to the French ECOPHYTO program aiming at reducing drastically pesticide use in France, most toxic molecules have been banned since 2009 (last year of the period covered by the Agribalyse systems). This means that a lot of molecules of pesticides used in our systems for apple and peach are no longer certified and used. Finally, it is important to keep in mind that designing representative practices over a period of 25 years represents a contradiction in itself and a difficult challenge especially for pesticide treatments which follow constantly changing rules.

5. Recommendations and conclusions

The Agribalyse® program permitted the production of a vast and consensual LCI database for French agricultural products including 4 fruits. This was definitely an important step forward. Effort should be continued to improve the representativeness of the average systems, develop the LCA beyond the farm-gate, include water deprivation and improve the methods for estimating field emissions under perennial cropping conditions in the South.

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