An LCA of French Beans from Kenya for Decision-makers

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Abstract:

Although challenging, private and public decision-makers increasingly demand for quantitative assessments of the environmental performance of value chains in South contexts. This paper presents and critically analyzes a complete LCA study performed with Endpoint indicators for a public decision-maker for the fresh French bean (FB) value chain of Kenya. A cradle-to-gate LCA study was done including five main stages: agricultural production, transport by road before packhouse, packhouse, and transport by road after packhouse, and intercontinental transport by air-freight; using 1 kg of raw French bean processed as functional unit. Supported by local experts, primary data were collected for all inputs and outputs for 33 farms over five counties and two packhouses. An expert-based typology defined four farm types: large-farm, medium-farm, smallholder farm (SHF) contracted and smallholder farm scattered. Best available methods for field emissions were used and adapted when possible to local conditions (e.g. P losses). At market-gate, air-freight was identified as main hot-spot pleading for the design of stabilized FB products that could be sea-freighted. At farm-gate, large differences were observed between farm types, with the medium-farm obtaining the least impacts per kg of French bean, and fertilizer, water and land use being the key-drivers of their eco-efficiency. Impacts due to pesticides applications were small at Endpoint level but were incomplete. These results should be validated with a greater sample of stakeholders and the scope of the LCA should be extended to the consumption stage. Further research is also needed to provide LCA practitioners with operational and reliable tools for a better inclusion of pesticides' impacts and uncertainty.

Key Words: *LCA; decision-makers; French bean; Kenya; pesticides*

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1. INTRODUCTION

To support their decisions, public and private decision-makers increasingly demand for quantitative and reliable evaluations of all dimensions of the sustainability framework for agri-food value chains in developing contexts, most of the time under a very tight time frame and producing a reduced set of results and indicators. Although recognized as the most consensual and relevant methodology for the assessment of environmental impacts, LCA remains difficult to apply in such conditions. This is mainly due to the diversity and complexity of production conditions and systems, the limited awareness and capacities in LCA by stakeholders, the scarcity and often low-quality of statistic data, and the limits imposed to LCA commissioned from abroad (e.g. time and budget constraints) [1]. Furthermore, to provide decision-makers with a reasonable set of aggregated indicators, the use of Endpoint indicators seems to be the most scientifically sound approach although still associated with uncertainty issues [2] especially under the pedo-climatic conditions prevailing in developing countries. One particular issue on which we wish to insist relates to the characterization of impacts and damages due to pesticide applications: most of these value chains raise high concerns regarding these potential impacts on both workers and consumers' health and the environment.

The fresh French bean (Phaseolus vulgaris (L.)) value chain for export, from Kenya, was selected by the Directorate General for International cooperation and development (DG DEVCO) of the European commission (EC) for a complete evaluation including economic, social and environmental (LCA-based) evaluations. The French bean (FB) sector in Kenya counts around 50 000 small farmers and some big and medium ones in the country. This crop has a great potential for reducing food insecurity, generating incomes and reducing poverty. However, its profitability is threatened by high and increasing production costs due to air-freight, heavy sanitary constraints imposed by the EC, and difficult open-field conditions of production. LCA studies demonstrated the great environmental impacts from air-freight for the fresh FB value chain from Kenya but did not account for the diversity of production systems, used default methods for estimating field emissions (or did not include them at all) and omitted important impacts such as (eco-)toxicity impacts due to pesticides, as well as freshwater deprivation [3][4].

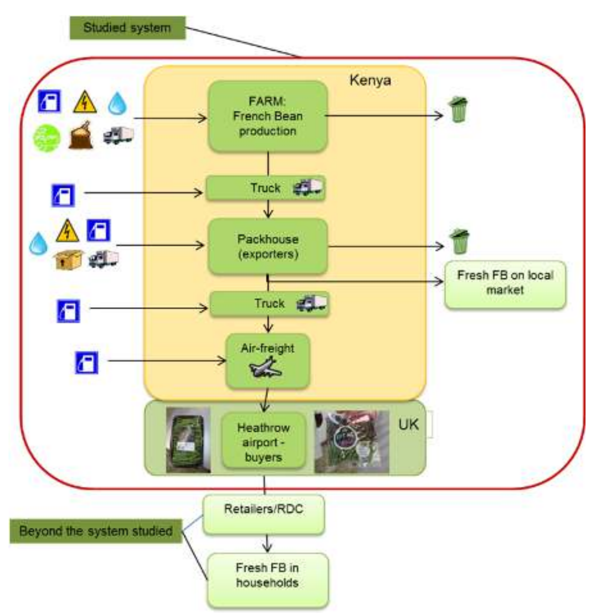
The objectives of this paper are:

- To present the results of a complete LCA study done for DG DEVCO on fresh French beans from Kenya for export to UK market using Endpoint indicators;
- to critically analyze the limits of the results for the decision-making process and especially regarding the evaluation of impacts due to pesticides applications at Endpoint level; and
- to make recommendations for the fresh FB value chain in Kenya and for methodological improvement in similar studies.

2. METHODS

2.1 Goal and Scope

The question asked in this LCA study was: "What are the environmental impacts associated to the current value chain of fresh FB produced in Kenya and consumed in the United Kingdom?". The UK was selected as main export market for Kenyan FB products. The system boundaries were set from cradle-to-gate at the arrival point in the UK (Figure1) and included five main stages: agricultural production, transport by road before packhouse, packhouse, transport by road after packhouse, and intercontinental transport by air-freight. The functional unit was 1 kg of raw French bean, processed and available at market in the UK.



RDC : Regional distribution Centre

Figure 1. System boundary (cradle-to-gate) for fresh French beans from Kenya exported to the UK

The production of all key inputs: fertilizers, pesticides, fuel use for irrigation and land preparation were included in the analysis, as well as their use and related field emissions. Their transportation from regional storehouse to the farm was not included due to lack of data. The transportation of FB by truck was included. The manufacturing and transportation of small materials and machines such as chemical sprayers, basins, wheelbarrow, watering cans and pumps were excluded due to their very small expected contribution. Only for the large-farm surveyed (see next section), agricultural machinery was included for land preparation by using a complete process available in the ecoinvent 3.3 database [5].

2.2 *System Studied*

During field visits, and later by the local team of experts, primary data were collected for all inputs and outputs (yield and residues) for a sample of 33 farms over five counties and two packhouses.

2.2.1 *Cropping system*

The farming system regarding French beans is mainly based on smallholder farmers, which traditionally produce the bulk of the product, but also considered medium-scale and large-scale farms. The majority of smallholder farms have a total land size of less than two hectares, and would produce FB on a portion of the farm, in addition to other crops such as maize, potato, cabbage, tomato, sugar cane, bananas, avocado, plus some livestock (e.g. one or two cows, a heifer or calf, goats, chicken). Among smallholder farmers (SHF), two sub-categories can be distinguished, namely SHF having links with exporters of fresh produce, the so-called SHF-contracted, and those that also produce for fresh exports but without links, the so-called SHF-scattered. An expert-based typology of the farm systems was proposed to account for the diversity of situations. Overall, four farm types were defined: large farm, medium farm, smallholder farm contracted and smallholder farm scattered. A stratified sampling was done following this typology (Table 1) and where possible (for the SHF-contracted type), weighting factors were used to account for the contribution of the different counties to the total production of fresh FB based on local expert's advice. Only one large farm and one medium farm could be surveyed. Agronomic data for all types are presented in Table 2.

2.2.2 *Packhouse*

Two companies sorting and packing fresh French beans for export were surveyed. Based on these two datasets, an average scenario was built and adjusted for data gaps using an LCA study for green bean factory in the USA, in particular the amount of wood pallets used (Table 3) [6].

Table 1. Sample of SHF surveyed across counties and production-weighting factors used for SHF-contracted type

Counties	SHF-contr.	*Factors used for SHF-contr.*	SHF-scatt	Total
Machakos	0	*0*	9	9
Meru	8	*35%*	0	8
Kirinyaga	5	*59%*	1	6
Murang'a	1	*4%*	0	1
Trans Nzoia	7	*2%*	0	7
TOTAL	21	*100%*	10	31

SHF-contr. = SHF-contracted farms; SHF-scatt. = SHF-scattered farms

2.2.3 *Transportation stages*

Based on discussions with surveyed companies and farms, we concluded that transportation distances by road in Kenya could vary a lot across situations but no data on the average distances of transport of FB was available. Based on expertise from our local expert, we defined a baseline scenario of transportation in Kenya by a lorry of 3.5 to 7.5 metric tons capacity over 50 km before packhouse and by a refrigerated lorry of same capacity over 50 km after packhouse. Regarding the transportation by air-freight from Nairobi airport to London airport, we calculated a distance of 6 750 km using the calculator available at: http://www.worldatlas.com/travelaids/flight_distance.

2.2.4 *Co-products and residues*

Farms producing fresh French beans for export have residues after sorting of beans and prior to transportation to the packhouse. One third of these rejected beans are used by the family, a second third is composted and ploughed into the fields, and the last third is fed to farm animals. These co-products were assumed to leave the system at no cost according to Koch and Salou [7]. They were neither co-products, since they had no economic value, nor wastes, as they were used for other purposes. At the packhouse level, another 30% of the initial amount of beans harvested was assumed to be rejected. One third of these residues was assumed to be sold on the domestic market, one third as animal feed and one third to be composted. These co-products had a very low economic value. Although not formally excluded from our analysis (see figure 1), these co-products received no impact due to their very low economic value and the main focus of our study. All impacts were allocated to the fresh FB exported. The flows of fresh FB for export are summarized in Figure 2.

Table 2. Key agronomic data for French bean cropping system types in Kenya

	Unit	Large farm	Medium farm	SHF contracted weighted	SHF scattered
General information					
Plot size	m^2	NA	12 146	1 767	1 104
Total yield	$kg.ha^{-1}$	8 000	11 280	7 851	4 568
Residues after sorting at farm level	$kg.ha^{-1}$	960	1 354	1 306	409
Yield without residues	$kg.ha^{-1}$	7 040	9 926	6 544	4 158
Crop duration	days	90	90	90	90
Fertilization					
Organic fertilizer					
Compost on French bean crop	$kg.ha^{-1}$	0	0	2 174	0
Compost on preceding crop	$kg.ha^{-1}$	15 000	15 000	5 294	15 000
N-org	$kg.ha^{-1}$	16	16	8	16
P_2O_5-org	$kg.ha^{-1}$	16	16	11	16
Mineral + Organic fertilizers					
N total	$kg N.ha^{-1}$	150	45	63	66
P_2O_5 total	$kg P_2O_5.ha^{-1}$	168	70	70	74
Irrigation					
Water volume	$m^3.ha^{-1}$	3 600	4 000	3 941	4 000
Fuel consumption	$kg.ha^{-1}$	0	28	418	62
Electricity for irrigation	$kWh.ha^{-1}$	1 062	0	0	0

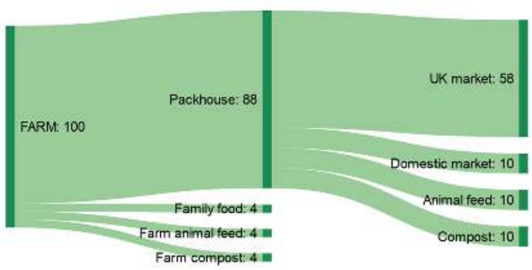


Figure 2. Overall scheme of products and residues over the fresh French bean value chain from cradle-to-export market to the UK.

2.3 Inventory

2.3.1 Field emissions and fluxes

We used emission factors from IPCC [8] to estimate direct (1% of nitrogen inputs) and indirect (1% of NH_3 emitted and 0.75% of NO_3 emitted) nitrous oxide emissions (N_2O) and to estimate nitrate (NO_3) leaching (as 30% of nitrogen inputs). Despite the lack of specificity of its emission factors, the IPCC report remains the most easily applicable to estimate emissions in the study's context, since the IPCC database includes measurements in tropical conditions. For ammonia (NH_3) emissions from mineral fertilizers, emission factors from Bouwman and Van Der Hoek [9] were used since they correspond to tropical conditions (4% for NPK, 2% for Calcium Ammonium Nitrate and Di-Ammonium Phosphate). We based our estimation of NO_x emissions on Nemecek and Schnetzer [10] assuming a ratio of 0.21 kg of NO_x per kg N_2O emissions to respect a chemical balance between these substances. Composts of cow manure are used sometimes on the FB crop, and more often on the previous crop, since GlobalGap rules require a complete analysis of the compost for a direct use on the FB crop. Those rules are internationally recognized for traceability and food security and facilitate the exports, although there are not mandatory. Based on advice from our local expert, a rate of 15 t/ha of compost of cow manure on the preceding crop was assumed for all FB plots with no direct application on the crop (Andrew Edewa, pers. comm.). To account for the nutrients provided to the FB crop from these applications of compost on the preceding crop we used recommendations from the Arvalis web site (http://www.web-agri.fr/conduite-elevage/culture-fourrage/article/integrer-les-valeurs-fertilisantes-des-produits-organiques-1178-115410.html). To account for ammonia volatilization during the composting process, we used the IPCC emission factors of 20% of N content of the manure weighted by the percent of nitrogen allocated to the FB crop. No process was modelled for the compost production.

For phosphorous losses to water, three components were included following the recommendations from Nemecek and Kägi [11]: leaching, runoff and erosion. For estimating phosphorous losses due to erosion, the quantity of eroded soil was estimated according to Angima et al. [12]. The annual soil eroded was allocated over the crop duration of 90 days. The phosphorous content of soil was estimated based on Zöbisch et al. [13].

Field water fluxes were generally unknown by the SHF themselves. It was not possible to do a proper water balance to estimate the water actually consumed. The amount of water withdrawn was estimated based on the expertise of our local expert taking into account the rainfall levels in the different counties. An amount of 400 mm/y was assumed for all plots from Machakos, Meru, Murang'a and Kirinyaga counties while an amount of 150 mm/y was assumed for all plots from the Trans Nzoia County where rainfalls are more abundant. Overall, the water is generally transported to the farm at no energy and financial costs. For all counties except Trans Nzoia, where no data was available for fuel use, only six farmers had declared fuel consumption for water pumps. This was quite consistent with the expertise of our local expert, of about 10% of farmers needing a gasoline pump for water. In Trans Nzoia County, given the flat topography of this region, we assumed that all farmers used a petrol pump for irrigation water. The fuel use for these plots was extrapolated from the average fuel use for the six plots in other counties corrected by the assumed amount of water used for irrigation in this county.

Gaseous emissions from gasoline combustion were calculated according to recommendations from Nemecek and Kägi [11].

2.3.2 Background processes

Background data for energy production[14], fertilizer production[11] and pesticide production[15] were mostly based on processes from the ecoinvent database (Ecoinvent 3 Allocation, recycled content, Unit) and the Agri-footprint database with economic allocation (Blonk Agri-footprint BV), available in the SIMAPRO software (version 8.3.0.0). The transportation stages from the ecoinvent processes for energy materials and inputs were not adapted to the Kenyan situation since this was not expected to have an important effect on the results. For developing the inventory of multi-nutrient fertilizers, which are used extensively in French bean crops, we applied the method from Nemecek and Kägi [11].

2.4 Impact Assessment

An Endpoint LCIA method allows calculating integrated environmental impacts for the three commonly used Areas of Protection: Human health, Ecosystem quality and Resources. Its utilization was well in line with the precise requirements from DG DEVCO who formulated three questions related to the three Areas of Protection in LCA. We selected the 2008 Endpoint version of the ReCiPe (Hierarchist) LCIA methodology (www.lcia-recipe.net) which was the most up-to-date version available at the time of our expertise. Each Area of Protection is expressed in Endpoint units: DALY (Disability Adjusted Life Years) for Human health, species*year for Ecosystem quality and $ for Resources, and consists of several impact categories.

In the (eco)-toxicity methods proposed in ReCiPe only about 60% of the pesticide active ingredients used in our inventory were characterized. Only the diafenthiuron could be characterized according to the substance group's factor (thiourea). For all other active ingredients with no characterization factor (CF) in ReCiPe, we calculated and tested the max and the mean CF for all pesticides used in our dataset. Results calculated with the mean CF were retained, since both calculations gave close results.

For evaluating the impact of water consumption, we used the method from Pfister et al. [16], which proposes CF compatible with the Endpoint version of ReCiPe.

2.5 Data Quality

All farms and packhouses surveyed were part of the studied population. A weighted average was calculated for the SHF-contracted type to account for the contribution of the different counties to the total production of fresh FB for this major type. However, the sample size was quite small compared to the total population and its inherent variability and representativeness cannot be claimed for our results. Primary data were collected for all inputs and outputs of farm and packhouse stages but data gaps remained, especially for energy and water use for irrigation, which were filled thanks to the expertise of our local expert Andrew Edewa. The main gaps and uncertainties of our dataset are as follows:

- potential mistakes on primary data given the lack of formal records of farmers,
- the uncertainty on farm inputs especially regarding compost rates, water and energy use for irrigation,
- the uncertainty due to the use of default emission factors for estimating field emissions and the non-inclusion of N fixation, and
- the uncertainty attached to the losses of FB across the supply chains.

The data quality of our dataset was assessed globally based on recommendations from the ILCD handbook [17]. This data quality assessment is based on six data quality indicators, namely: technological representativeness (TeR), geographical representativeness (GeR), time-related representativeness (TrR), completeness (C), precision and uncertainty (P), and methodological appropriateness and consistency (M). For each indicator a score between 1 and 5, 1 being the best score and 5 the worst, is given independently. Then, the overall quality of the dataset can be derived from the quality rating of the various quality indicators based on Eq. (1):

$$DQR = \frac{TeR+GeR+TrR+C+P+M+X_W \, x \, 4}{i+4} \qquad \text{Eq. (1)}$$

with X_w the weakest quality level obtained among the data quality indicators and i the number of indicators scored.

Values given for the different data quality criteria were as follows: TeR: 1; Ger: 2; TrR: 1; C: 2; P: 3; M: 2, resulting in an overall value of DQR calculated for our datasets of 2.3, corresponding to a basic quality (between 1.6 and 3).

2.6 Comparison with Published LCA Studies

Comparing LCA results is always difficult due to differences in goal and scope and methods used. LCA studies generally present Midpoint indicators such as Global Warming Potential (GWP = Climate change) in kg CO_2-eq. To compare our results with existing literature, we calculated the GWP in kg CO_2-eq per kg raw FB and compared it with a review of cradle-to-farm-gate LCA studies on vegetable crops from Perrin et al. [18], with a study on FB exported to UK from Kenya by Milà i Canals et al. [4] and with a study done by Stoessel et al. [19] on carbon and water footprint of fruits and vegetables for a Swiss retailer.

3. RESULTS

3.1 Contribution Analyses at Market-gate

At market-gate, the four studied systems showed a similar profile. The variations across the four system types only depended on the impacts of the agricultural production, which will be analyzed in more detail in the next section. The general Endpoint profile for our four systems can be explained by a contribution analysis of the main stages of the life cycle of the fresh FB products:

- cradle-to-farm-gate (agricultural) production,
- transport by road in Kenya from field to packhouse,
- packhouse,
- transport by road in Kenya from packhouse to airport, and
- air-freight from Nairobi airport to London airport.

As shown in Figure 3 a,b,c, air-freight had the greatest contribution to Human health (81-89%), Ecosystem quality (51-65%) and Resources (83-86%) across the four systems. Packhouse was the second most important contributor for Human health and Resources while agricultural production was the second most important contributor for Ecosystem quality.

The transportation phases by road in Kenya showed very small contributions to all Areas of Protection. Of course, the impacts for these phases are sensitive to the distances assumed. However, even doubling the distances would not give to these phases a large contribution to the cradle-to-market-gate impacts.

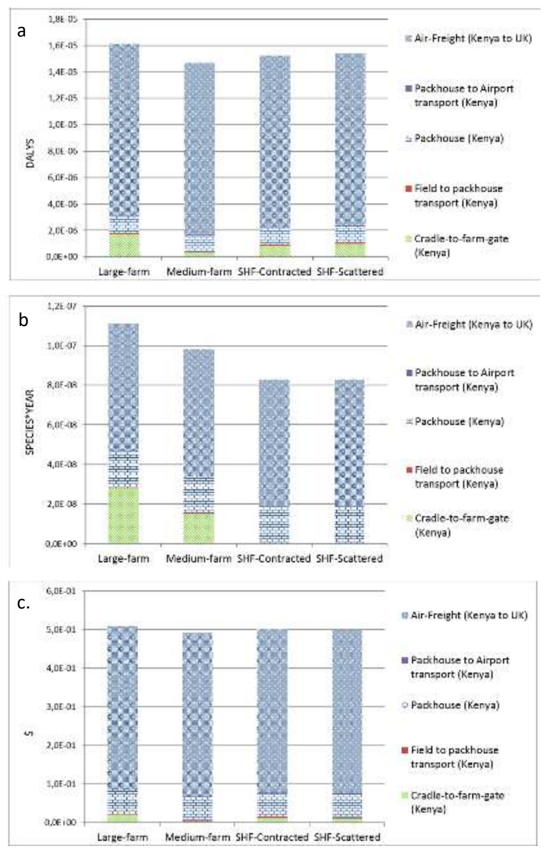


Figure 3. Contribution of the main cradle-to-market-gate (UK) life-cycle stages to the three Areas of Protection for 1 kg of fresh French bean product according to systems: large-farm, medium-farm, SHF-contracted and SHF-scattered, a. Human health; b. Ecosystem quality; c. Resources.

For Human health, climate change constituted most of the damage, around 77-78% of the total impact for each system (not shown). The second most important impact category to the Human health Endpoint was particulate matter formation, with contributions around 20% for all systems. All other impact categories had only minor contributions, the greatest being human toxicity around 2%.

For Ecosystem quality, climate change was again the main impact category with contributions between 54 to 66% (not shown). Agricultural land occupation was the second contributor at 16-21% and water deprivation was the third most important impact category at 12-18%. Natural land transformation represented 4-5%.

For Resources, fossil depletion appeared as the only major impact category at about 98-99% across all studied systems (not shown).

3.2 Contribution Analysis at Farm-gate

The contributions to the total Endpoint indicators at farm-gate of fertilizer production, N field emissions, P field emissions, pesticide production and emissions, land preparation, water use for irrigation, energy use for irrigation and land use were calculated for the four fresh FB systems and are shown in figure 4a, b, c. The large-farm system showed the greatest impacts for Human health and Resources, followed by SHF-scattered, SHF-contracted and then by the medium-farm system with the least impacts. SHF-scattered had the greatest impacts for Ecosystem quality.

For Human health, the main contributors at about 80% were fertilizer production and associated N emissions (N_2O). For Ecosystem quality, the two main contributors were water for irrigation and land use. For Resources, the main contributors were fertilizer production and energy use for irrigation. The land preparation done mechanically for the large-farm contributed 9% of Human health and 18% of Resources.

Among all systems, the pesticide applications contributed only a few percents of the total impact, the greatest contribution being obtained by the large-farm at 6.5% of the Resource Endpoint and SHF-Scattered with 5% for Ecosystem quality.

4. DISCUSSION

4.1 Environmental Damages and Hot-spots of Fresh FB from Kenya

To present aggregated environmental impacts for the Kenyan fresh FB value chain to decision-makers, our study calculated Endpoint results using the ReCiPe 2008 (H) Endpoint method and Pfister et al. [16] for water deprivation at both market-gate and farm-gate. At market-gate, air-freight arose as the most impacting stage for Human health, Ecosystem quality and Resources. The ecoinvent process used in this study gave a similar result per kg of product transported as that found in a report from BioIS for ADEME in 2007[20]. From this report, each kg of fruit transported by plane from Ivory Coast to France produced a GWP of 5.8 kg CO_2-eq corresponding to 1 kg CO_2-eq.kg fruit^{-1} for 840 km. The distance from Kenya to the UK being estimated at 6 750 km, using this reference we would have obtained exactly the same GWP per kg FB transported at (6750/840) ≈ 8 kg CO_2-eq.

At market-gate, the studies from [4] and [19] confirm the very high environmental cost of air-freighted fresh vegetables (Table 4).

For Ecosystem quality, the agricultural production and the packhouse were the second and third most important contributors at 15 – 33% and 15 – 19%, respectively.

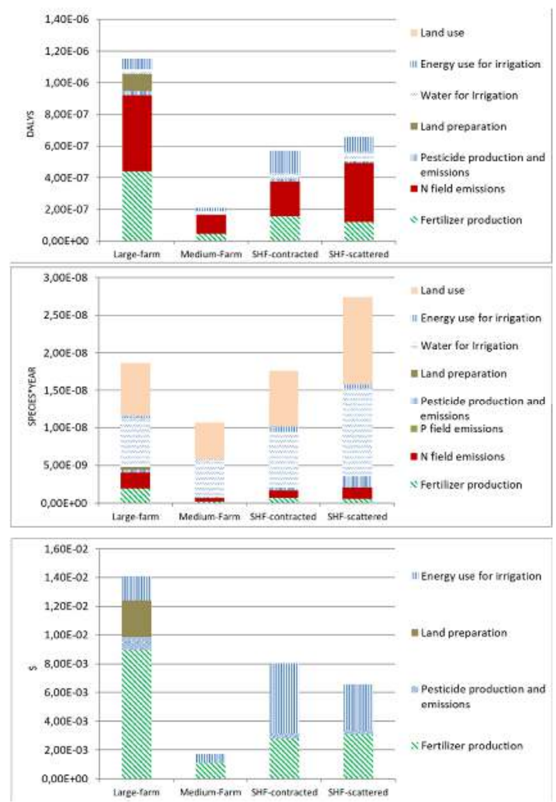


Figure 4. Contribution analysis of the main cradle-to-farm-gate life-cycle stages for the four fresh FB studied systems to the total Endpoint results: a. Human health, b. Ecosystem quality, c. Resources.

Although greater that most samples used in LCA studies, our sample of farms and factories remained too small to claim representativeness for our results. However, the use of an expert-based typology to design a stratified sampling contributed to improve its relevance and was well in line with the resource and time frame of this study. Of course, validating our results through the survey of a greater sample of stakeholders of the value chain would be valuable. If we exclude the uncertainty attached to the modelling of impacts, several sources of uncertainty due to data quality and data gaps exist and were listed in section 2.5. One improvement for this type of study dedicated to decision-makers would consist in performing an uncertainty analysis. However, a preliminary work would be needed to help practitioners operationalize such a procedure in line with their time constraints in similar studies.

Table 4. Comparison of cradle-to-market-gate and cradle-to-farm-gate GWP (in kg CO_2-eq/kg product) for our fresh French bean systems with existing literature.

	Fresh FB (this study)	[4]	[18]	[19]
Cradle-to-farm-gate	0.0893 – 0.565	-	All vegetables: -0.36* – 0.89* Green bean: 0.5	-
Cradle-to-market-gate	8.17 – 8.89	10	-	Air-freighted asparagus: 12.2 – 13.5

*: Averages for all vegetable product groups; negative value is due to an assumption of avoided dumping of organic wastes.

At farm-gate and market-gate, GWP for fresh FB from Kenya is well in line with existing literature (Table 4). The FB farms sampled show variable impacts but in the range of impacts for other open-field vegetables in general and green beans in particular.

4.2 Critical Analysis of Assessment of Impacts due to Pesticide Applications

While Midpoint indicators for freshwater and terrestrial ecotoxicities revealed a major contribution of field pesticide emissions (not shown), at Endpoint level, the contribution of impacts due to pesticides to the three Areas of Protection was minor at both market-gate and farm-gate. This is counter-intuitive compared to the importance of this issue for the whole supply chain. The exhaustive inventory of all pesticides (more than 30) across our sample of farms (n=33) combined with the calculation of missing characterization factors for certain active ingredients constituted one of the greatest tasks of this study. However, due to time constraints and scarcity of data, it was not possible to model the different pesticide fractions at field level: air, soil, water and crop using the PestLCI model [21][22] and dynamiCROP [23]. Therefore, the exposure through environmental compartments was not modelled properly since all applied pesticides were assumed to be emitted to the soil following Nemecek and Schnetzer [10]. Moreover, the residue exposure by consumers was not included, in line with the scope of the study. However, this exposure pathway can be potentially predominant [23]. Moreover, the characterization factors for (eco)-toxicity impacts are uncertain especially at Endpoint level and for a Kenyan context.

Conversely, land use had a great contribution to Ecosystem quality based on relative species richness associated to quite generic land use categories from Köllner [24]. Can this impact category account for the impacts of pesticide applications on soil biodiversity? The characterization factors available correspond to European conditions and the land use categories available do not allow differentiating the different practices of our farm types. Moreover, characterization factors for conventional or organic crops are similar in the version of ReCiPe we used (2008) and are identical in ReCiPe 2016. Overall, the modelling of land use occupation impacts is global and does not seem to account for the pressure of pesticides on soil ecosystems.

4.3 Future Outlook and Recommendations

4.3.1 *On the fresh FB value chain*

Our study contributed to raise awareness on the hot-spots of the fresh FB value chain from Kenya, primarily air-freight and secondarily agricultural production. In the future, research and development could be devoted to explore more stabilized FB products with high added value, which could be sea-freighted. This should reduce drastically the overall impact of FB products from Kenya.

Overall, good agricultural practices in fresh FB production should be based on a better recording of actual practices and inputs' use. As shown in this study, the N use intensity (ratio kg of N fertilizer per kg of FB) can be high in certain farms and is a key driver of their eco-efficiency. Water use is another hot-spot of the fresh FB value chain. Water use on farm is generally unknown and seems to be more restricted by factors such as energy use (e.g. electricity or gasoline for pumps) rather than the amount of water used. Water is free, apart from a nominal user fee producers have to pay. Given the water problems Kenya is likely to encounter over the years to come, also as a result of climate change, it is recommended that the amount of water use be monitored through the installation of flowmeters and more investments are undertaken in water management. This can include investments in drip irrigation, thereby reducing the use of irrigation systems whereby part of the water is poorly used.

Regarding pesticide use, a few forbidden molecules in Europe are still used and pest management practices are not always optimal. Mistakes could be avoided by a better training of farmers but also of technical staff. Some companies appear to have undertaken efforts in this direction, but more efforts are required.

4.3.2 *On the methodological aspects of the study*

Our results would warrant some validation by the analysis of a greater sample of farms and factories across the country. It should be seen as a preliminary study guiding future research and more in-depth analyses. Widening the scope of this LCA study up to the consumer stage would also be interesting in combination with the use of the dynamiCROP model for taking account of the impacts due to pesticide residues in French beans consumed. Moreover, estimating the pesticide emission fractions to the environment (soil, air, water) depending on soil, climate and practice on the field would also be highly relevant. However, the pesticide emissions consensus model requires some adaptations to tropical conditions [25]. Its implementation would also require more field data such as the dates and material of application, the field characteristics, etc., which would increase the time needed for the data collection. Operational and reliable tools would be useful to help practitioners evaluate these pesticide emission fractions at field level. In addition, it is important to bear in mind that our results remain dependent on several value and methodological choices regarding the functional unit, the system boundaries, the allocation rules, the method used to estimate field emissions and the LCIA method selected. Regarding allocation rules, given the main market of fresh FB from Kenya we chose to use an economic allocation leading to allocate 100% of the impacts to the exported beans. From Figure 2, a mass allocation could be applied leading to an allocation of impacts of 66% to fresh FB for export and 11% to local FB. Moreover, field emissions of nitrogen are important contributors to the damages and it could be important to test the sensitivity of results to the methods used. However, the most impacting nitrogen fluxes were primarily nitrous oxide emissions and secondarily ammonia emissions. In the ReCiPe Endpoint method no Endpoint model exists for marine eutrophication limited by N, leading to no damage associated to nitrate leaching. Therefore, it was not deemed relevant to use a more refined method to estimate leaching at field level, such as SQCB from Faist Emmenegger et al. [26].

5. CONCLUSION

A complete LCA study including the diversity of farm practices and all key impacts (water deprivation, (eco)-toxicity) was performed using Endpoint indicators for decision-makers on the fresh FB value chain of Kenya. It allowed for identifying hot-spots at both market and farm-gate where efforts should be made. Drastic reduction of impacts could potentially be achieved by designing stabilized FB products that could be sea-freighted. At farm level, training of farmers and better recording of practices could also help improve the eco-efficiency of farms. However, given the sample size and the uncertainty attached to certain data and results, our study should be seen as a preliminary study needing validation through the analysis of a greater sample of stakeholders but also a more in-depth analysis of impacts due to pesticides applications. Extending the scope of the study up to the consumption stage would allow including impacts due to pesticide residues in FB. Field pesticide emission fractions would warrant a better estimation taking account of soil, climate and practices. Adding uncertainty intervals to the results would also be highly relevant for decision-makers. However, both a better inclusion of impacts due to pesticides and an evaluation of the uncertainty of the results would necessitate the development of operational and reliable tools for LCA practitioners in such contexts.

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