Comparison of the environmental impacts of three support wires for tomato farming: paper, jute and polypropylene

Damien Evrard, F. Betmont, Peggy Zwolinski

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 80 (2019) 411–416

www.elsevier.com/locate/procedia

26th CIRP Life Cycle Engineering (LCE) Conference

Comparison of the environmental impacts of three support wires for tomato farming: paper, jute and polypropylene

D. Evrard[a,*], F. Betmont[a], P. Zwolinski[a]

[a] Univ. Grenoble Alpes, CNRS, Grenoble INP*, G-SCOP, 38000 Grenoble, France * Institute of Engineering Univ. Grenoble Alpes

Abstract

Small companies encounter difficulties to adapt to new markets with a sustainable perspective. The subject of this article is a paper transformation company which has been eager to develop the organic farming market by developing a new plant support. Alternatives made from plant fibres or plastics exist, such as jute and polypropylene. The main difficulty of this project was to ecodesign a paper product with a multicriteria approach. The factors considered have been divided into two categories. Firstly, the environmental impacts calculated according to the Life Cycle Assessment methodology (on raw material extraction, manufacturing and end-of-life) are summarised. Secondly, the characteristics of the product are discussed in regards to these results and sustainability questions as part of the interpretation phase. Finally, ways of improvement of the LCA methodology to improve the study in terms of geographical representativeness and societal considerations are discussed.

Peer-review under responsibility of the scientific committee of the 26th CIRP Life Cycle Engineering (LCE) Conference.

Keywords: environmental assessment; ecodesign; agriculture; sustainability comparison; paper; plastic; jute.

1. Context

This article presents some of the results of a project funded by the French Environmental Protection Agency (ADEME) and carried out from 2016 until 2018. This project aimed to develop a support wire for plant cultivation which would be entirely biodegradable after harvest. Indeed, the support wires currently used for tomato production are often made of polypropylene which has satisfactory mechanical properties, but presents difficulties to be disposed after use. Although, they have the advantage of being technically reliable with a low percentage of breakage over the growing season, their major disadvantage is that they are not biodegradable and are made of fossil resources. Moreover, when the season is over, the plants are pulled up and the wires are intertwined in the plants. The conventional approach consists in manually separating the wires from the plants in order to allow, the elimination of the strings and the composting of the plants. This operation is costly in terms of manpower and time. In practice, most market gardeners simply crush the whole plant before burial or incineration, although the latter practice has been prohibited in France since 2011 [1]. The objective of this project was therefore to develop biodegradable paper wires for tomato plant support so that market gardeners can crush the entire crop after harvest to finally bury or compost it, without having to resort to a sorting phase.

The task presented in this article concerned an environmental assessment of a product under development by Textilos Curtas Technologies (TCT), a French small company located in the Alps. The following section presents the methodological background used for the environmental assessment of the product, i.e. Life Cycle Assessment (LCA). It is followed by its application to the Paper Wire, as well as a comparison to equivalent support wires made of plastic (polypropylene) and vegetable fibre (jute). The interpretation step of the LCA includes a qualitative analysis of the product in terms of societal and environmental criteria. Ways of improvement for the LCA methodology are also discussed in this section. Finally, eco-design perspectives are proposed in order to improve the environmental performance of the Paper Wire, by targetting both the life cycle phase with the highest impacts, and the step where the manufacturer have more freedom of action. Finally, conclusions are drawn and possible future works are proposed.

* Corresponding author. Tel.: +33 476 575 071 ; fax: +33 476 574 695.
E-mail address: damien.evrard@g-scop.grenoble-inp.fr (D. Evrard).

Peer-review under responsibility of the scientific committee of the 26th CIRP Life Cycle Engineering (LCE) Conference.
10.1016/j.procir.2019.01.038

2. Methodological background

This study was based on the Life Cycle Assessment methodology for the characterisation of potentiel environmental impacts caused by the product systems under scrutiny. Then, considerations of other criteria was included on a qualitative basis in order to localise and contextualise the interpretation of the results. This section briefly describes the methodological approaches used.

LCA is a tool to assess the potential environmental impacts of a product system [2], along its entire life cycle (i.e. from raw material extraction to end-of-life) with a holistic approach. Therefore, it is a relevant approach to get a holistic analysis of the material and energy flows involved in each life cycle phases in terms of environmental impacts. This Life Cycle Impact Assessment links entering and exiting elementary flows to impact categories (e.g. global warming potential, eco-toxicity, etc.), then attributes a quantitative value to each.

The study presented in this article is not strictly speaking an LCA since there has been no peer-review and the sensitivity analysis is not detailed here. However, it follows the four steps defined in the standard: (1) Goal and scope definition, (2) Life Cycle Inventory, (3) Life Cycle Impact Assessment, and (4) Interpretation of the results.

3. LCA applied to the case study

The objective of this study was to determine the environmental impacts of the Paper Wire and then to compare them with products having an equivalent function. This application was carried out in the context of the product design project Three product systems were thus studied: (1) Paper Wire, (2) Polypropylene Wire, and (3) Jute Wire. The presentation of the results follows the four steps of LCA as defined in the standard.

3.1. Step 1: Scope and objectives of the LCA

This first step includes defining the boundaries of the system under study and the functional unit. The objectives and other parts of this step have already been mentioned above and have not been repeated in this section.

System boundaries. Impacts were assessed on the following life cycle stages: raw material extraction, manufacturing, distribution, use and end-of-life. For each product system, the processes considered at each stage of the life cycle have been specified. In the case of the Paper Wire, the precise data provided by TCT about the different processes were used. Thus, the unbleached kraft paper was produced in the South West of France, the production took place in the French Alps, with the stages specific to the company's process. The users, market gardeners, were located in France and the end of the wire's life was at the same location.

The second system that has been studied was a Polypropylene Wire. The location and production assumptions used were based on research on the subject company's main competitor. Use and end of life were similar to the previous system and manufacturing in the North of France with polypropylene coming from Germany. Finally, the Jute Wire was processed in the same way as the two previous systems, with a jute cultivation phase in Southeast Asia.

Functional unit. The wires can be used for different types of crops: from small fruits, such as raspberries, to larger ones, such as tomatoes. In this study, the application of greenhouse tomato cultivation was considered. The functional unit chosen was as follows: *To support a 35kg tomato plant for 11 months under greenhouse conditions*. To meet the functional unit, 12m of support wire was necessary, regardless of the material used.

Environmental impact assessment method. The European Union has developed its own calculation method in the framework of the International Life Cycle Data (ILCD) project [4]. This calculation method is based on a review of the existing methods, according to the analysis of their accuracy, comprehensiveness, and representativeness. The proposed reference ILCD method is updated regularly and provides midpoint (effects) and endpoint (damages) indicators. However, the relevance of endpoint indicators is too debatable to be considered here. Therefore, only midpoint impact categories were studied. Table 1 shows the list of the various midpoint impact categories which are considered in this study.

This list of indicators also illustrates that the distinction between local and global impacts is poorly considered. For instance, the midpoint categories "Climate change" and "Land use" are considered at the same level, whereas the latter is a local impact of the other is global. Generally, local impacts in current LCIA methods are averages, and do not reflect the actual characteristics of a specific location.

3.2. Step 2: Life Cycle Inventory

The data used are summarised in Table 1 for each life cycle phase considered. The masses have been weighed from commercial products. In the absence of information about the locations where the different life cycle phases took place, market data form the EcoInvent database were used.

Raw materials. For the Paper Wire, a European unbleached kraft paper process was used. Transportation distances were those of TCT's main supplier. In the case of the Polypropylene Wire, an extruded plastic from Europe was used. More precisely, a German supplier was considered. Finally, for the Jute Wire, yarns made in South East Asia were chosen, since they were the only fibre available.

Manufacturing. The data corresponding to the wire manufacturing process came from measurements made in the studied company. They correspond to four manufacturing steps: cutting, twisting, winding and packaging. The electricity consumed for production was mostly hydroelectric, since the region produces more than it consumes. In the other cases, national energy mixes have been considered.

Table 1. Life Cycle Inventory for Paper Wire.

Life Cycle step	Process	Value
Paper Wire		
Raw material extraction	Unbleached kraft paper	48,0g
Manufacturing	Electricity high voltage	8,8Wh
Manufacturing	Tap water	100,8g
Distribution	Transport Lorry > 32T Euro 3	24kg.km
Usage	No data	NA
End-of-life	Biogenic carbon	NA
Polypropylene Wire		
Raw material extraction	Polypropylene granulate	19,2g
Raw material extraction	Extrusion molding	19,2g
Manufacturing	Same hypotheses as Paper Wire	
Distribution	Transport Lorry > 32T Euro 3	28,8kg.km
Usage	No data	NA
End-of-life	Municipal incineration	19,2g
Jute Wire		
Raw material extraction	Jute yarn, market	60g
Manufacturing	Same hypotheses as Paper Wire	
Distribution	Included in market dataset	
Distribution	Transport Lorry > 32T Euro 3	30kg.km
Usage	No data	NA
End-of-life	Same as Paper Wire	

The processes for the three products were considered to be similar and all applied at the same location. This approach enabled to compare the specificities of the different materials rather than to focus on transportation to multiple locations. It was considered that the energy consumption did not vary with the type of material. A specific extrusion process has been used for the Polypropylene Wire. No specific process was identified for the Jute Wire.

Distribution. Distribution concerned the delivery of the wire to the customers. It was considered that the finished product should be transported over 500km. The environmental impacts were related to the weight of the transported material. For 1m of yarn, this corresponds to 4g of paper, 1.6g of polypropylene, and 5g of jute.

Use. The impacts of the use phase have been neglected, as they correspond to manual operations during the installation and removal of the wires depending on the materials. In the absence of precise information on the subject, the product has been considered to be completely passive. Therefore, no difference in use was considered among the different alternatives.

End of life. The proposed scenarios differed according to the raw materials and have been established by the information provided by the company. In the case of the Paper Wire and Jute Wire: composting on the field; a supply of biogenic carbon was used. For the Polypropylene Wire, the product was incinerated with energy recovery in the appropriate facility; a specific module for the incineration of plastics, including polypropylene, in Europe was used.

3.3. Step 3: Life Cycle Impact Assessment

The results are presented in three parts. The first deals with the environmental impacts of the manufacture of the Paper Wire, which is the main concern on this study; the second, focuses on the comparison of the impacts of the Paper Wire with equivalent products made of polypropylene and jute; and finally, the third deals with the end of life of the three products studied.

Environmental impacts of raw material extraction and manufacture of the Paper Wire. Environmental impacts were characterized on the 16 indicators of the ILCD method and on the five life cycle stages studied, from craddle to grave. First of all, it can be seen in Fig. 1 that the production of kraft paper in the raw material extraction step is the stage with the most significant environmental impacts compared to the others. This result is consistent with what is generally obtained with paper-based products. As far as greenhouse gases emissions are concerned, the LCIA method takes into account biogenic carbon from plant growth.

Finally, if we model the entire life cycle, the share of the manufacturing step is considerably reduced when considering hydro-electricity rather than the French mix, as it is likely to happen in the alpine region (3.3). This would tend to show that it is not on the manufacturing process that the most relevant eco-design paths can be found.

The normalized Paper Wire assessment results (crosses in fig. 1), provided an indication about the most important impacts, the four main indicators were human toxicity, non-cancer effects; mineral, fossil and renewable resource depletion; human toxicity, cancer effect and freshwater ecotoxicity. These are the four indicators that were monitored as a priority in the rest of the study.Finally, it is important to notice that distribution and end of life are invisible here compared to the raw material extraction and manufacturing phases.

By far, the most significant step is the extraction of raw materials. The interpretation of this observation requires points of comparison. This was then done with polypropylene and jute wires.

Comparison of the environmental impacts of Red Wire with the impacts of Polypropylene and Jute wires. Jute and polypropylene are two materials commonly used to make support wires. Their impacts were calculated and compared with those of the plastic wire. The only major differences were the materials, forming processes and transport distances depending on the main producers.

In general, Fig. 2 tends to show that the Paper Wire's impacts are between the Jute Wire and the Polypropylene Wire with much higher impacts for Jute. The Polypropylene Wire has higher impacts than the Paper Wire on climate change and freshwater ecotoxicity impacts, which should be put in perspective with the importance of these indicators in the normalized results.

The Paper Wire has the highest impacts on indicators of human toxicity (non-cancer) and resource depletion. The first

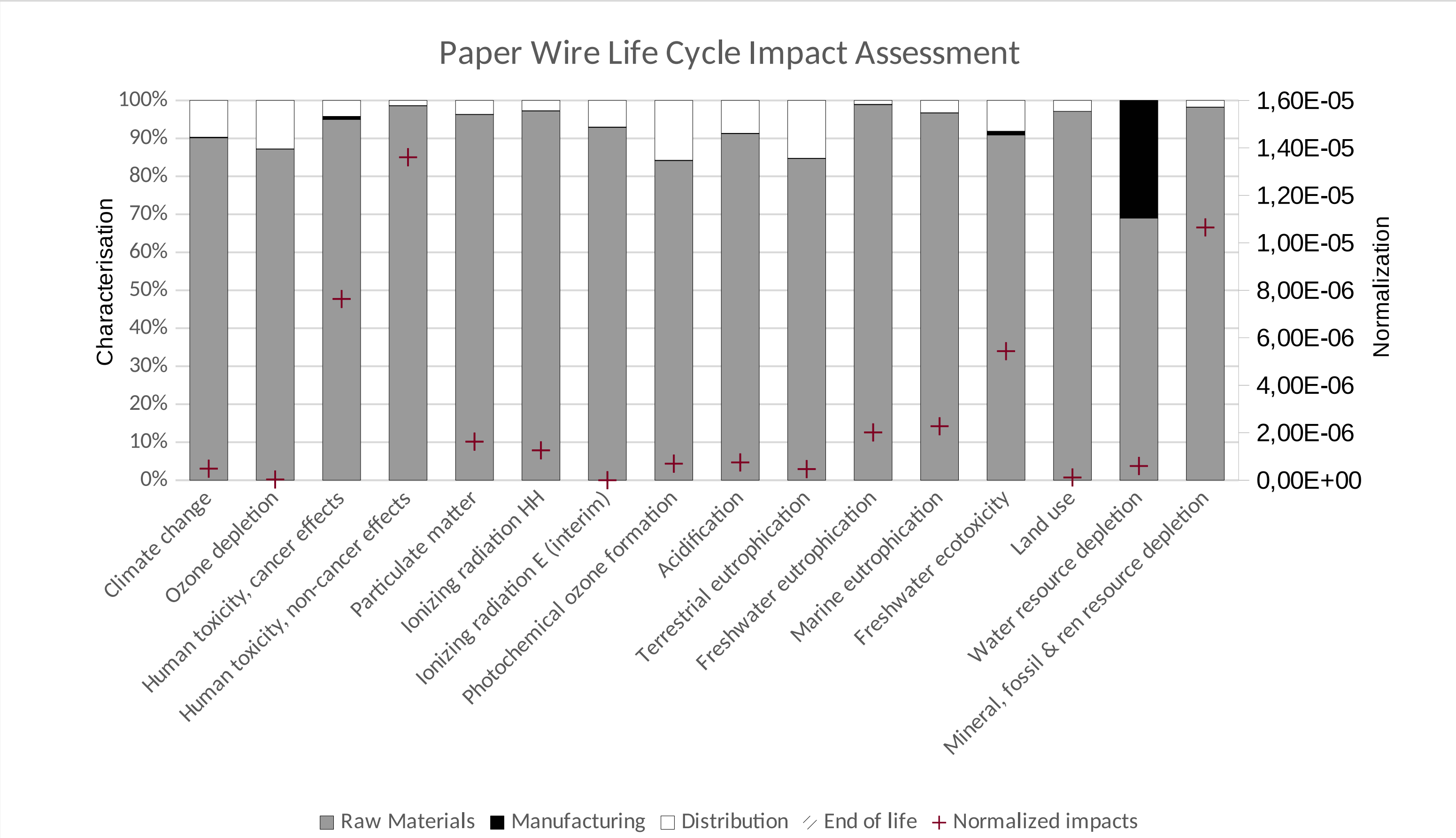

Fig. 1. LCA results for the Paper Wire on raw materials, manufacturing and distribution.

point may be explained by the production of wood ash during the manufacturing of the paper (incineration of wood waste) in the EcoInvent dataset. The second might be due to a possible bias or gap in the impact calculation method. Indeed, zinc oxide used for sodium dithonite anhydrous in the kraft paper process is by far the main contributor to the paper wire impact.

The material with the highest impacts on almost all indicators is the jute. Indeed, this material is produced from a plant grown intensively in Southern Asia. As a result, fuel, field, fertilizer and pesticide consumption is significant. Hence the high impacts on climate change, the ozone layer, toxicity, particulate emissions, acidification, eutrophication, water and land use. In general, it is the carbon-intensive energy in the producing countries that is the cause of the impacts. These results need to be interpreted to be able to draw conclusions for the environmental performance of the Paper Wire.

Analysis of end-of-life scenarios. When the different end-of-life scenarios were compared, it was noticed that the incineration with energy recovery of the Polypropylene Wire has very high impacts compared to the other two. This conclusion seems obvious considering the simplicity of the end-of-life scenarios for the paper and jute products. More detailed data about the way they are degraded in the soil should be taken into account for a more precise analysis.

3.4. Step 4: Interpretation of the results

The study of the environmental impacts of paper showed that the extraction of raw materials was by far the most significant. The manufacturing stage in the French Alps was negligible in front of the latter, especially if we consider the hydro-energy model. It could therefore be interesting to study the use of recycled paper to reduce the impacts.

The comparative study with polypropylene and jute showed seems to make the plastic wire appear as a good alternative, due to the lowest mass of material used, and despite the fact that the resource is not renewable. However, this material cannot be used in organic vegetable gardening. It therefore seems more relevant to compare jute and paper in the case of this targetted market. In the latter case, the paper has less impact on almost all the indicators. In the case of the two indicators for which the Paper Wire has the highest impacts (human toxicity, non-cancer effects and mineral, fossil and renewable resource depletion), it is useful to look at which processes contribute most to the impacts. In this case, papermaking is the life cycle stage with the highest impacts.

Moreover, since the location where the paper is made is known, more specific data would probably improve the results compared to the European-wide datasets used in this study. This

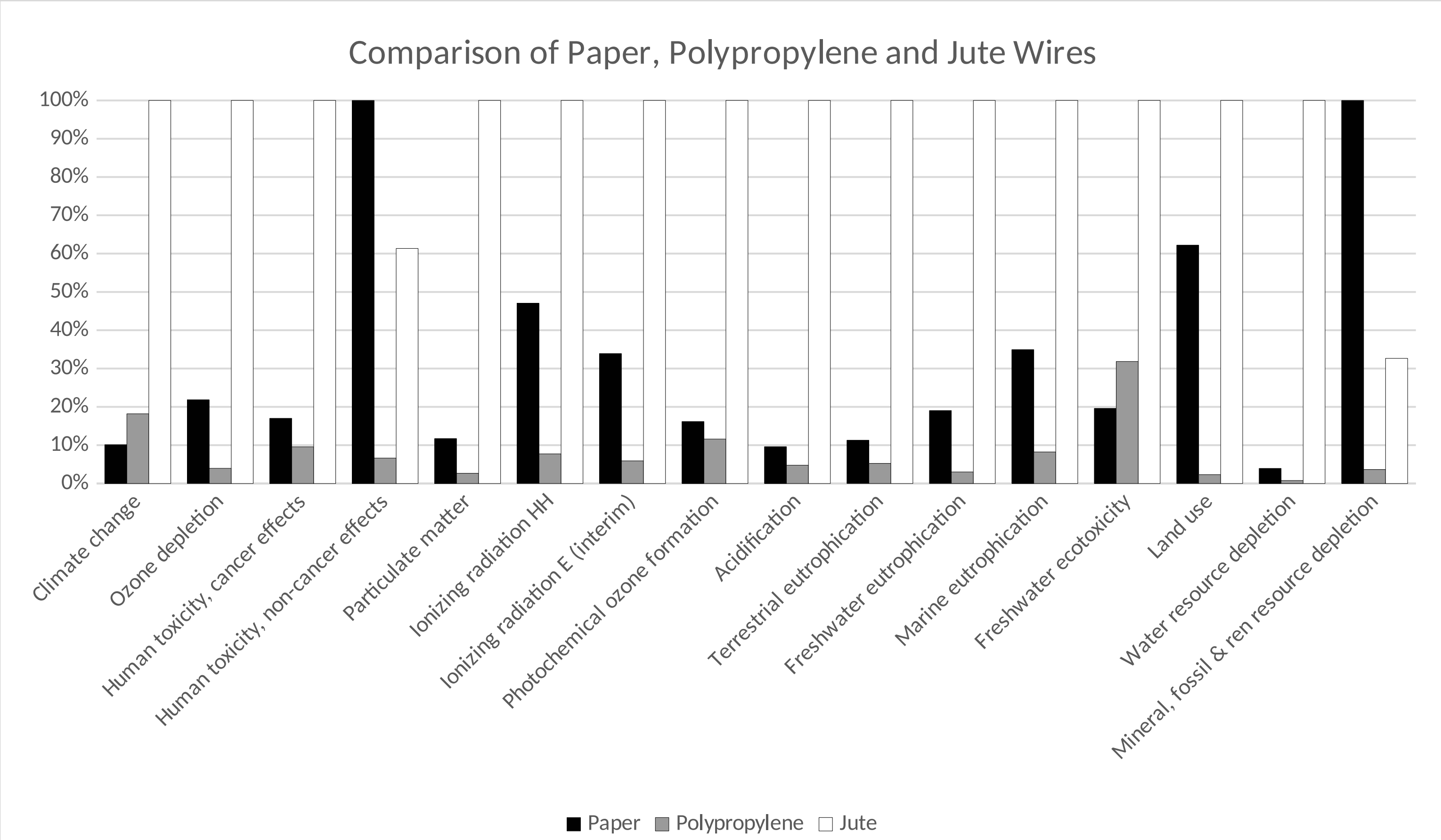

Fig. 2. LCA results for the comparison of the 3 product systems.

would require to contact the companies, but could be undergone in a future work.

Regionalised LCA. This issue illustrates the need for a precise localisation of the processes and the impacts. In this aspect the entire value chain of the Paper Wire could be followed to have a precise assessment of its impacts. However, this may induce discrepancies with the other products in the absence of the same level of information. This is all the more important in a context of sustainability research or in a particular regulatory context, such as an organic market gardening activity.

It would be possible to go further by linking the production and processing sites of raw materials with the biocapacities of local environments. Thus, it could be said, for example, whether the high impacts of the cultivation of jute in India threaten the sustainability of the place; or whether silviculture in southwestern France is compatible with a sustainable paper industry. Unfortunately, such a level of detail is not available in commercial software or even in scientific research with comparable methodologies to be used.

This is also relevant for the end-of-life scenarios. Indeed, the determination of data on paper composting would help to refine the results. However, this difficulty could be overcome by considering other criteria that cannot be directly taken into account in the LCA. In the case of waste treatment by appropriate means, there is a saving on collection and treatment costs.

Societal aspects. Still in the end-of-life considerations, given a common practice of burial or incineration in the field, the Paper Wire prevents visual pollution of plastic and could probably save some fertilizers. Another way to consider this would be to extend the duration of the functional unit to several years in order to better consider the gain of nutrients from one crop to the next.

Besides, in an organic market gardening context, the Paper Wire is positioned as having better environmental performance compared to its main competitor, jute. In the absence of other plant fibres available in the EcoInvent database, it was not possible to study any others. In particular, hemp would have been an interesting subject for comparison since this plant is the subject of important crops in France and is reputed to consume little water and treatment.

Going further on local impacts, it would be interesting to include in the study the societal impact of the production of the Paper Wire in an isolated region of the French Alps, compared to the production of equivalent products in other regions or countries. To this end, criteria and means of measuring them would be necessary. As far as human health is concerned, existing toxicity indicators could be applicable, provided that it is ensured that the flows taken into account are relevant to the geographical area studied. Again, commercial software does not allow this type of study to be carried out and scientific research is still ongoing on the subject. Furthermore, the social impacts of the various life cycle steps for local inhabitants should be included to consider both positive and negative aspects of these economic activities.

The most available elements are those concerning the impact of this eco-design project for the product or process of an SME located in a relatively isolated environment and whose economic objective is to gain market share in sectors in which it was previously absent. This development strategy is carried out with a strong desire to seek sustainability.

Finally, the integration of the mechanical characteristics tested during this project, in particular on the resistance of the Paper Wire, as well as the feedback from market gardeners on the uses that have been made of the product, in relation to the alternatives could be included in a study that would be independent from the chosen software solution. Thus, greater ease in installing or dismantling the Paper Wire could be counted as a positive impact for users by accelerating, facilitating or reducing the difficulty of the work.

4. Eco-design perspectives

A few eco-design approaches are presented in this section. However, the simplicity of the products limits the number of possible solutions (e.g. the 10 golden rules of ecodesign [6]) The objective was to reduce the environmental impacts over the entire life cycle of the Paper Wire. As noted in the previous section, the impacts of manufacturing and transport are small compared to the production of raw materials. It is therefore on the latter that eco-design efforts should focus. In a second step, the particular context of TCT should be taken into account in a more detailed way. Indeed, the data and impact calculation methods available are at best based on national averages, which do not take into account the location of the company. Finally, societal considerations, which are still difficult to include in LCA, deserve to be taken into account.

Recycled paper. The use of recycled paper could reduce the environmental impacts of the raw material extraction phase. Incorporating an increasing recycled paper content reduces the environmental impacts proportionally. Thus, the incorporation of 25 and 50% recycled paper leads to a reduction of the of approximately the same ratio. This eco-design approach should be assessed in the light of the possibilities for supplying the company and the mechanical properties of the Paper Wire obtained from recycled materials. Indeed, recycled paper is considered as having poor mechanical properties, and the share of recycled paper may remain low. Besides, it is essential to prevent the introduction of pollutants when composting the wire in the fields.

Making it lighter. Another ecodesign option would be to reduce the mass of paper necessary. This would involve to find a way to strengthen the products to satisfy the constraints of the functional unit.

Improving the manufacturing process. Even thought, the manufacturing step has not the highest impacts, this is the step on which the company can work most. One way to do so would be to reduce the number of operations to make the wire, thus reducing the quantity of electricity consumed. Other sources of energy could be a possibility.

Conclusion

This study has compared three alternatives for plant support. It has showed that the choice of raw material is key in this case, and the need for a contextualised LCA, in order to be able to have a relevant interpretation of the results. Thus the Paper Wire appeared as a good alternative to another natural fibre-based product (jute), especially under a context of organic agriculture.

More generally, this study enabled to raise a few issues in the LCA methodology such as the need for regionalised data, and the integration of societal criteria in order to guide the interpretation.

Acknowledgements

The authors would like to acknowledge the funding of the ADEME under the Perfecto call for projects, and TCT for providing the data used in this study and the discussions along the project.

References

[1] French Ministry of the Environment, 2011. Circulaire du 18 novembre 2011 relative l'interdiction du brulage l'air libre des dechets verts. France, 9 p.

[2] ISO, 2006. ISO 14040:2006 – Environmental management – Life cycle assessment – Principles and framework, 20p.

[3] IPCC, 2013. Anthropogenic and Natural Radiative Forcing, in: Fifth Assessment Report - Climate Change 2013: The Physical Science Basis. UNEP, pp. 659–740.

[4] European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2011. International Reference Life Cycle Data System (ILCD) handbook framework and requirements for life cycle impact assessment models and indicators. Publications Office, Luxembourg, 116p.

[5] Suhr, M., Klein, G., Kourti, I., Gonzalo, M.R., Santonja, G.G., Roudier, S., Sancho, L.D., 2015. Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board, 906p.

[6] Luttropp, C., Lagerstedt, J., 2006. EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development. Journal of Cleaner Production 14, 1396–1408.