COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) OF ARTIFICIAL VS NATURAL CHRISTMAS TREE

Sylvain Couillard, ing. M.Sc.

Gontran Bage, ing. Ph.D.

Jean-Sébastien Trudel, B.Com B.Sc.Soc. M.Env.

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ellipsos

Strategists in Sustainable Development

ellipsos

1030 Beaubien E. Suite 305
Montreal Quebec H2S 1T4

514.463.9336

i@ellipsos.ca
www.ellipsos.ca

ellipsos is a consulting firm based in Montreal. We offer solid professional expertise in sustainable development. We help business leaders build a competitive advantage using Life Cycle Management. This approach is used by the most qualified teams of executives in large corporations worldwide, recognized by the United Nations and supported by the International standardization Organization (ISO 14040).

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About the Authors

Sylvain Couillard ing. M.Sc.

Sylvain Couillard graduated as a Mechanical Engineer from École Polytechnique de Montréal (1998). He obtained his Master's Degree in Biomedical Engineering from the University of Calgary (2002). He specialized in Quality Assurance (QA) of medical devices and was QA Manager at SCL Medtech. As a professional and team member of ellipsos inc., Mr. Couillard has performed Life Cycle Analysis (LCA) studies. They include those delivered to the bovine industry and the ISO 14040 compliant study on Christmas trees. Mr. Couillard is recognized for his strong analytical skills that focus on practical solutions to sustainable development projects.

Gontran Bage ing. Ph.D.

Gontran Bage is an expert in sustainable development and life cycle management. Prior to joining ellipsos, Mr Bage worked for 6 years (2002-2008) at the CIRAIG (Interuniversity Research Centre for the Life Cycle of Products, Processes and Services) as the scientific coordinator and researcher specialized in life cycle inventory (data estimation, uncertainty management) and life cycle tools development. As the CIRAIG's scientific coordinator, he had to manage the scientific progress of more than 35 research projects, write scientific proposal grants and supervise graduate students. Mr Bage holds a PhD in chemical engineering (Ecole Polytechnique of Montreal) for which he has developed a tool for the selection of the most appropriate technology for contaminated site remediation based on both environmental, technical and economic aspects.

Jean-Sébastien Trudel B.Com B.Sc.Soc. M.Env.

Founder of ellipsos, Jean-Sébastien Trudel helps executives and management deal with and benefit from the ever changing conditions of emerging markets, a process that he's called the "new industrial evolution". In the last five years he's acted as adviser on the topic of sustainable development for corporations and governments. Jean-Sébastien Trudel is also a well known author in the business community. He is the author of a book on sustainable business practises, titled "Arrêtons de pisser dans de l'eau embouteillée", published by Transcontinental. HEC Montreal School of Management has called it one of the "must read book of 2007 for executives", and it has been been awarded the "Entrepreneurship Book France-Québec 2008" prize, handed by the Paris Chamber of Commerce and Industry, in France. Mr Trudel holds a Bachelor of Commerce, a Bachelor of Economics, both from the University of Ottawa, and a Masters of Environment specialized in Life Cycle Management, from the University of Sherbrooke in partnership with CIRAIG–Ecole Polytechnique of Montréal.

Executive Summary

Every year, when comes the time to prepare for the Christmas Holidays, one question seems to come back time and time again: Should one buy a natural or an artificial Christmas tree? From an environmental perspective, this question raises many passions, since both type of trees seem to have advantages and drawbacks. Most people think that the traditional fir is better. For one, they say, the natural tree is... natural! It is often argued that it contributes to fighting global warming through carbon sequestration. Others argue that the artificial tree can be reused year after year, and it does not need fertilizers and pesticides. Some say that the true environmentalist go in the wood to cut down his wild seedling. The most radicals have even suggested to stop using Christmas trees altogether.

After all these years, the question remains. ellipsos has undertaken to put an end to this dilemma using a scientific approach.

Goal and Scope

The purpose of this study is to compare the environmental impacts of a natural vs. artificial Christmas tree using Life Cycle Assessment methodology. Since the trees are to be used in Montreal, Canada, for the holiday season, data representative of the trees sold in Montreal was preferred. The modelled natural tree is harvested in a plantation located 150 km south of Montreal. The artificial tree is manufactured in China and shipped by boat and train to Montreal via Vancouver.

The Life Cycle Assessment (LCA) method was chosen to perform this study. It follows the recognized ISO 14040 and 14044 standards and it was reviewed by an independent third-party of peers. The LCA method allows for the evaluation of potential environmental impacts of a product or an activity over its entire life cycle. It is therefore a holistic approach that takes into account the extraction and processing of raw materials, the manufacturing processes, transport and distribution, use, reuse and, finally, recycling and disposal at the end of life.

This study is aimed at guiding the general public for the selection of the best type of Christmas tree based on environmental considerations. It is an independent study with no funding (direct or indirect) by any of the concerned stakeholders.

Considering the function of the trees -decorating the interior of a house - one natural tree with one artificial tree for one Holiday period are compared. Both trees are assumed to be 7 foot high. For better comparison purposes, the lights and decorations are excluded from the analysis. Since the artificial tree can be reused multiple times, calculations are based on a 6-year life span, the average time an artificial tree is kept in North America. The data was collected from primary and secondary sources: direct contact using surveys, literature and life cycle inventory databases.

Methodology

An LCA consists of four major phases:

Phase 1: Definition of the objectives and the scope of the study;

Phase 2: Data collection and calculation procedures to quantify relevant inputs and outputs of a product system;

Phase 3: Evaluation of the significant potential environmental impacts from the various inputs and outputs of a product system;

Phase 4: Interpretation of the inventory data and results of the impact assessment in relation with the goal and scope of the study.

Natural Christmas tree: The primary data for the natural tree was collected from two main sources. First, one tree nursery provided data (nursery is confidential). This data may not represent the entire production in Quebec, but no other data was available. Second, the Centre de Recherche en Agriculture et Agroalimentaire du Québec provided an economic model of natural Christmas tree production in field, which was revised in March 2007. This model represents the activities and inputs for an average Quebec producer with a good experience in Christmas tree production. A detailed description of the natural Christmas tree model is given in the full report. Briefly, the life cycle of the natural Christmas tree is divided into four steps: production in a nursery for 4 years, production in a field for 11 years, use at home and end of life (Figure A).

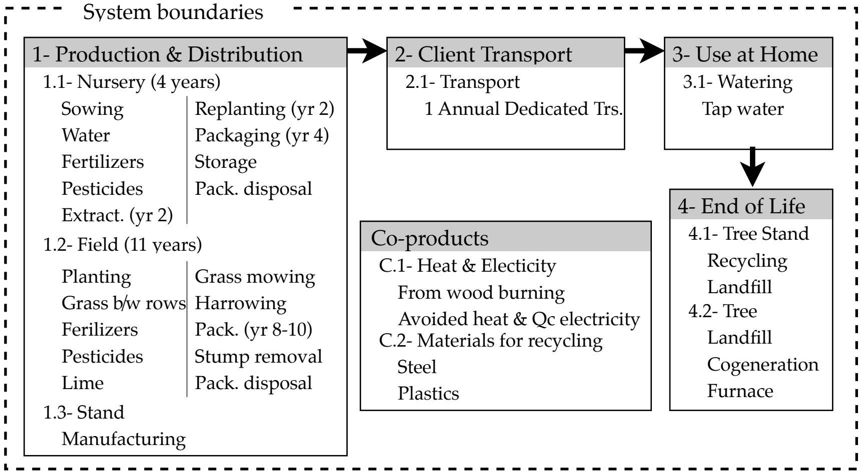

Figure A – The Product system for the natural Christmas tree includes all processes from production, transport, use and end of life.

Artificial Christmas tree: The data for artificial trees came from two main sources: a manufacturer of premium Christmas trees in the United States (confidential) and a student report that was provided by the Centre interuniversitaire de recherche sur la gestion du cycle de vie des produits et services (CIRAIG), which studied the typical artificial tree made in China. Data obtained directly from Chinese manufacturers was generally incomplete or unreliable.

The data from the premium tree was used as a basis for the typical Chinese tree, knowing that the premium trees are generally sturdier and last longer. A detailed description of the artificial tree model is given in the full report. Briefly, the life cycle of the artificial Christmas tree is divided into four steps: production at a plant in Beijing (including distribution), client transport, use at home and end of life (Figure B).

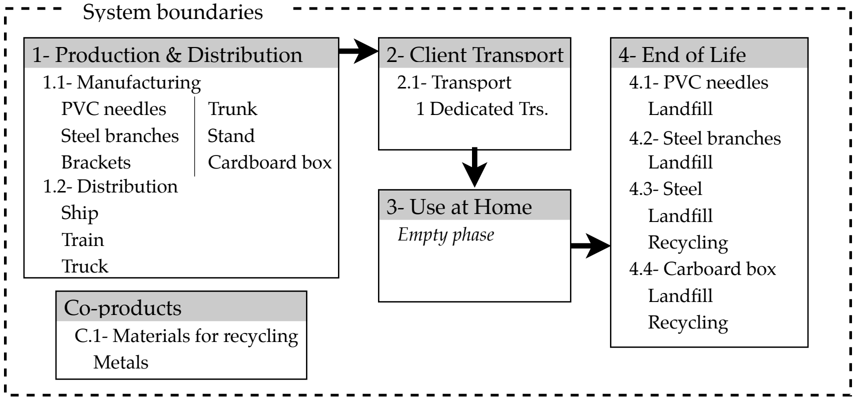

Figure B – The Product system for the artificial Christmas tree includes all processes from resources extraction and manufacturing, transport, use and end of life.

Impact Assessment

The primary impact assessment method used in this study is Impact 2002+ (Jolliet et al., 2003). This choice is justified from the need to present the understandable and important results to the general public. The Impact 2002+ method was slightly modified to include the effects of biogenic gases on climate change.

Impact 2002+ is an impact assessment method of the life cycle that allows the grouping of problem oriented-impacts into four damage-oriented impacts on the environment. These categories are: human health, ecosystem quality, climate change and resource depletion. Figure C shows the fourteen problem-oriented (Midpoint categories) that contribute to the damage categories. To evaluate the result sensitivity to the impact assessment method, a second analysis was conducted with the North American method TRACI2.

Results and Discussion

As mentioned above, this study uses an artificial tree with a life span of six (6) years. The results for this tree are normalized on an annual basis and compared to one natural tree. We are therefore comparing the impacts of one year of an artificial tree (1/6th of its life span) with one natural tree.

The environmental impacts of the natural and artificial trees are shown in Figure D. These results show the relative impacts of each tree for the four damage categories: human health, ecosystem quality, climate change and resources. The impacts are presented in relative terms for each category, where the tree with the most impacts is the reference.

When compared on an annual basis, the artificial tree, which has a life span of six years, has three times more impacts on climate change and resource depletion than the natural tree. It is roughly equivalent in terms of human health impacts, but almost four times better on ecosystem quality compared to the natural tree.

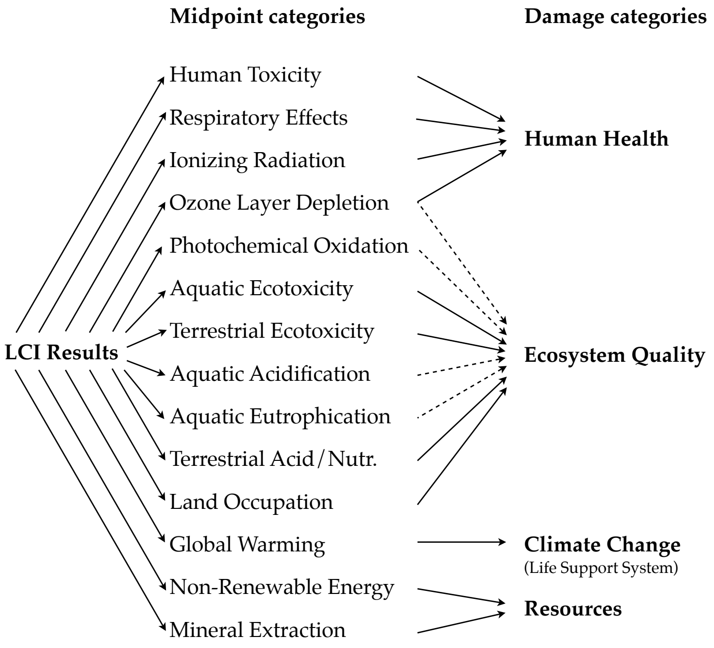

Figure C – General outline of the Impact 2002+ assessment method for problem-oriented and damage categories.

The hot topic these days is climate change. When looking at these impacts, the natural tree contributes to significantly less carbon dioxide emission (39%) than the artificial tree. Nevertheless, because the impacts of the artificial tree occur at the production stage, and since it can be reused multiple times, if the artificial tree were kept longer, it would become a better solution than the natural tree (Figure E). It would take, however, approximately 20 years before the artificial tree would become a better solution regarding climate change.

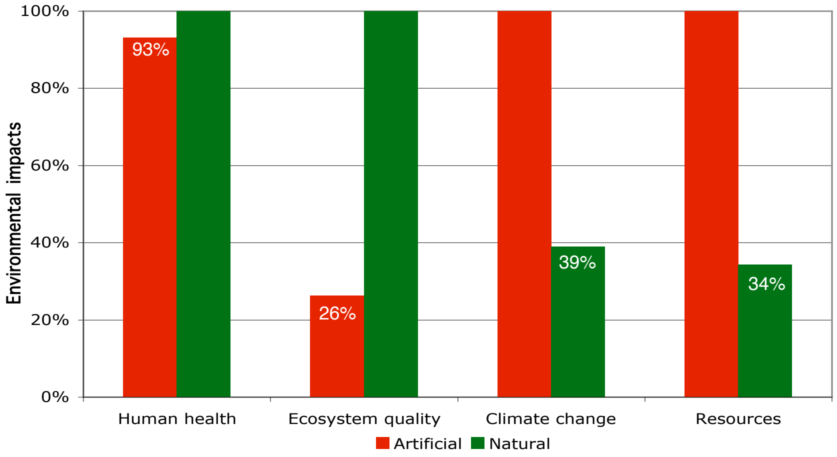

Figure D – LCA results comparing relative impacts for four damage categories comparing main life cycle stages of an artificial tree (red) and a natural tree (green) for one year using a modified IMPACT 2002+ method to include biogenic CO_2 emissions.

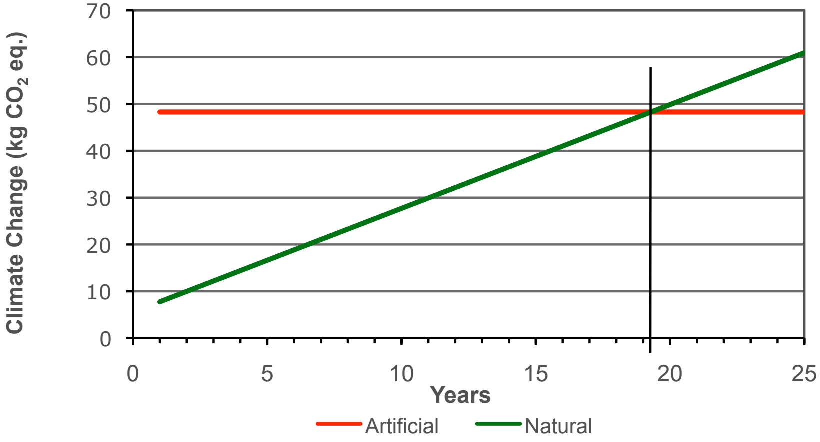

Figure E – The artificial tree can be reused multiple times. This reduces its impacts overtime relative to a natural tree bought every year. The threshold at which point the artificial tree become a better option for climate change impacts is after 20 years.

Impacts on climate change occur at different stages of the life cycle for the natural tree and the artificial tree (Figure F). For the former, the main source of impacts comes from client transport from the house to the Christmas tree store. For the latter, the production stage, which includes manufacturing (85%) and transport from China to Montreal (8%), accounts for almost all of the impacts (93%).

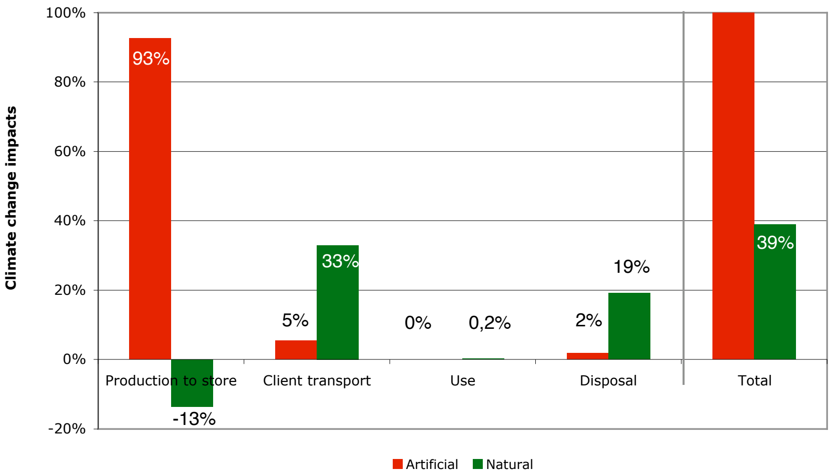

Figure F – LCA results for Climate Change category comparing main life cycle stages of an artificial tree (red) and a natural tree (green) for one year using a modified IMPACT 2002+ method to include biogenic CO_2 emissions.

It is interesting to note that the natural tree production has positive impacts on climate change because natural trees sequester CO_2 during their growth. Besides, the impacts of client transport shown here are for a store located at 5 km from home. These impacts would steeply increase with travelled distance since this activity occurs year after year. Watering the tree in the use stage only has marginal impacts, whereas the disposal of the natural tree is the second largest contributor on climate change. The end of life faith is twofold: 50% is send to a landfill and the remainder is turned into wood chips as a replacement for heavy oil in a paper mill and electricity from Quebec province.

To put things into perspective, the emitted CO_2 over the entire life cycle are approximately 3.1 kg CO_2 per year for the natural tree and 8.1 kg CO_2 per year for the artificial tree (48.3 kg for its entire life span). These CO_2 emissions roughly correspond to driving an average car (150 g/km) 125 km and 322 km, respectively. Therefore, carpooling or biking to work only one to three weeks per year would offset the carbon emissions from both types of Christmas trees.

Another point of view would be to consider the impacts on ecosystem quality as the hot topic. This would shift the advantage of the natural tree to the artificial tree by a factor of approximately five (Figure D). One of the major contributors of ecosystem quality is, for example, land occupation. Tree plantations, however, traditionally occupy areas where no other use of the land can be made (e.g. under electrical lines). In addition, these impacts are generally local while the impacts on climate change are global.

Limits of the study

The current LCA study has limitations. It does not take into account noise, odor, human activities (eating, lodging, etc.), soil erosion that is avoided by the plantations, dioxin emissions from plastic in the artificial tree during use and disposal (if burned), impacts of fillers contained in PVC. Also, the electricity from China was mostly modelled with electricity from Europe. In addition, the CO_2 sequestration as well as fertilizer emissions can vary greatly with environmental conditions (soil content, sun exposure, rainfall, etc.) and add uncertainty to the results. Finally, results are specific to Montreal and may vary depending on geographic location because of differences in processes such as travelled distances and the end of life of the natural tree.

Conclusion

A Life Cycle Assessment was performed to guide the environmentally conscious consumers on their choice of Christmas tree. The natural tree is a better option than the artificial tree, in particular with respect to impacts on climate change and resource depletion. The natural tree, however, is not a perfect solution as it results in important impacts on ecosystem quality. Clients who prefer using the artificial tree can reduce their impacts on all categories by increasing the life span of their tree, ideally over 20 years.

Although the dilemma between the natural and artificial Christmas trees will continue to surface every year before Christmas, it is now clear from this LCA study that, regardless of the chosen type of tree, the impacts on the environment are negligible compared to other activities, such as car use.

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LIST OF ACRONYMS AND ABBREVIATIONS

CIRAIG	Centre interuniversitaire de recherche sur le cycle de vie des produits, procédés et services
CRAAQ	Centre de référence en agriculture et agroalimentaire du Québec
HDPE	High Density Poly Ethylene
ISO	Organisation internationale de normalisation
LCA	Life Cycle Assessment
LDPE	Low Density Poly Ethylene
MAPAQ	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
NA	North America
PE	Poly Ethylene
PVC	Polyvinyl Chloride
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

1. Introduction

1.1. Context

Every year, when comes the time to prepare for the Christmas Holidays, one question seems to come back time and time again: Should one buy a natural or an artificial Christmas tree? From an environmental perspective, this question raises many passions, since both type of trees seem to have advantages and drawbacks. Most people think that the traditional fir is better (Tremblay, 2003; La Presse, 2003; Collard, 2005). For one, they say, the natural tree is... natural! It is often argued that it contributes to fighting global warming through carbon sequestration. Others argue that the artificial tree can be reused year after year, and it does not need fertilizers and pesticides. Some even say that the true environmentalist go in the wood to cut down his wild seedling (Francoeur, 1992). The most radicals have even suggested to stop using Christmas trees altogether.

After all these years, the question remains. ellipsos has undertaken to put an end to this dilemma using a scientific approach.

1.2. Project objectives

ellipsos has initiated a project to guide the general public in their selection of a Christmas tree with respect to environmental impacts, as a first step towards sustainable development. To achieve this goal, ellipsos will communicate a comparative assertion of the natural Christmas tree versus the artificial Christmas tree, based on a Life Cycle Assessment.

1.3. Method

The Life Cycle Assessment (LCA) was chosen to perform this study. This LCA follows the recognized ISO 14040 and 14044 standards. This method allows for the evaluation of potential environmental impacts of a product or an activity on its entire life cycle.

It is therefore a holistic approach that takes into account the extraction and processing of raw materials, the manufacturing processes, transport and distribution, use, reuse and, finally, recycling and disposal at the end of life. Figure 1.1 illustrates the major steps of the life cycle of a product.

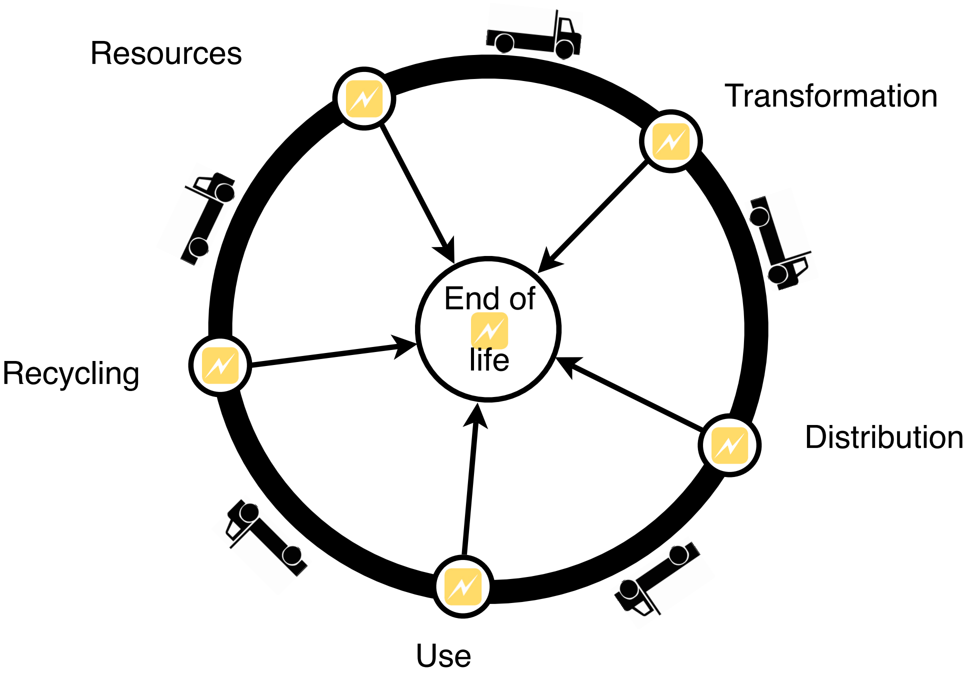

Figure 1.1 – Major steps in the life cycle of a product.

1.3.1. ISO 14040 standard

This analysis method is primarily aimed at reducing the environmental impacts of products and services, through decision-making. It is a more holistic assessment tool than the traditional ones.

Results from this method help people take into account the entire set of activities related to their product or service to follow the principles of sustainable development. LCA's comprise the identification and quantification of inputs and outputs related to the product or service as well as the assessment of potential impacts associated with these inputs and outputs.

Figure 1.2 shows the framework of an LCA, as suggested by the ISO standard. As shown in this Figure, the LCA is an iterative process and the choices made during the analysis can be modified when new data is acquired.

The current study was reviewed by a panel of interested parties or external experts. The findings from their review are located in Appendix D.

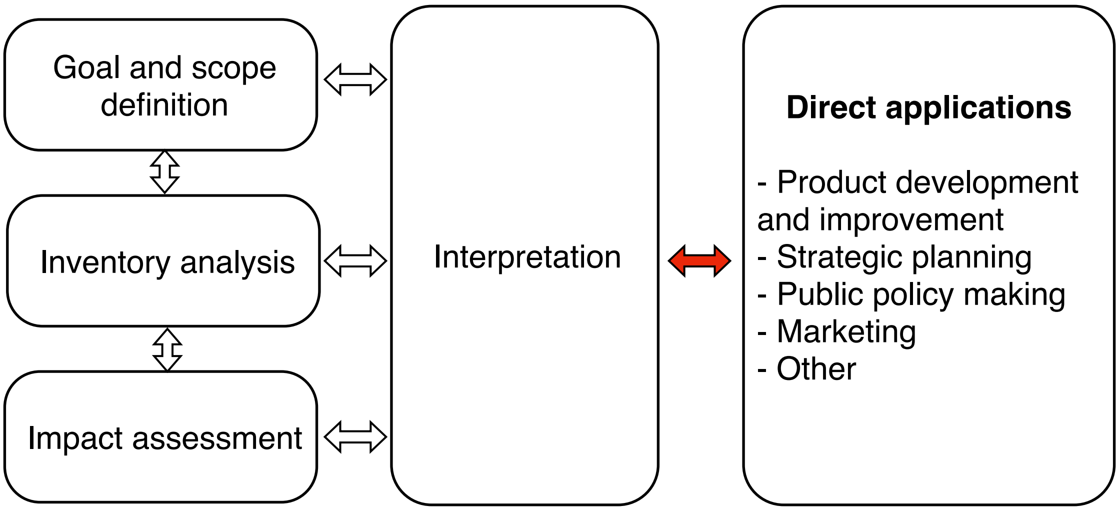

Figure 1.2 – Stages of an LCA (ISO 14040: 2006).

An LCA consists of four major phases:

Phase 1: Definition of the objectives and the scope of the study;

Phase 2: Data collection and calculation procedures to quantify relevant inputs and outputs of a product system;

Phase 3: Evaluation of the significant potential environmental impacts from the various inputs and outputs of a product system;

Phase 4: Interpretation of the inventory data and results of the impact assessment in relation with the goal and scope of the study.

2. Model definition

2.1. Goal of the analysis

This study is aimed at guiding the general public for the selection of the best type of Christmas tree based on environmental considerations. More precisely, the objectives of the study are:

- Position both types of Christmas trees with respect to environmental impacts; this is a condition required by a sustainable development approach (environment, economy, society) (Gendron, 2004);
- Communicate the results of this comparative assertion to the general public.

2.1.1. Context of the analysis

ellipsos will examine which type of tree is better for the Montreal consumers amongst the following two models:

Model A: Natural Christmas tree, produced in Quebec.

Model B: Artificial Christmas tree, manufactured in China.

The results allow the identification of hot spots for both types of tree. They also reveal the number of years that an artificial tree needs to be reused for so that its environmental impacts are lower compared to a new natural tree every year.

2.1.2. Intended audience

This study is aimed for the general public and will be communicated through the appropriate media. This study was therefore reviewed by an external panel of independent experts, as state in the ISO 14040 standard.

2.2. Scope

2.2.1. Function

To adequately compare the two Christmas tree models, both models need to be functionally equivalent. In fact, a simple comparison of both trees would not make sense because of their different life spans would directly influence the results. The LCA will therefore be aimed at the function of the trees rather than the products themselves.

The Christmas trees are primarily used to decorate the interior of a house during the Christmas Holidays, once a year.

Function:

To decorate the interior of a house during the Christmas Holidays.

Although the decoration function necessarily implies accessories that are hung from the trees (lights, festoons, etc.), these are excluded from the current study because they are deemed identical for both types of trees. In addition, although the natural Christmas tree can be combusted at the end of its usable life, the function of making heat and electricity from tree combustion is secondary and less important than that of decorating the interior of a house.

2.2.1.1. Functional unit

The functional unit allows for the quantification of the function mentioned above. Several tree heights are available, especially for artificial trees. The most common natural tree is 6-8 feet high (CRAAQ, 2007). The majority of artificial trees also fall into this category. A 7-foot high Christmas tree will therefore be used in the current study as it is most representative of the consumer purchases.

Functional unit:

Decorate the interior of a house during the Christmas Holidays with a 7 foot-high Christmas tree used for one single Christmas Holiday season.

2.2.1.2. Reference flows and key parameters

Reference flows bind the functional unit to the systems being studied. They are usually different for each system. In our case, we consider that a natural Christmas tree can only be used for one Christmas Holiday season, while the artificial Christmas tree is used for six years, on average (CCTGA, 2007). Therefore, the number of reuse of a tree is the primary key parameter in this study.

Reference flows:

To decorate a house for one Christmas Holiday season, we have: For the natural tree, because of its single use, 1 natural tree and 1/6th of a stand (because it is reused for 6 years, on average). For the artificial tree, because of its multiple use potential, 1/6th of an artificial tree is necessary.

2.2.1.3. System boundaries

In the framework of an LCA, one must define the system boundaries to include all necessary processes to fulfill the desired function. The system boundaries definition then guides the selection of the processes to take into account (Jolliet et al., 2005).

According to Jolliet et al., who interpret the ISO 14040 standard, three rules are essential to determine these boundaries:

Rule #1 : For a comparative assertion, the system boundaries must reflect the same functional reality for all scenarios.

Rule #2 : The processes that need to be included in the system are the ones which contribute to a previously defined percentage of the input mass, energy consumption or pollution emissions. To ensure that all important processes are included in this study, we have fixed this percentage at 3%.

Rule #3 : Identical processes in the various scenarios can be excluded if the reference flows affected by these processes are strictly equal. One must be careful when establishing exclusion criteria to avoid situations that would exclude important elementary processes.

Taking these three rules into consideration, we have elaborated two models (Figure 2.1 and 2.2). They include extended system boundaries to account for the energy produced by the wood combustion and a credit was given for recycling.

2.2.1.4. Geographic boundaries

Activities from the Quebec Christmas tree producers primarily occur in Quebec, namely in the Eastern Townships, about 150 km southeast of Montreal. When possible, the LCA will include data from this specific region. For example, the electricity grid mix was modelled according to the Hydro-Quebec production including imports from other provinces and the United States (Hydro-Quebec, 2007). In this model, 92.33% of the electricity is hydraulic (more details regarding the Quebec electrical mix is included in Appendix A). However, some phases of the life cycle, such as the provisioning in oil and machinery do not occur within this territory. The most appropriate data will then be used.

Activities from the artificial Christmas tree manufacturers are located in China. The same approach is used when data from China is available. In this model, the electricity grid mix could be modelled based on ecoinvent, a database of international industrial life cycle inventory data. The process for China, called Electricity Mix / CN U contains 78.6% of electricity produced from hard coal. However, within the various ecoinvent processes, it was not always possible or desirable to change the electricity content from European to Chinese. This constitutes a limit of this study.

2.2.1.5. Temporal boundaries

Two choices can be made when defining the temporal boundaries. It is possible to take into account only the technologies and markets that are currently in use. Alternately, it is also possible to model the systems using futuristic scenarios, based on projected technologies and markets. To be as realistic as possible, the data in this study is based on current times. For example, the plastic from the artificial Christmas trees is made of PVC, even if there is a trend to include polyethylene (PE) with polyvinyl chloride (PVC) to make the needles. The PE needles were analysed as an alternate scenario.

2.2.1.6. Excluded processes

As mentioned in Rule #3, identical processes for both models can be excluded from this comparative study since they will result in the same impacts and, therefore, will not allow the distinction of one model relative to the other. Similar processes, however, that will results in different impacts cannot be excluded from this study. Here is the list of excluded processes:

- Decoration and use of decoration for both Christmas trees are excluded from this study. We assume that tree decoration is identical for both tree types.
- Noise and odours are omitted from this study. There is no characterization method to assess these impacts.
- Human activities required for the production of both types of trees are neglected. They include drinking, eating, housing, etc.

2.2.2. Description of inventory data

The LCA is a data treatment method. Consequently, low quality data entry leads to low quality results. Keeping this in mind for this study, we favoured primary data when they were available, i.e. data specific to each model. These data were verified and completed with secondary data:

- The *ecoinvent v2.01* database;
- Scientific literature ;
- Newspapers, magazines, specialized journals, student reports and web sites.

To collect primary data, a questionnaire was given to key actors of the life cycle, when possible. For any LCA, and therefore for this study, an appropriate quantification of the inputs and outputs is necessary. Quantified data mimics average technologies as much as possible. For this reason and for confidentiality purposes, data sets from only one source were used only when no other data was available, but the source was kept confidential.

To analyse the data, SimaPro 7.1.7 was used along with the ecoinvent 2.01 database.

2.2.2.1. Natural Christmas tree

The primary data for the natural tree was collected from two main sources. First, one tree nursery provided data (nursery is confidential). This data may not represent the entire production in Quebec, but no other data was available. Second, the CRAAQ (2007) provided an economic model of natural Christmas tree production in field, which was revised in March 2007. This model represents the activities and inputs for an average Quebec producer with a good experience in Christmas tree production. A detailed description of the natural Christmas tree model is given in Appendix B.

Briefly, the life cycle of the natural Christmas tree is divided into four steps: 1- production (1.1- nursery for 4 years, 1.2- field for 11 years, 1.3 stand), 2- client transport, 3- use at home and 4- end of life (Figure 2.1 and Table 2.1).

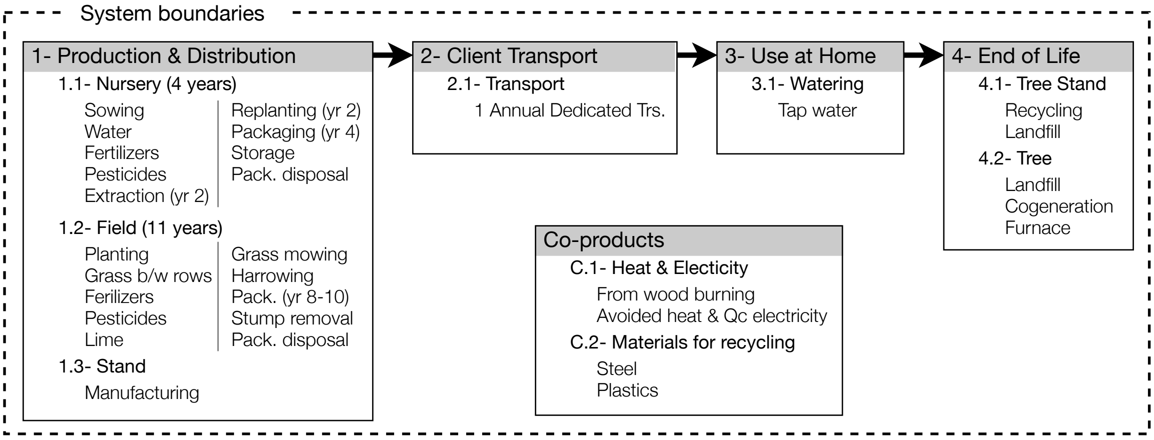

Figure 2.1 – Life cycle of the natural tree in Quebec (Model A).

For the production phases, the amounts are generally given per hectare of trees. At the nursery, the tree seeds are sown in plastic pots with an automated sowing machine that uses electricity. The pots are filled with peat moss from the Rivière-du-Loup area. The pots themselves are neglected since they are re-used several times and their mass, energy and impacts associated is under the selected 3% cut-off. Pots are laid on the ground for two years. Fertilizers and pesticides are sprayed every year as per general agriculture practices. The field used at the nursery is irrigated. At the end of year 2, the trees are manually extracted, the peat moss is transferred in a trailer and dumped in a pile further on the field. The trees are stored in a cold room for one week and are sown again using mechanized equipment. At the end of year 4, the trees are manually extracted, packaged in bunches of 100 and stored for two weeks until they are shipped to the field producer.

In the field, the trees are sown and grass is sown between ranks. Fertilizers and pesticides are generally spread as granules or sometimes sprayed. Lime is also used to neutralize the soil pH. For the first years and few last years the grass is mown between rows of trees. For the middle years, the amounts of herbicides and shade from the trees make mowing unnecessary. The trees are graded, chosen and manually cut with a small chain saw (neglected, less than 3% of impacts). The trees are then packaged in PE bags using a small generator or tractor energy, loaded onto a large lorry and shipped. When the trees have been cut, various tillage processes prepare the soil for a new cultivation period. They include mechanized stone and stump unearthing. Stones and stumps are then manually removed from the field.

The amount of CO_2 sequestration was estimated from various studies. Gaboury (2006) states that a plantation of black spruce in Quebec can sequester a net amount of 1.2 t C/ha/yr (4.6 t CO_2/ha/yr) during the first 70 years. This sequestration is non-linear with a peak sequestration rate occurring around 30 to 35 years. Helm (2000) states that the UK conifer plantations can sequester as much as 3.7 t C/ha/yr (13.6 t CO_2/ha/yr), but the climate in the UK may be too favourable compared to the Eastern Townships. Villeneuve (2003) gives a direct amount of CO_2 sequestration from black spruce plantations in Abitibi-Téminscamingue, 600 km north of Montreal: 1 to 2 t CO_2/ha/yr. Finally, Tremblay et al. (2006) estimates the mean net sequestration rate at 2 t CO_2/ha/yr for a white spruce plantation in southeastern Quebec, over a 22-year period. Knowing that the climate is more favourable in the Eastern Townships than in northern Quebec, and knowing that the balsam fir or douglas fir may have a growth pattern more similar to the white spruce than the black spruce, we estimate that the rate of CO_2 sequestration is 2 t CO_2/ha/yr. Since the trees are harvested on year 8 (30%), 9 (45%) and

10 (25%) (CRAAQ, 2007), the CO_2 sequestration was therefore calculated over 8.95 years, giving 17.9 t CO_2/ha.

In our model, we neglect the contribution of the first four years of production because the trees are too small and we assume that the tree density in the field is the same as the ones presented in the referenced studies. The C storage in trees is modelled as follows: The aboveground C storage is, on average, 1.8 t C/ha/yr, litter accumulation is negligible, and C content from the soil decreases by 1.3 t C/ha/yr. This still gives an overall plantation C sink of 0.5 t C/ha/yr (2 t CO_2/ha/yr) (Tremblay et al., 2006). From Gaboury et al. (2009), we assume that 60% of C sequestration occurs in the aboveground compartment (stem, foliage and branches) and that the below ground compartment sequesters 40% of C (soil, 26%; roots, 14%). From Peichl et al. (2007), we assume that the stump and major roots represent 45% of the root system and are buried further on the plantation (Pettigrew, 2008). The stump emissions follow the calculations from Micales and Skog (1997) with a proportion of carbon emitted as methane (19 g C emitted as CH_4/kg wood) and carbon dioxide (13 g C emitted as CO_2/kg wood). Finally, we assume that the soil and root compartments left in the soil do not contribute to emissions in air or water and that they stay in the soil indefinitely.

Modelling of the N-P-K fertilizers followed a general principle used by most in the industry (Raymond, 2008). First, the amount of phosphorus as P_2O_5 was completed by taking the appropriate amount of Mono Ammonium Phosphate (MAP). The transport was modified in the ecoinvent database so that the fertilizer came from Florida. This MAP also included a portion of the required nitrogen (N). The nitrogen (N) content was then filled with Urea or Calcium Ammonium Nitrate (CAN), depending on period at which the fertilizer is spread. Again, the transport data was modified so that the fertilizer came from the American Mid-West . Finally, The required amount of K_2O was filled with Potassium Chloride or Potassium Sulphate, depending on the plant resistance to these corrosive ingredients. The transport data was also modified so that the fertilizer came from Saskatoon. Usually, the percentages of N-P-K do not add up to 100%. The rest of the fertilizer weight is filled with non-active ingredients that were considered as dead weight.

Modelling of the emissions from fertilizers was difficult because they are a function of soil type and composition, content of the fertilizer, application method and environmental conditions when they are applied (Brentrup et al., 2000; Sidebottom, 2008; Bates, 2008). These emissions are based on the model for Corn, at farm/US from the ecoinvent database. The ratios of N entering the system versus emitted N is proportional to the corn data, giving an amount of N emissions of approximately 70% of applied N. The emissions are in the air compartment as NH_3, N_2O and NO_x as well as in the water compartment as NO_3. The data was then verified with the data from wheat mentioned in Brentrup's work and the proportions between NH_3, N_2O, NO_x and NO_3 were respected within a factor of 2. The amount of P emissions were also based on the corn data, giving an amount of P emissions of approximately 2% of applied P, 92.5% of which was dedicated to the river and 8% to groundwater.

The pesticide emissions were included in the soil compartment at 100% of the input mass of pesticide. This is acceptable since, regardless of the environmental conditions (e.g. wind), most of the pesticides will eventually be incorporated in the soil. This model was based on the ecoinvent unit process "Corn, at farm/ US U". This also represents a worst-case scenario.

Data for the use and the end of life phases are given for one single tree. Use of the tree occurs in Montreal. It includes a dedicated transport by car to pickup the tree, everyday tree watering and the purchase of a tree stand that comes from China (transport of stand by the client is included in the transport of year 1 for the natural tree). These processes are shown separately to show their individual impacts. All other home processes are neglected since they are manual (e.g. Re-cutting the tree trunk).

At the end of life, the trees are collected and sent to the Complexe environnemental de Saint-Michel to make wood chips (Ville de Montréal, 2008). For the 2008 Christmas trees (not for earlier Christmas seasons), the wood chips are then transported to the Kruger company in Trois-Rivières and Bromptonville to produce heat and electricity. The wood chips are assumed to be sent equally to both destinations. The Bromptonville plant was modelled using primary data for both electricity production and heat production (Hamel, 2008). The Trois-Rivières plant was modelled with the same heat loss but with 100% heat production. The plants use burning processes based on the Rankine cycle. With the electricity produced from wood, the same amount of electricity from the QC grid mix can be avoided. With the generated heat from wood, the same amount of heat produced from heavy oil can be avoided (Hamel, 2008). Hamel provided data that defined the proportion of wood combustion that is transformed in heat (86%), in electricity (14%) and that is lost (35%). The stand is sent to the landfill or recycled at a facility located 40 km from Montreal. Since the reference flow relates to the use of a tree for one year. The artificial tree and the stand of the natural tree are assumed to have a life span of six years.

Transportation can generally be described as follows. If the ecoinvent data is used without modification to the transport portion, the regional storehouse was thought to be in Montreal. The materials are then transported by truck to the regional Coop, in Sherbrooke, and then to the producer, in Ayer's Cliff. Otherwise, the transportation was modified to reflect the Quebec reality. For the transport of disposed packaging used during the production, the materials are collected at the producer's field and shipped to a landfill or a sorting facility near Sherbrooke. The sorted materials are then shipped to Montreal and recycled at the same facility as for the artificial tree (40 km away from Montreal).

Table 2.1 - Natural tree major economic flows

Component	Sub-component	Qty	Unit	Source / Hypothesis
Tree in nursery		196,700	trees/ha	Nursery
	Seeds	130.3	kg/ha	Nursery / Seeds
	Peat moss	30	t/ha	Nursery / Peat moss
	Fertilizing	4,062	kg/ha	Nursery / 33 applications
	Pesticides	70.4	kg/ha	24 applications, transported by boat from Europe
	Irrigating	2,103	m^3/ha	Nursery
	Extraction and replanting	606	kWh/ha	Nursery / Manual extraction, cold room for storage , mechanical sowing, peat moss removal
	Harvesting	1	ha	
	Packaging	196.7	kg/ha	PP extrusion, 20% new, 80% reused 10 times. 1976 bags/ha
	Storage	1,104	kWh	Nursery / Electricity consumption for cold room
	Transport	50	km	To field, 0.25 kg/tree over 50 km
	Land occupation	4	ha*a	4 years

Component	Sub-component	Qty	Unit	Source / Hypothesis
Tree in field		2,910	trees/ha	CRAAQ model 2007
	Tree in nursery	3,483	trees/ha	CRAAQ / Includes losses
	Sowing	1	ha	CRAAQ / Model = potato planting
	Fertilizing	3,650	kg/ha	CRAAQ / 9 applications of various fertilizers
	Pesticides	56.25	kg/ha	CRAAQ / 32 applications, transported by boat from Europe
	Grass	14	kg/ha	CRAAQ / 1 application
	Lime	4,500	kg/ha	CRAAQ / model = 1 slurry spreading
	Manual cutting	negl.		CRAAQ / negligeable
	Packaging	0.059	kg/tree	Standish, 2008
	Mowing	5	ha	CRAAQ / 1 ha per year for 5 years
	Tillage	2	ha	CRAAQ / 1 ha, 2 passes
	Stump removal	1.19	kg/tree	CRAAQ; Pettigrew, 2008, Peichl et al., 2007 / Stump is 45% of root system, manual operation + trailer, CO_2 and CH_4 emissions
	Transport in field	33.1	tkm/ha	Lemieux, 2008 & estimate / 11.36 kg/tree * 1 km * 2910 trees
	Loading	0.41	m^3/tree	Model = fodder loading
	Pickup use	5,000	km/yr	CRAAQ / general pickup use for tree activities for 50 ha * 11 yrs
	Transport	195	km/yr	Transport to Montreal
	CO_2 sequestration	17.9	t/ha	Villeneuve, 2003; Tremblay et al., 2006 / 2 t CO_2/ha/yr for 8.95 years
	Land occupation	9.95	ha*a	CRAAQ / for 8.95 years + 1 year in soil preparation
Home use	Stand - steel	1.5	kg	Same tree stand as for the artificial tree (from China) + reservoir to hold 4 L of water. Transport by client included in tree's 1st year
	Water	65	L/yr	PEI, 2008 / 3L/day for 15 days and 2L/day for 10 days
	Transport home	10	pkm/yr	Dedicated car 5 km both ways
Disposal	Stand-steel	1.5	kg	20% steel recycling, 80% landfilling
	Tree	11.36	kg/yr	50% combusted, 50% landfilled
	Packaging	negl.		0.5% of total tree weight

2.2.2.2. Artificial Christmas tree

The data for artificial trees came from two main sources: a manufacturer of premium Christmas trees in the United States (confidential) and a student report that was provided by the CIRAIG, which studied the typical artificial tree made in China (Levasseur et al., 2007). Data obtained directly from Chinese manufacturers was generally incomplete or unreliable.

The data from the premium tree was used as an alternate scenario to the typical Chinese tree, knowing that the premium trees are generally sturdier and last longer. The typical Chinese tree sold in Quebec was modelled with the PVC amount found in the student report obtained from the CIRAIG. The steel content was partially taken from this same report (metal for branches and brackets) and partially from the US manufacturer (stand and trunk). The cardboard was estimated based on dimensions given by the US manufacturer.

Briefly, the life cycle of the artificial Christmas tree is divided into four steps: 1- production (1.1- manufacturing, 1.2- distribution), 2- client transport, 3- use at home and 4- end of life (Figure 2.2 and Table 2.2).

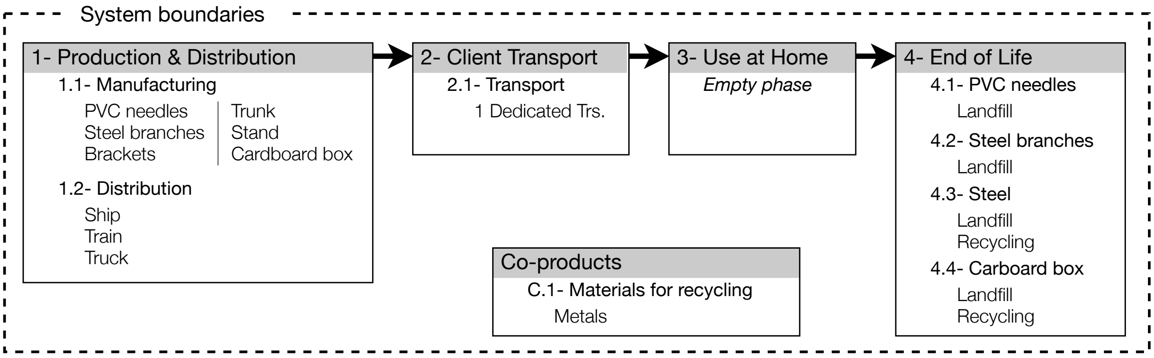

Figure 2.2 – Life cycle of the artificial tree from China (Model B).

Briefly, the tree is made of a steel stand with four legs (Figure 2.3). A trunk made of two sections get inserted in the stand centre hole. Then, eight brackets get fitted onto the trunk. These brackets have eight holes capable of receiving branches. A total of 64 branches of various lengths need to be assembled to get the tree. Each branch has a number of needles that are caught between two twisted wires. Details in Appendix C.

Figure 2.3 – Christmas tree stand from China (Model B), weighting 1.19 kg

The amount of PVC calculated by Levasseur et al. (2007) came from the weight of 24 needles (0.174 g), the needle count over one inch multiplied by the total length of branches A total of 387,360 needles and 2.808 kg of PVC was calculated. In this study, the same amount of PVC is taken. The pigments have been modelled based on dyes from the Input-Output database from Danemark and account for 1% of the plastic weight (Confidential plastic expert, 2008; maximum 1%). To stabilize the PVC, nowadays, approximately 1-2% of tin is used instead of 2-5% of lead (Gibb, 2008). This data is, however, is assumed to be included in the PVC data.

The amounts of steel for the branches and the brackets are also taken from Levasseur et al, 2007. They calculated the volume and mass of each branch and brackets using a steel density of 7.85 g/cm^3 (4.74 kg and 0.100 kg, respectively). The stand weight is estimated based on the stand for the premium trees made in the United States since these stands are outsourced to a Chinese manufacturer (Figure 2.3). This data also includes paint. Although a rubber feet and a PE bag make the complete stand (the stand is outsourced by the tree manufacturer who receives it packaged in a PE bag), they have been neglected since they represent less than 0.5% of the tree weight and do not lead to important environmental impacts (< 3%). The trunk data is also taken from the US manufacturer who weighted the trunk. The trunk looked similar to those made in China and is made of two sections that wedge into each other.

The tree is finally put in a double cardboard box, one for shipping and one for the client to use for storage.

To get to Montreal, the completed and packaged tree is transported from Beijing to the port of Xingang by truck, from Xingang port to Vancouver by freight ship, from Vancouver to Montreal by train and from the train station to a store by truck (Matta, 2008).

The use process only includes the dedicated transport to purchase the tree. The tree is primarily sent to a landfill 40 km from Montreal. The stand, trunk and brackets are partially recycled in a facility located 40 km from Montreal as well. The branches are 100% sent to a landfill.

Table 2.2 - Artificial tree major economic flows

Life cycle steps	Component	Qty	Unit	Source / Hypothesis
Tree production	Total weight	10.549	kg	
	PVC	2.808	kg	Levasseur et al., 2007
	Branches	4.74	kg	Levasseur et al., 2007
	Trunk	0.782	kg	US manufacturer / 2 sections, 33 inches long, 24 gauge, 1.25 in OD, that wedge into each other
	Stand	1.19	kg	US manufacturer & estimate / 4 legs, 32 cm, 7/16 in OD, 1/8 in thick + center piece (equiv. 2 legs)
	Brackets for branches	0.100	kg	Levasseur et al., 2007
	Packaging - cardboard	0.929	kg	US manufacturer & estimate / 2 boxes 40 in x 20 in x 20 in, 1 for shipping, 1 for client storage, density = 150g/cm^2, 20% cardboard overlap for joints
Transport from China to Mtl	Truck	180	km	Estimate / Beijing to port Xingang
	Ship	9,000	km	Freight ship from China to Vancouver
	Train	5,000	km	Diesel train from Vancouver to Montreal
	Truck	30	km	Estimate / Train station to stores
Client transport		10	pkm	Dedicated car 5 km one way for a total of 10 km
Disposal	Steel (brackets, trunk and stand)	2.072	kg	Estimate 20% recycling, 80% landfilling
	Steel (branches)	4.74	kg	100% landfilled, too difficult to separate from PVC
	PVC	2.808	kg	100% landfilled, too difficult to separate from steel
	Cardboard	0.929	kg	50% recycling, 50% landfilled

2.2.3. Data quality

Data quality was evaluated with the Weidema method, adapted by Toffel (Toffel et al., 2004; Weidema et al., 1996). Table 2.3 presents the six evaluation criteria for data quality, ranging for one to five, where one is the best quality and five the most uncertain.

The data quality for the natural tree is generally better than for the artificial tree (Table 2.4). On the one hand, the natural tree production in field obtains the best scores for the data quality, while, on the other hand, the artificial tree production is amongst the data with the lowest quality. It is also worth mentioning that all primary data comes from recent years.

Table 2.3 - Data quality evaluation, from the Weidema method, adapted from Toffel et al. 1996

Indicator score	**1**	**2**	**3**	**4**	**5**
Acquisition method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate (by expert)	Nonqualified estimate
Independence of data supplier	Verified data, information from public or other independent source	Verified information from enterprise with interest in the study	Independent source but based on nonverified information from industry	Nonverified information from industry	Nonverified information from the enterprise interested in the study
Representativeness	Representative data from sufficient samples of sites over an adequate period to even out normal fluctuation	Representative data from smaller number of sites but for adequate periods	Representative data from smaller number of sites, but from shorter periods	Data from adequate number of sites but shorter periods	Representativeness unknown or incomplete data from smaller number of sites and/or from shorter periods
Data age	Less than 3 yrs	Less than 5 yrs	Less than 10 yrs	Less than 20 yrs	Age unknown or more that 20 yrs
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological correlation	Data from enterprises, processes, and materials under study	Data from processes data from processes and materials under study but from different enterprises	Data on related and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Table 2.4 - Data quality for the natural and the artificial trees

Tree type	Life cycle steps	Acquisition method	Independence of data supplier	Representativeness	Data age	Geographical correlation	Technological correlation
Natural tree	Nursery	2	4	5	1	2	3
	Field	2	1	1	1	1	1
	Use (water+car)	4	3	1	1	3	3
	Combustion	2	4	5	1	3	3
	Recycling	5	3	5	1	5	4
	Landfill	5	3	5	1	5	4
Artificial tree	Production	3	4	5	1	5	5
	Transport	4	3	3	1	3	4
	Use (car)	5	3	1	1	3	3
	Recycling	5	3	5	1	5	4
	Landfill	5	3	5	1	5	4

2.2.4. General hypotheses

We assume that the type of Christmas tree does not influence the customer's use. Therefore, the decoration is identical for both types of trees as well as the energy consumption.

We assume that the natural Christmas trees come from the Eastern Townships and that the artificial Christmas trees come from Beijing in China.

We assume that the transition from one type of tree to another does not imply additional environmental impacts, should consumers change their type of tree.

We assume that the consumers purchasing the artificial and natural trees have the same recycling habits. We also assume that the Quebec producers of natural trees recycle a portion of the packaging they use while the packaging can be neglected for plastics and metals in China.

Finally, we assume that the collected data, whether from interested parties or databases, represents current technologies. When possible, we have verified this hypothesis, otherwise, we considered it correct.

2.2.5. Impact assessment method

The primary impact assessment method used in this study is *Impact 2002+* (v2.05) (Jolliet et al., 2003). This choice is justified from the need to present the understandable and important results to the general public. *Impact 2002+* is an impact assessment method of the life cycle that allows the grouping of problem-oriented impacts into four damage-oriented impacts on the environment. These categories are: 1) human health, 2) ecosystem quality, 3) climate change and 4) resources. It is important to note that the problem-oriented impacts for aquatic acidification and aquatic eutrophication are not included in the damage category for ecosystem quality. This results in an underestimation of the impacts for ecosystem quality.

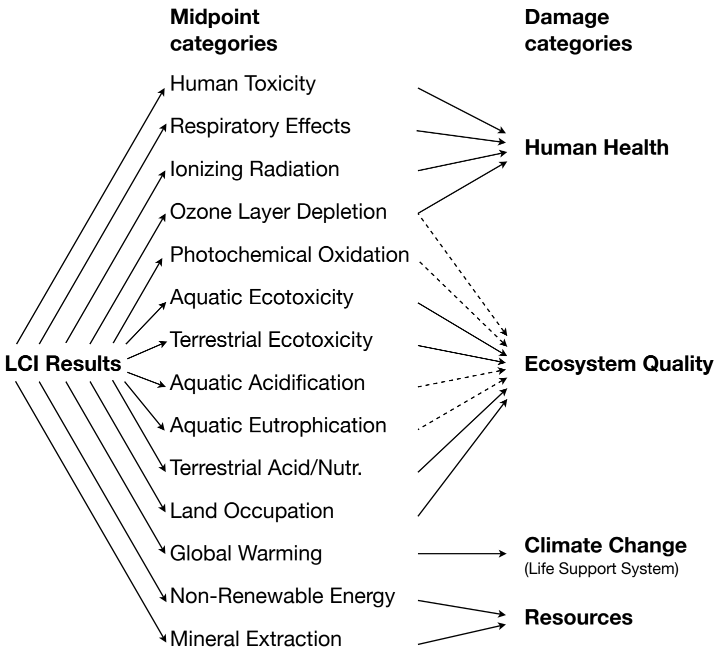

Figure 2.4 – General outline of the Impact 2002+ assessment method for problem-oriented (mid points) and damage categories.

The *Impact 2002+* method was slightly modified to include the effects of various gases on climate change, as per Table 2.5.

Table 2.5 – Impact 2002+ modifications to include the effect of biogenic gases on climate change

Compartment	Characterization factor	Impact 2002+	Modified to...
Air	Carbon dioxide, biogenic	0	1
Air	Carbon monoxide, biogenic	0	1.57
Air	Methane, biogenic	0	7
Raw	Carbon dioxide, in air	0	-1

For both types of trees, we expect that the dominant impacts will be related to the following activities: agriculture (ecosystem quality), transport (climate change), pesticides and fertilizers (all four damage categories).

Precautions must be taken when presenting normalized results with *Impact 2002+* to show the relative importance of the different impact categories. The normalization factors in *Impact 2002+* are representative of the impacts made by an average European (Western Europe) over one year. Because life and consumption habits, as well as population density are not equivalent between Quebec and Western Europe, special caution must be taken when presenting these results.

Besides, to evaluate the result sensitivity to the impact assessment method, a second analysis will be conducted with the north american method *TRACI2*. However, because this method is problem-oriented and not damage-oriented, the comparison will be made for each problem category.

2.2.6. Interpretation method

The interpretation allows the identification of important steps in the life cycle that are major contributors to the environmental impacts. This last phase of the LCA summarizes the results while verifying that they meet the goal and scope of the study.

The ISO 14040 standard also requires that a series of controls be completed to inform the general public of the data quality:

- **Contribution analysis** to quantify which steps of the life cycle contribute most to the environmental impacts.
- **Sensitivity analysis** to evaluate the impacts of the processes that may vary the most because of the hypotheses made during the construction of the system. The following hypotheses were tested for sensitivity:
    - Recycling and special disposal rates
    - Transport distances: the most uncertain distances (in China) were increased and reduced by appropriate values.
    - Tree weights: the tree weights were increased for one of the tree types (10%) while decreased for the other one (-10%), and vice-versa. CO_2 sequestration was modified linearly with tree weight.

- CO_2 sequestration rates: from a C source of 0.5 kg CO_2/ha/yr to a C sink of 3 kg CO_2/ha/yr.

- Pesticides emissions: The value of pesticide emissions were made null in the sensitivity analysis.

- Fertilizer emissions: The value of fertilizer emissions were made null in the sensitivity analysis.

- **Completeness checks** to evaluate the impacts of the completeness of data used, a control list that includes emissions to air, water and soil and wastes for each process identified within the product system has been used. This was an iterative process.
- **Consistency checks** A consistency check was done to evaluate if data respect the geographic and temporal boundaries. This was done as an iterative process.
- **Uncertainty analysis** An uncertainty analysis was performed with the Monte Carlo method for 100 iterations using SimaPro. Uncertainties for primary data were modelled with the triangular distribution when the data quality was good and with the rectangular distribution when the distribution was unknown.

2.2.7. Alternate scenarios

There is a possibility that the tree manufacturers in China are still using lead instead of tin to stabilize the PVC resin. A PVC with lead was modelled to account for this possibility and was compared to the tree without lead.

Nowadays, Christmas trees are sometimes made with PE instead of PVC, or with a combination of both. The PE tree looks more real since the needles have a 3D shape instead of being flat. To evaluate the potential environmental impacts of the PE tree, a tree made with 100% PE instead of PVC was modelled. The differences in density between PE (0.93 g/cm^3) and PVC (1.38 g/cm^3) were taken into account. This means that the PE tree would likely have the same quality as the PVC tree.

2.2.8. Limits of this study

The goal of this study is to position both types of Christmas trees with respect to environmental impacts, as a first step towards the requirements of sustainable development. To achieve this goal, an LCA is used to identify the hotspots of the life cycle for both tree types. The results from this study must reflect this goal.

An LCA is an efficient and rigourous method based on scientific knowledge. Yet, subjective aspects such as data quality and validity (e.g. data from secondary suppliers), risks of omissions of important flows and the subjectiveness of the impact assessment method can limit the quality of the conclusions. For example, the results from an LCA indicate potential environmental effects, and that they do not predict actual impacts on category endpoints, the exceeding of thresholds or safety margins or risks.

A complete evaluation of the quality of results, according to Phase 4 of the ISO 14044 standard, will allow for a better understanding of these limits.

3. Impact Assessment

To efficiently determine the life cycle phases and processes that are major contributors most to the various mid-point impact categories, the modified *Impact 2002+* method was used (Table 2.3). The results presented here represent the use of a Christmas tree for one Christmas Holiday season, taking into consideration the life span of each type of tree.

When appropriate, the uncertainties for each type of tree are presented. They are therefore outlined in graphs that show only one type of tree in absolute terms, where the error bars represent Mean ± 2 standard deviations (SD).

3.1. Natural Tree

The results for the natural tree is divided into three phases: production, use and end of life. To better show some details, the three phases are further divided and are presented as: tree production in nursery, tree production in field, steel stand production and transport, client transport, water usage and end of life. There are therefore six stages for the natural tree. Four of these six stages are major contributors to the environmental impacts over the entire life cycle: tree production in field, stand, client transport and the end of life (Figure 3.1). The tree production in a nursery, has less than 3% impacts for all mid-point categories except for non-carcinogens (12%), land occupation (7%) and global warming (5%). Tree watering at home has little environmental impacts on the entire life cycle for all mid-point categories (< 3%), except for aquatic ecotoxicity (3.2%).

Tree production in field has significant impacts on global warming for a CO_2 sequestration of 2 t CO_2/ha/yr. A thorough analysis of this contribution is included in the sensitivity analysis (section 4.1). For all other mid-point categories, tree production in field represents at least 20% of the life cycle impacts (up to 89, 92 and 96% for aquatic ecotoxicity, land occupation and aquatic eutrophication, respectively).

The stand impacts represent 18% or less of the life cycle impacts, for all mid-point categories except mineral extraction (63%).

Client transport over 10 km (return trip) every year plays an important role in the overall life cycle of the natural tree. Depending on the mid-point category, the contribution of this dedicated transport varies from 1 to 68% of the impacts. For global warming, the dedicated car contribution represents 49% of the total impacts.

The end of life includes impacts that may be negative (e.g. non-carcinogens, 26%; respiratory inorganics, 12%; terrestrial ecotoxicity, 35%; global warming, 28%) or positive (e.g. ozone layer depletion, 68%; aquatic acidification, 36%; non-renewable energy, 56%). The results are mixed because the burning of the wood chips at the end of life replaces heavy oil that was used at the Kruger plant (Hamel, 2008).

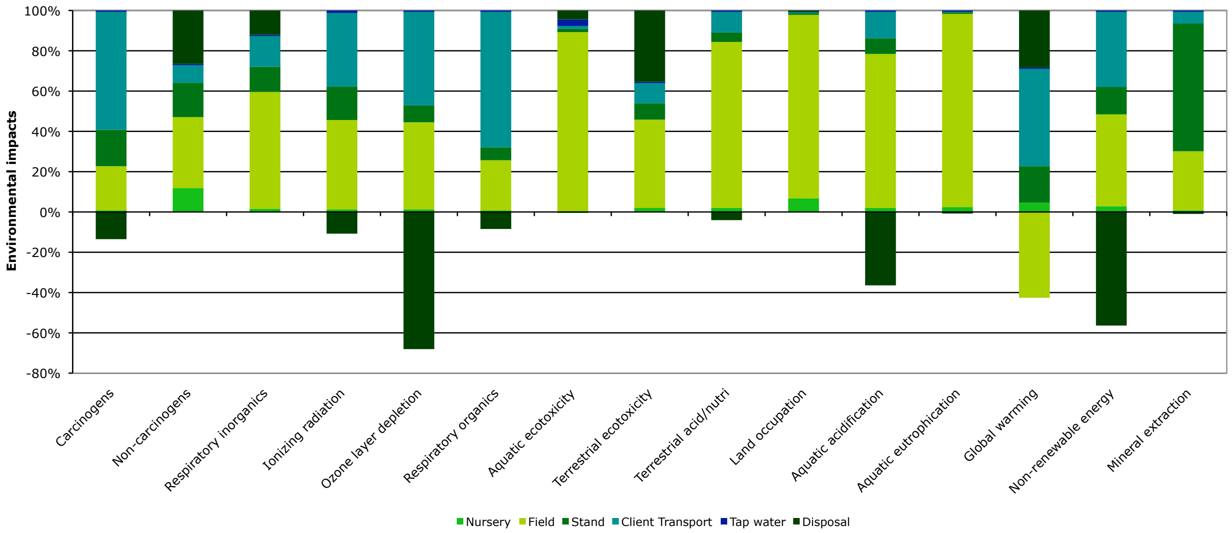

Figure 3.1 – Mid-point impacts for the life cycle of six natural trees.

Although the relative importance of the tree production at the nursery is small, the mid-point impacts for this stage are presented in Figure 3.2. The process sowing the trees includes the application of peat moss in pots, which has significantly negative impacts on non-renewable energy for its production and significant impacts on global warming when it is dumped in a pile on the field (Figure 3.2). Important impacts are mainly divided between fertilizers, pesticides, except for land occupation where tree growth was modelled as land occupation. Note that CO_2 sequestration was neglected for this stage of the LCA because the trees are assumed to be too small.

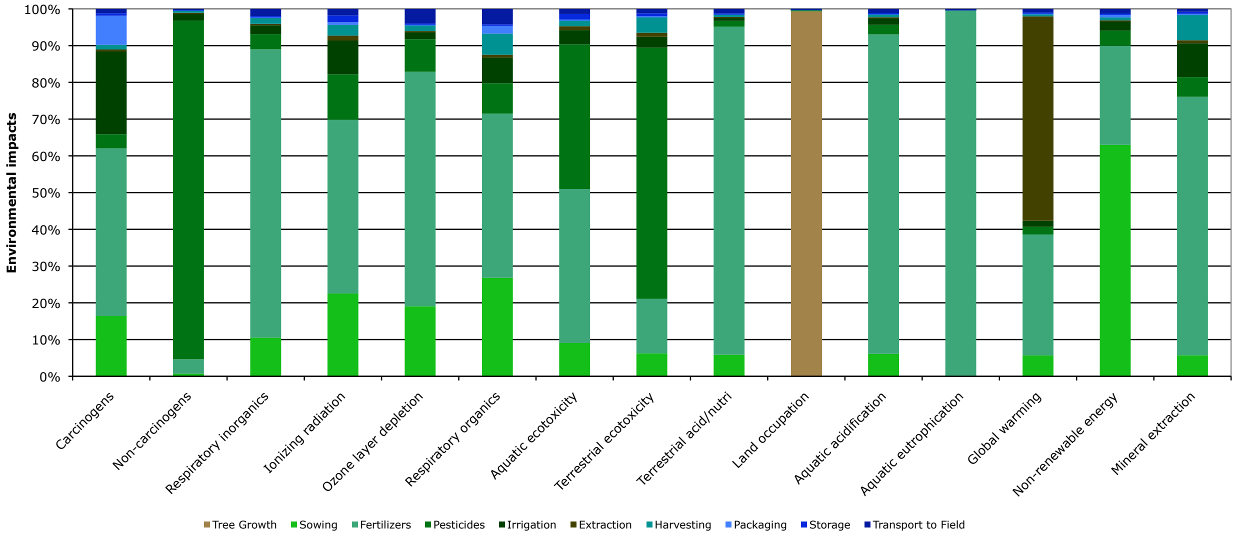

Figure 3.2 – Mid-point impacts for the production of trees in a nursery to produce one mature tree.

For the tree production in field, tree growth includes CO_2 sequestration and land occupation. This growth plays a major role on global warming and land occupation, respectively (Figure 3.3). Then, in order of importance for most mid-point categories come the fertilizers, pesticides and lime pulverization. It is worth mentioning that the grass between tree rows has important impacts on land occupation, although it may be a necessary space for the trees to grow. In Figure 3.3, the impacts below zero represent positive impacts on the environment and the impacts above zero are negative impacts.

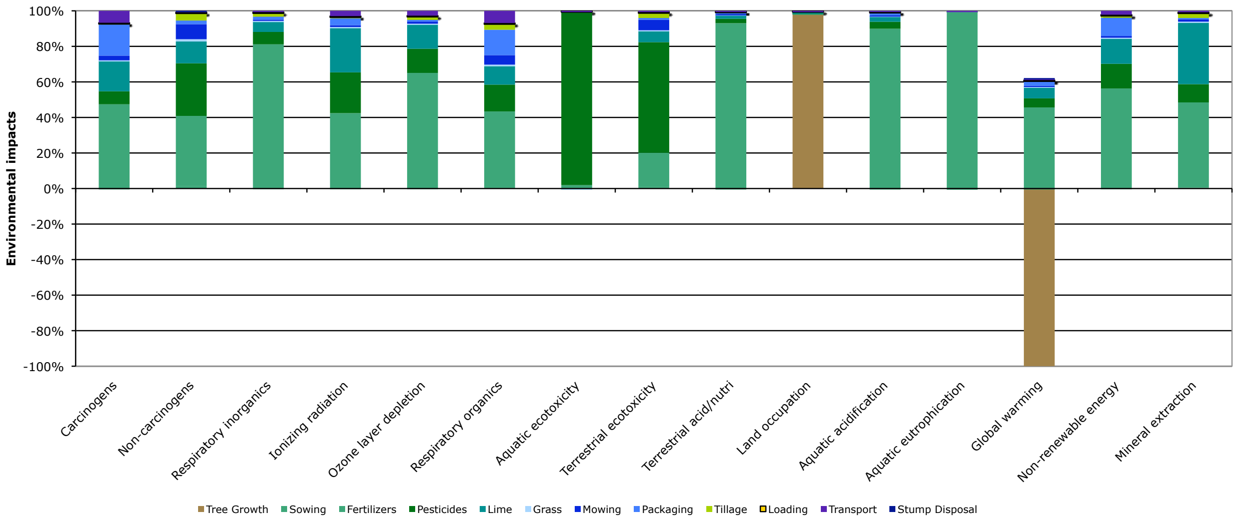

Figure 3.3 – Mid-point impacts for the production of one tree in a field.

For the stand, the various metal working processes are outlined in Figure 3.4. The amount of steel has the most impacts and its transport from China to Montreal are roughly 15% of the impacts with the highest value for terrestrial acidification / nutrification (35%).

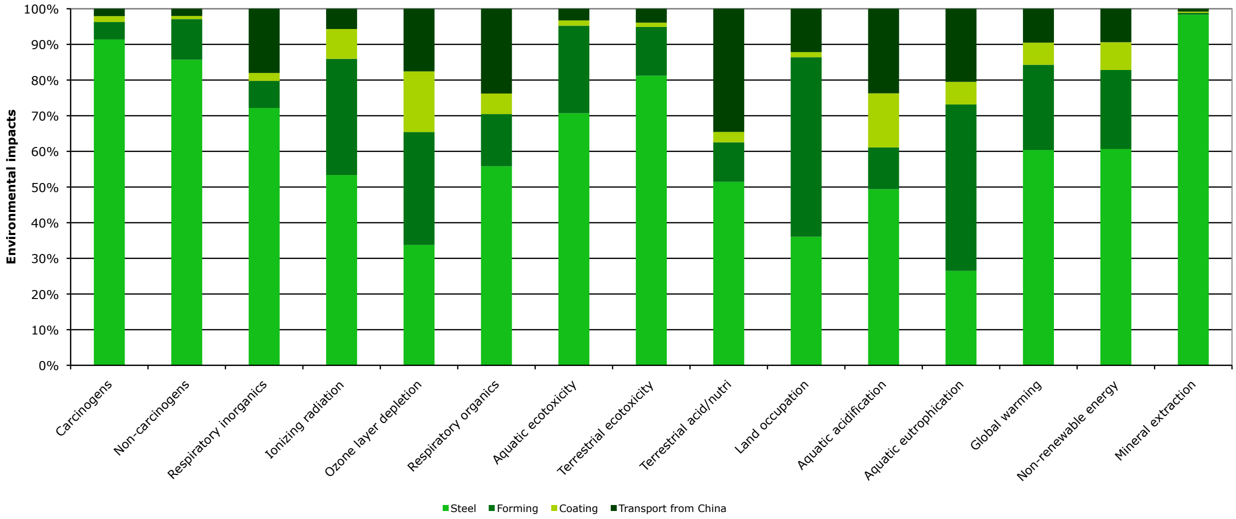

Figure 3.4 – Mid-point impacts for the steel stand made in China and transported to Montreal.

Use of the natural tree is presented in Figure 3.5. It includes water usage and dedicated dedicated car transport annually. The consumer transport dominates the impacts for all categories except aquatic ecotoxicity.

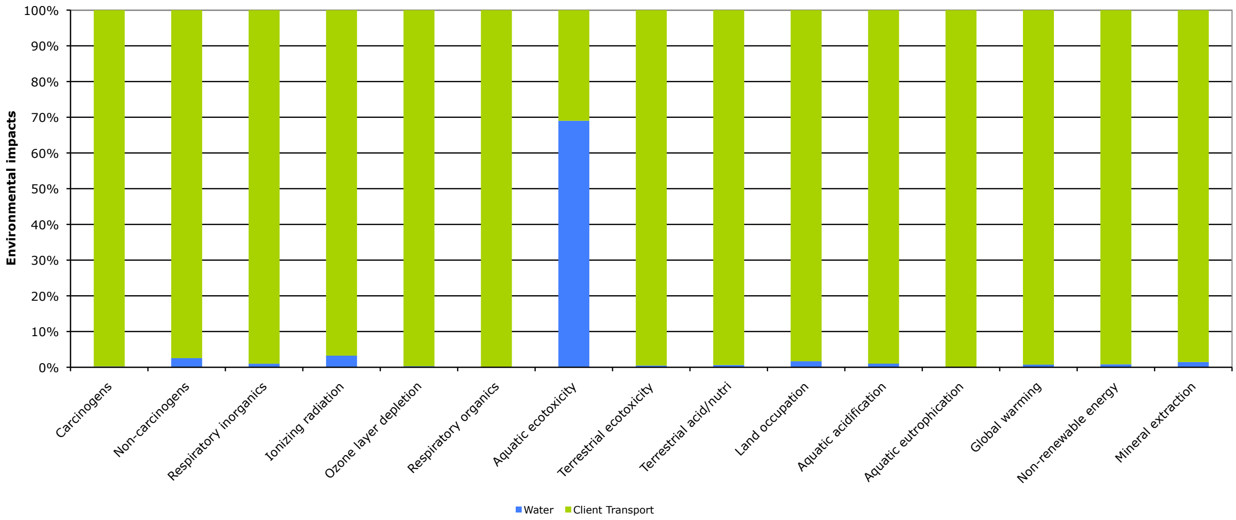

Figure 3.5 – Mid-point impacts for the use of one natural tree at home (water and client transport).

The environmental impacts for the end of life of the natural trees can vary greatly. In this study, 50% of the trees are combusted and this combustion replaces the combustion of heavy oil (Figure 3.6). The avoided heavy oil has positive impacts for many mid-point categories, but the combustion of wood also has important impacts for other categories. The other half of the trees is sent to a landfill, which has generally smaller impacts (positive or negative) on the environment. The stand disposal accounts for small impacts for all mid-point categories except mineral extraction (63%), where recycling plays a major role.

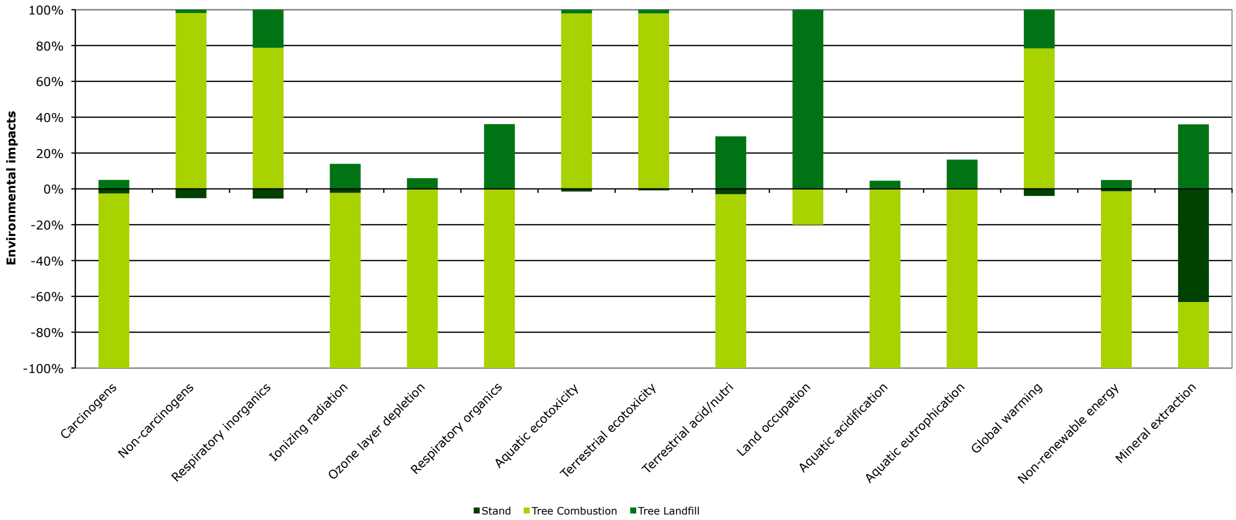

Figure 3.6 – Mid-point impacts for the end of life of on natural trees and a stand with a life span of six years.

To understand the relative importance of each category in the overall life cycle, it is possible to normalize the data with respect to the average European (*Impact 2002+*). The normalization methods are not recommended for public communication since the average European is not necessarily representative of the average Quebecer or average Chinese. Nevertheless, to understand the system at hand, normalization is used here for the damage categories. Ecosystem quality is not the most impacted category for the natural tree, as would be expected for agricultural processes (Figure 3.7).

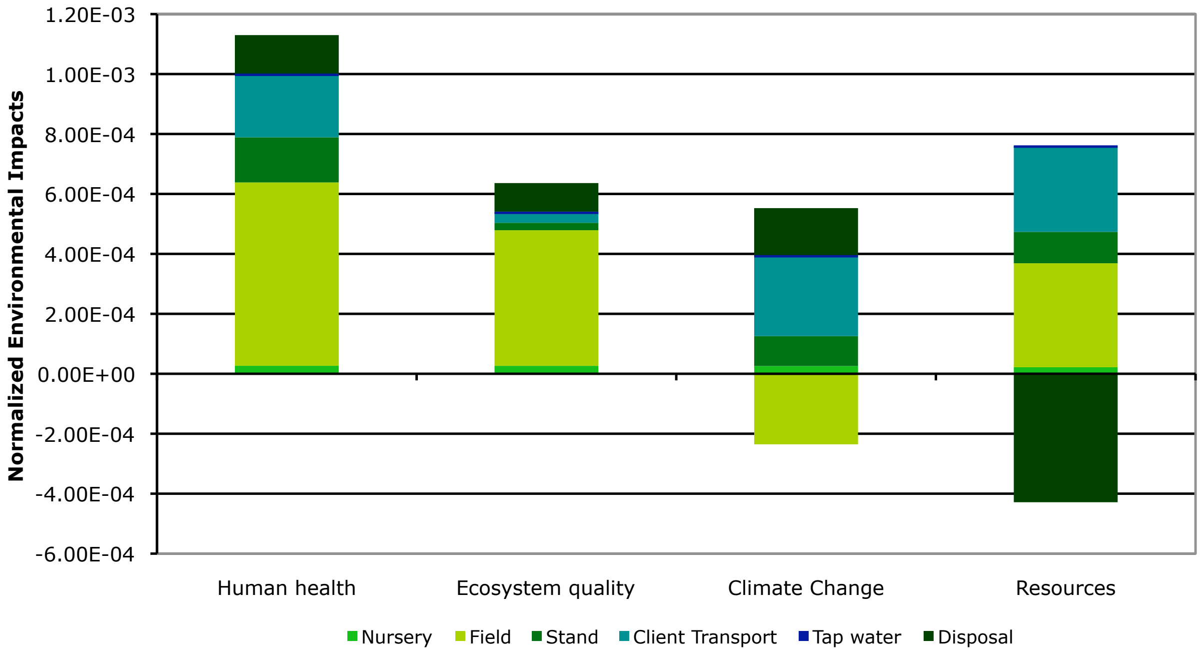

Figure 3.7 – Normalized impacts per damage category for the life cycle of one natural tree with a stand having a life span of six years.

To further understand the natural tree life cycle, the absolute results are presented below for each damage category (Figure 3.8 to 3.11). The total amount shown is Mean ± 2SD. The values in these figures are presented for one year, based on a stand life span of six years and a tree life span of one year. For Figure 3.10 (Climate Change), the total amount of CO_2 eq. is 3.1 kg CO_2 eq/year. This amount is roughly equivalent to driving a car over 21 km, when considering a car emitting 150 g CO_2/km. In general, the absolute values are rather small in comparison with other human activities.

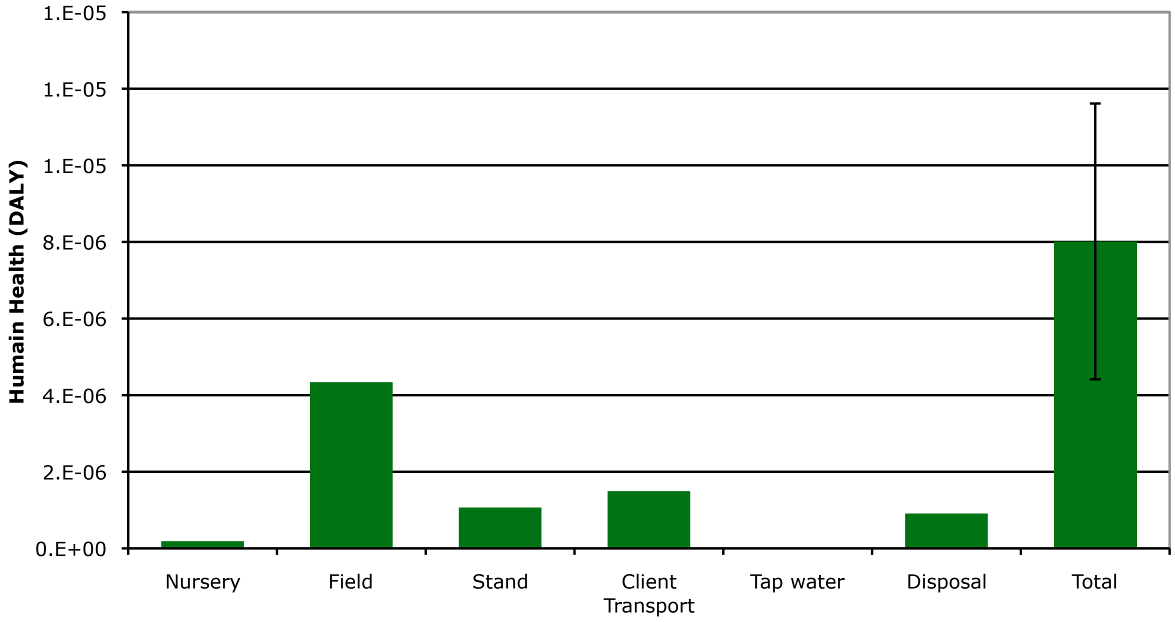

Figure 3.8 – Absolute impacts for Human Health per life cycle stage for one natural Christmas tree.

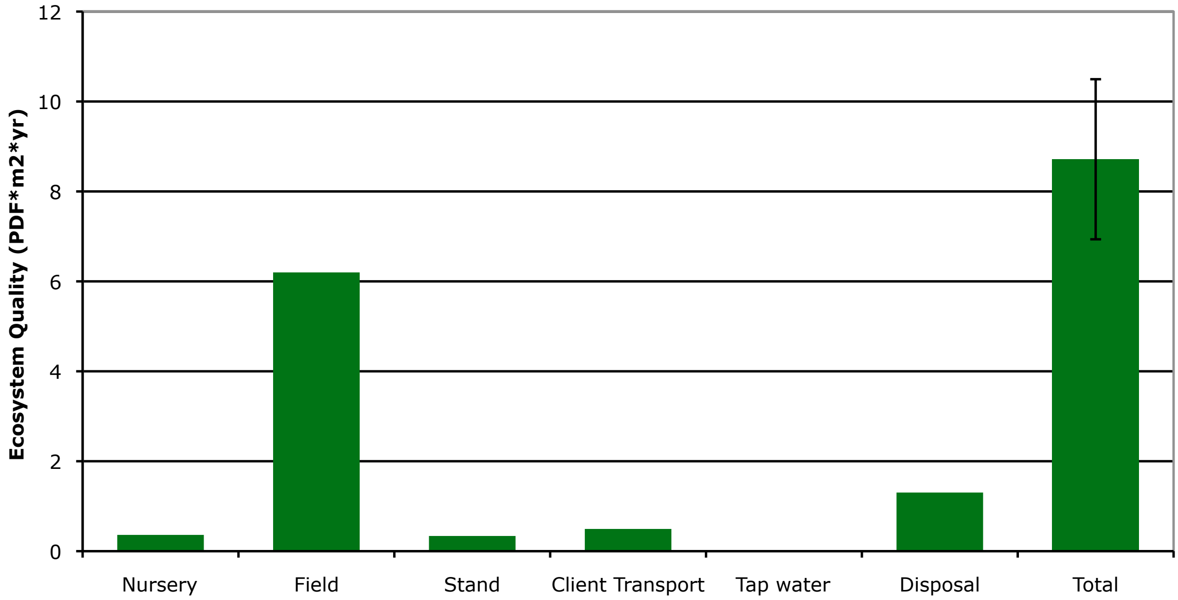

Figure 3.9 – Absolute impacts for Ecosystem Quality per life cycle stage for one natural Christmas tree.

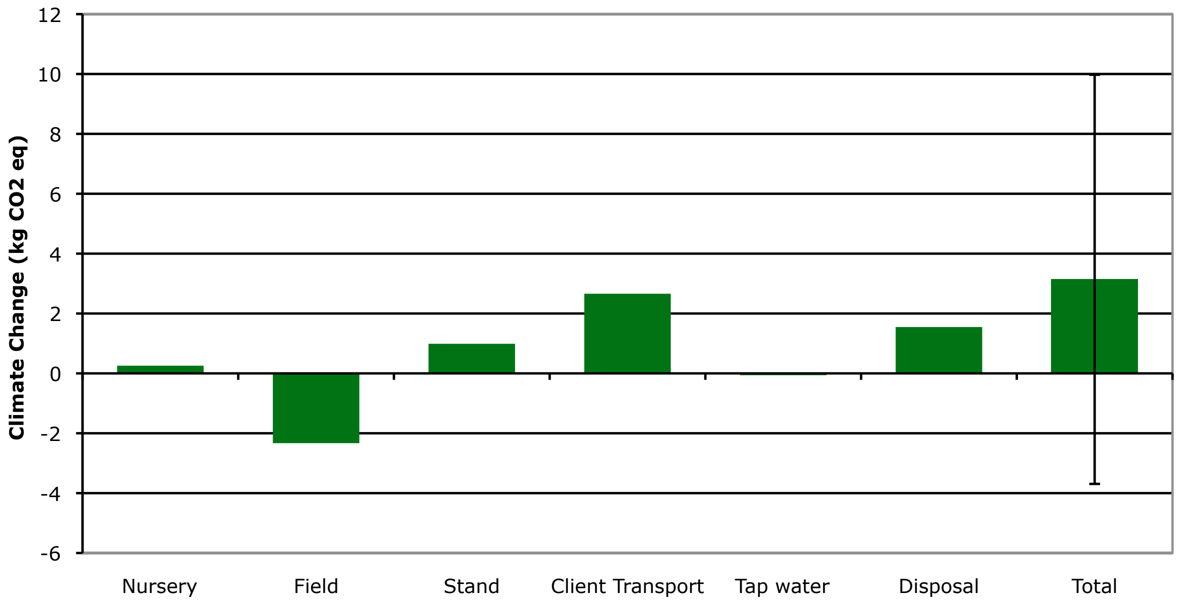

Figure 3.10 – Absolute impacts for Climate Change per life cycle stage for one natural Christmas tree. The negative values for field are caused by CO_2 sequestration during tree growth.

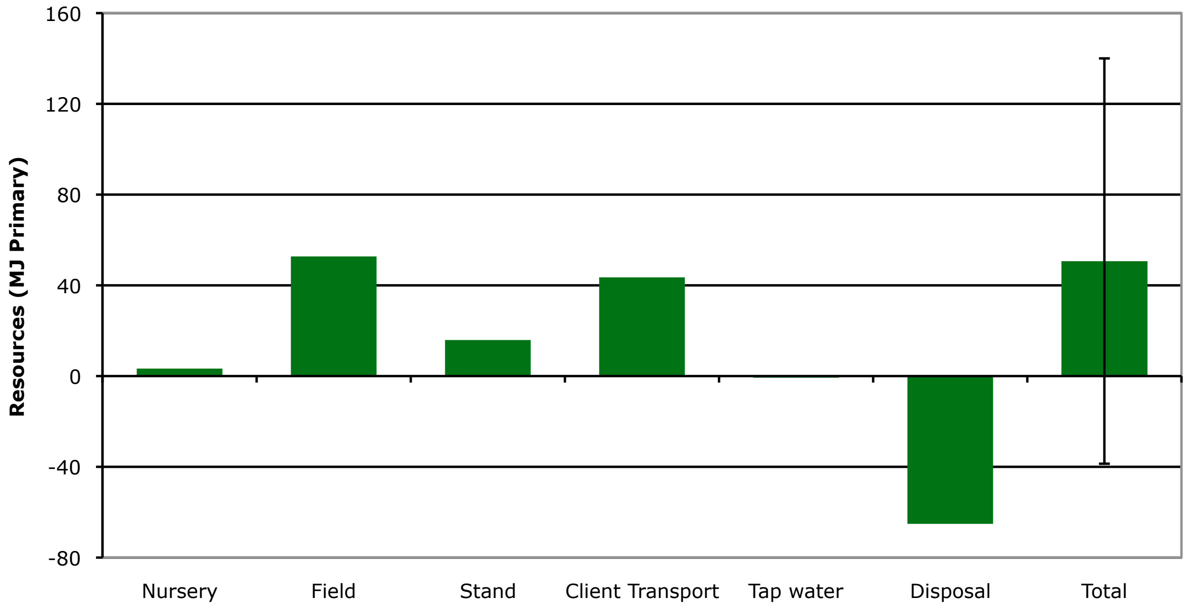

Figure 3.11 Absolute impacts for Resource Depletion per life cycle stage for one natural Christmas tree.

The process contribution for the three most important mid-point impact categories (not shown) was also analysed: respiratory inorganics, global warming and non-renewable energy (Table 3.1). The respiratory inorganics impacts primarily come from the tree end of life when it is burned or the avoided heavy oil, as well as from car operations (primarily by the consumer) and fertilizer production (Urea). The global warming positive impacts (shown here with a minus sign) primarily come from the CO_2 sequestration in the field and the avoided heavy oil at the end of life. The negative impacts of global warming come from multiple sources: wood burning in cogeneration system (Bromptonville) and furnace (Trois-Rivières), car operation (consumer), fertilizer production (ammonia and natural gas), stand (pig iron), some transport, peat moss (extraction and replanting of baby trees), and LDPE (seed, fertilizer and peat moss bags), and electricity (lignite). The non-renewable energy impacts primarily come from crude oil (input to dedicated car operation), natural gas (input to urea and other fertilizers) and uranium (input to electricity used in multiple processes).

Table 3.1 - Process contribution of the natural trees for the three major mid-point impact categories
Process names were directly taken from the ecoinvent database.

Mid-point category	Process	Unit	Total
Respiratory inorganics	Wood chips, burned in cogen ORC 1400kWth/QC U	%	34.6
	Fertilizing trees in field	%	26.7
	Wood chips, from industry, softwood, burned in furnace 1000kW/QC U	%	24
	Operation, passenger car, petrol, fleet average/RER U	%	7.35
	Urea, as N, in Mtl	%	3.17
	Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	%	-41.6
Global warming	Wood chips, from industry, softwood, burned in furnace 1000kW/QC U	%	98.4
	Wood chips, burned in cogen ORC 1400kWth/QC U	%	84.9
	Operation, passenger car, petrol, fleet average/RER U	%	62.6
	Fertilizing trees in field	%	39.9
	Ammonia, steam reforming, liquid, at plant/RER U	%	17
	Natural gas, burned in industrial furnace >100kW/RER U	%	14
	Pig iron, at plant/GLO U	%	9.43
	Transport, municipal waste collection, lorry 21t/CH U	%	5.91
	Disposal, wood untreated, 20% water, to sanitary landfill/CH U	%	5.75
	Operation, lorry >32t, EURO3/RER U	%	4.8
	Extraction & Replanting of baby trees	%	4.52
	Lignite, burned in power plant/DE U	%	3.44
	Polyethylene, LDPE, granulate, at plant/RER U	%	3.42
	Operation, freight train, diesel/RER U	%	3.15
	Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	%	-129
	Tree in field	%	-196
Non-renewable energy	Natural gas, at production onshore/RU U	%	18.8
	Crude oil, at production onshore/RAF U	%	10.7
	Uranium natural, at underground mine/RNA U	%	10.6
	Polyethylene, LDPE, granulate, at plant/RER U	%	9.42
	Natural gas, at production onshore/DZ U	%	9.03
	Crude oil, at production/NG U	%	8.97
	Natural gas, at production offshore/NO U	%	8.51
	Natural gas, at production onshore/NL U	%	8.2
	Hard coal, at mine/EEU U	%	7.48
	Uranium natural, at open pit mine/RNA U	%	7.1
	Lignite, at mine/RER U	%	5.16
	Hard coal, at mine/WEU U	%	5.04
	Peat, at mine/NORDEL U	%	3.59
	Natural gas, at production offshore/NL U	%	3.41
	Crude oil, at production offshore/GB U	%	-8.30
	Crude oil, at production onshore/RU U	%	-8.33
	Crude oil, at production onshore/RME U	%	-8.91
	Crude oil, at production offshore/NO U	%	-9.98

Finally, to verify the previous analysis with *Impact 2002+*, it is possible to evaluate the mid-point impacts using *TRACI2*. Figure 3.12 shows the mid-point impacts for the entire life cycle of the natural tree using this North American method. The relative contribution of the various phases of the life cycle resembles that of the *Impact 2002+* method. Still, the impact of the consumers' dedicated car transportation is significantly less with *TRACI2* than with *Impact 2002+*. The disposal of the natural tree is more important with *TRACI2*.

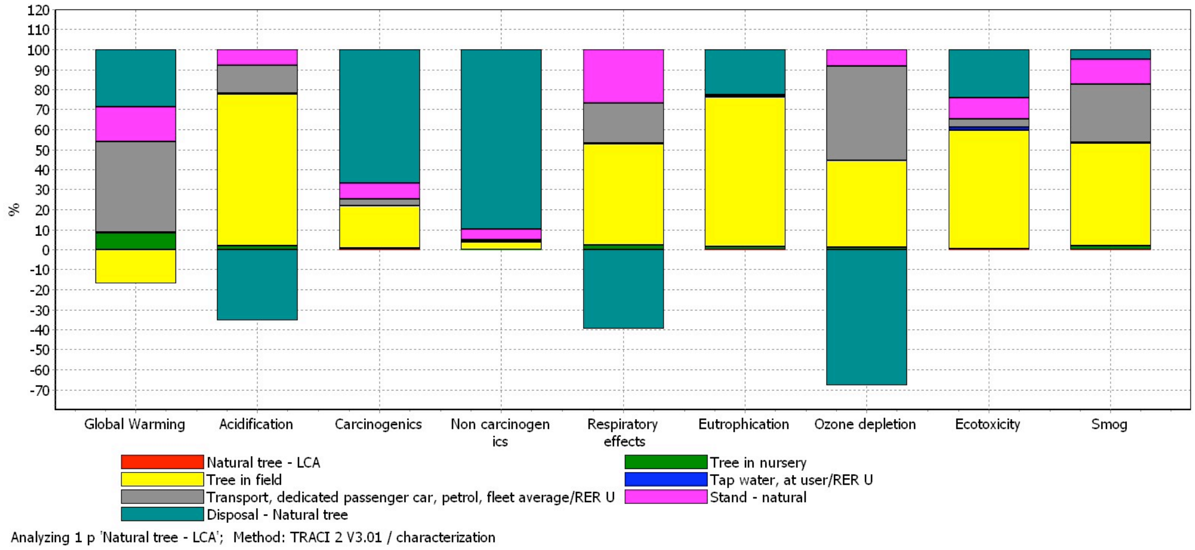

Figure 3.12 – Mid-point impacts for the life cycle of six natural trees using TRACI2.

3.2. Artificial Tree

The model for the artificial tree contains one predominant phase o the life cycle for all mid-point categories of impacts: the tree production in China (Figure 3.13). This phase contributes for 65% (terrestrial acidification) to 109% (land occupation) of the impacts. The transport phase from China to the store in Montreal and the transport by the consumers to their home come in second and third place, respectively, for all categories of impacts except for carcinogens and respiratory organics, where they come in third and second place, respectively. The tree's end of life contributes least to the impact categories, mostly due to steel recycling.

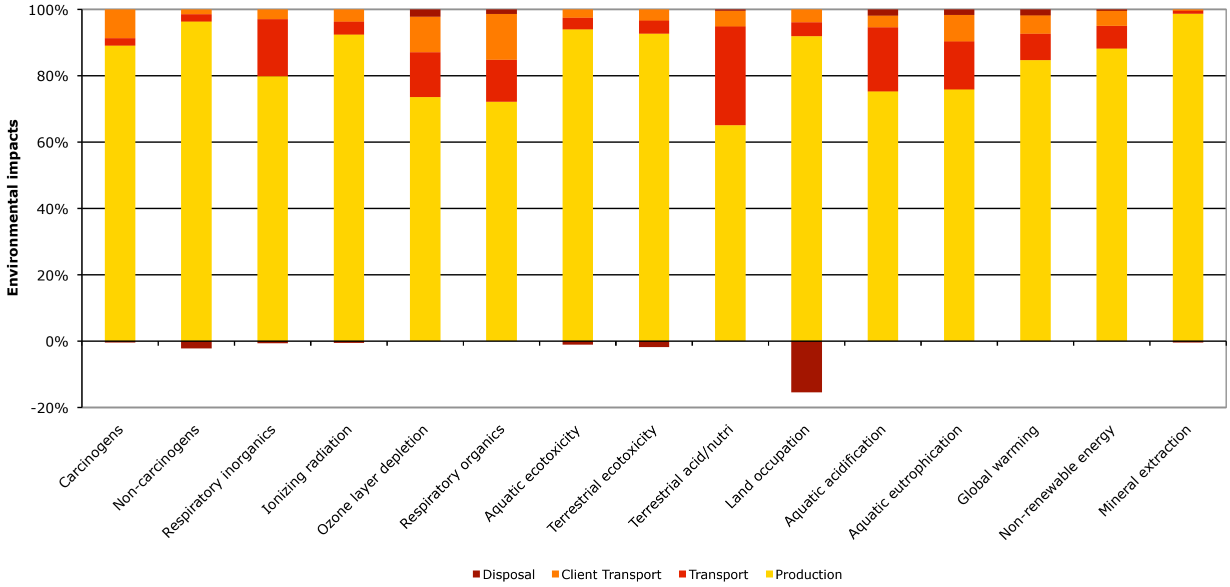

Figure 3.13 – Mid-point impacts for the life cycle of the artificial tree used for on Christmas Holiday season, based on a life span of six years.

The process of tree production in China (Figure 3.14) results in environmental impact from two major contributors: the steel in the branches and the PVC for the needles. When combining the steel for the branches, the trunk, the stand and the brackets, steel has the most important impacts on tree production for all mid-point categories (58 to 96%) except for land occupation (cardboard box, 66%).

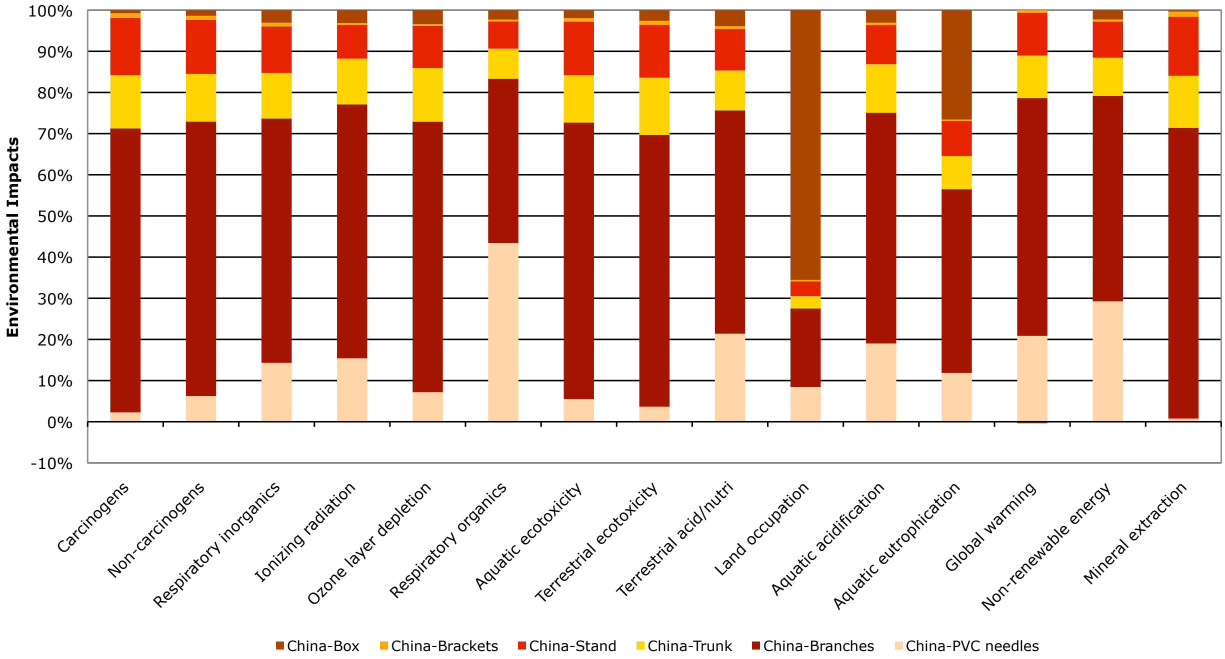

Figure 3.14 – Mid-point impacts for the artificial tree production in China.

The transport from China to the store in Montreal is divided in four stages: truck in China, ship from Beijing to Vancouver, train from Vancouver to Montreal and truck in Montreal. Figure 3.15 presents this transport with the dedicated transport by the consumers to purchase the tree. All other transports have been modelled and included in their respective phase of the life cycle (production or disposal) and they are not represented here. Between the manufacturer in China to the consumer's home, the dedicated transport by the consumer and the train portions are most important. Then comes the ship portion for most categories.

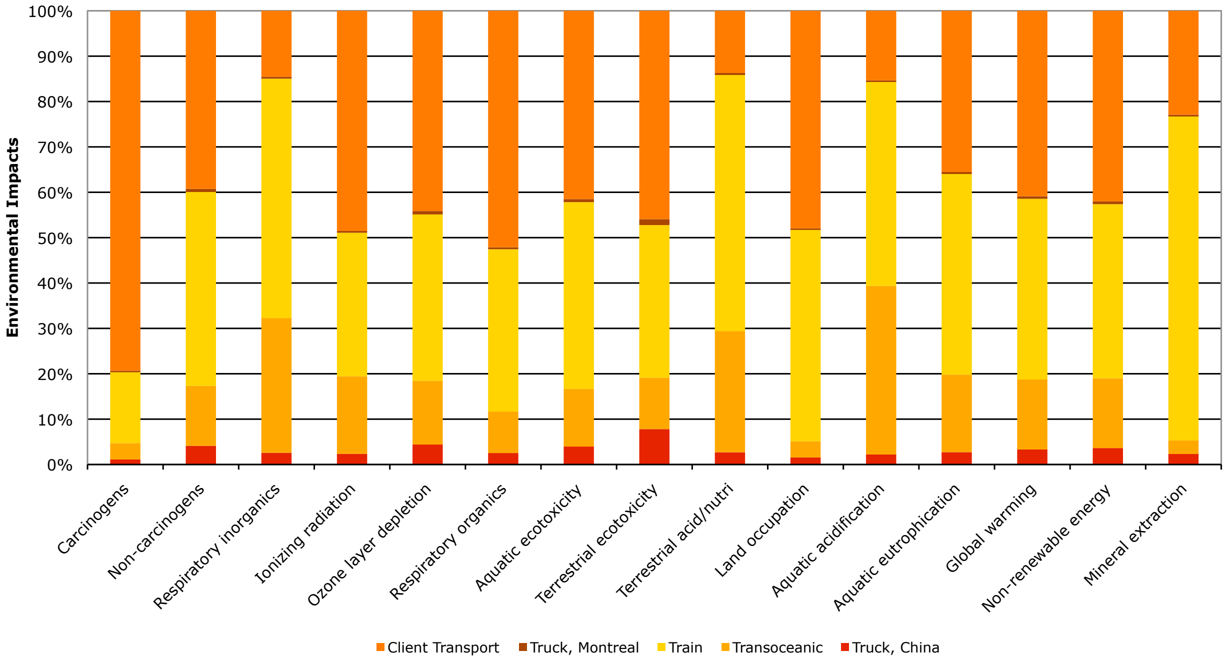

Figure 3.15 – Mid-point impacts for the artificial tree transport from China to the consumer's home in Montreal.

The end of life of the artificial tree has some positive impacts because of the steel (20% recycling except for branches) and cardboard (50% recycling) (Figure 3.16). Its low level of impact on the overall life cycle, however, does not require further analysis, except, perhaps for the net gain in land occupation due cardboard recycling.

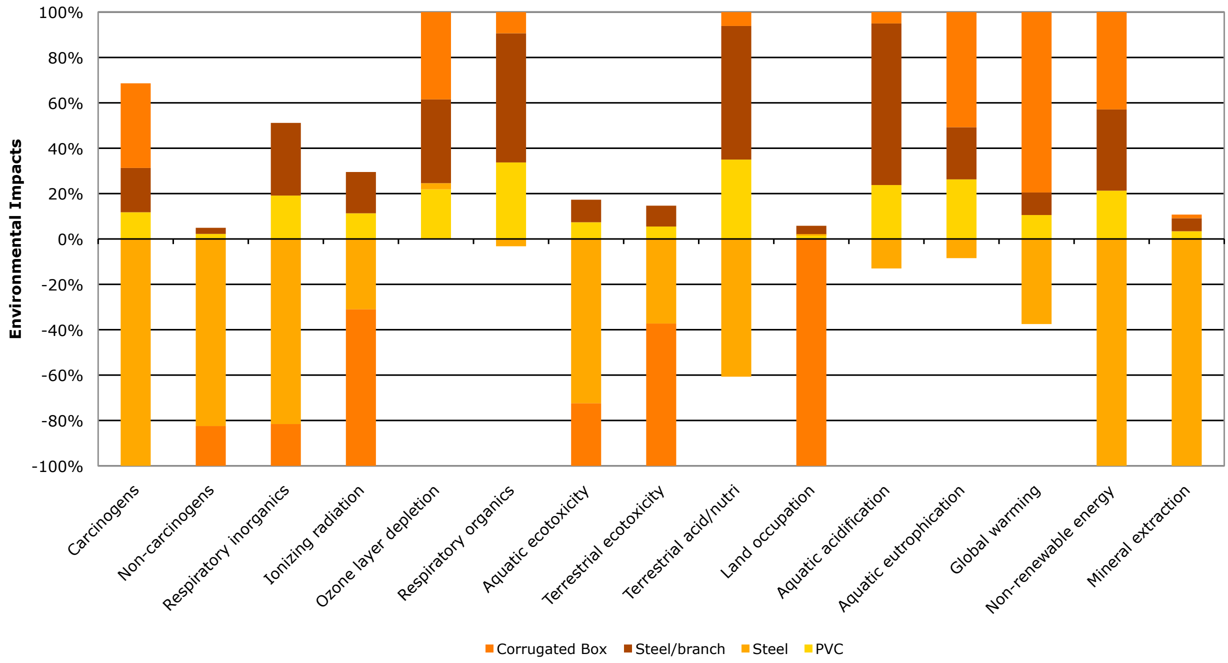

Figure 3.16 - Mid-point impacts for the disposal of the artificial tree.

To understand the relative importance of each category in the overall life cycle, it is possible to normalize the data with respect to the average European, as was carried out for the natural tree. When looking at the normalized impacts for the damage categories (Figure 3.17), the category for ecosystem quality is least impacted, as would be expected for the types of materials handled for the artificial tree.

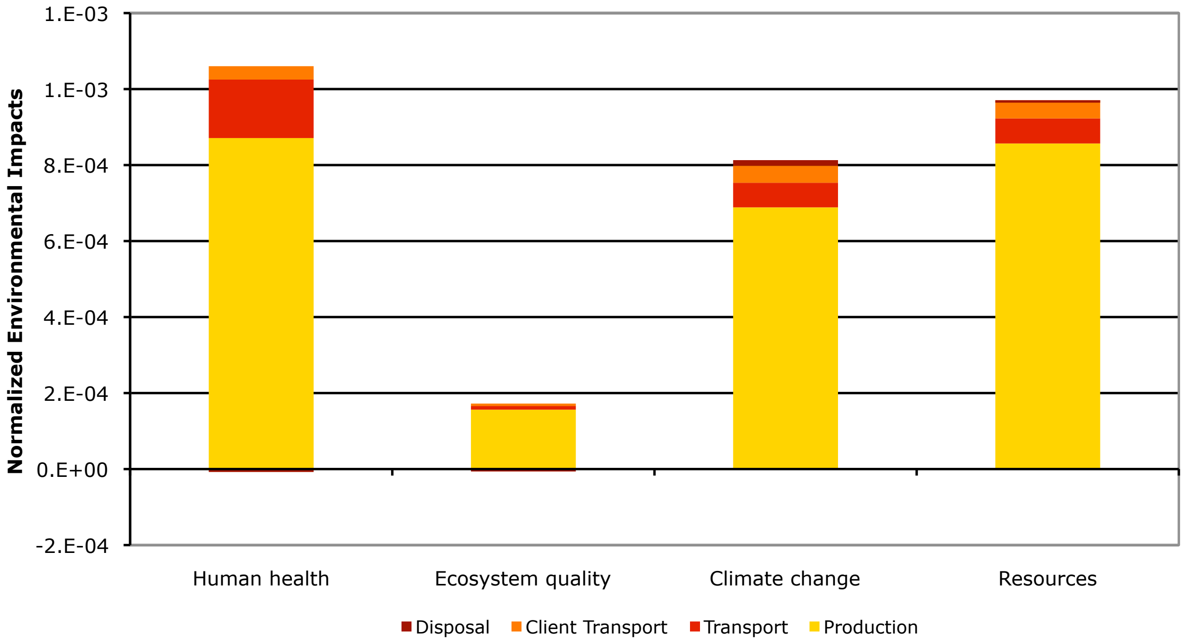

Figure 3.17 – Normalized impacts for the life cycle of the artificial tree with a life span of six years, used during one year.

To further understand the artificial tree life cycle, the absolute results are presented below for each damage category (Figure 3.18 to 3.21). The total amount shown is Mean ± 2SD. The numbers presented in the these figures are shown for one year, considering a tree life span of six years. For Figure 3.20 (Climate Change), the total amount of CO_2 eq. is 8.1 kg CO_2 eq./year or 48.3 kg CO_2 eq for its entire life span. The yearly amount of CO_2 eq is roughly equivalent to driving a car over 53 km, when considering a car emitting 150 g CO_2/km. The absolute values are rather small in comparison with other human activities.

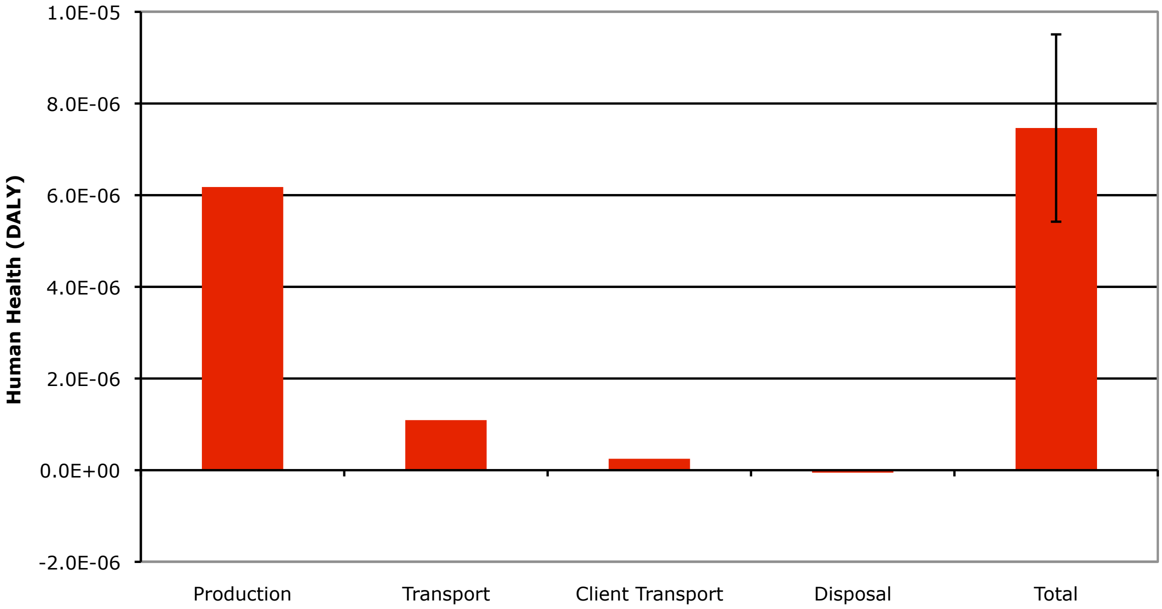

Figure 3.18 – Absolute impacts for Human Health per life cycle stage for an artificial tree with a life span of six years, used during one year.

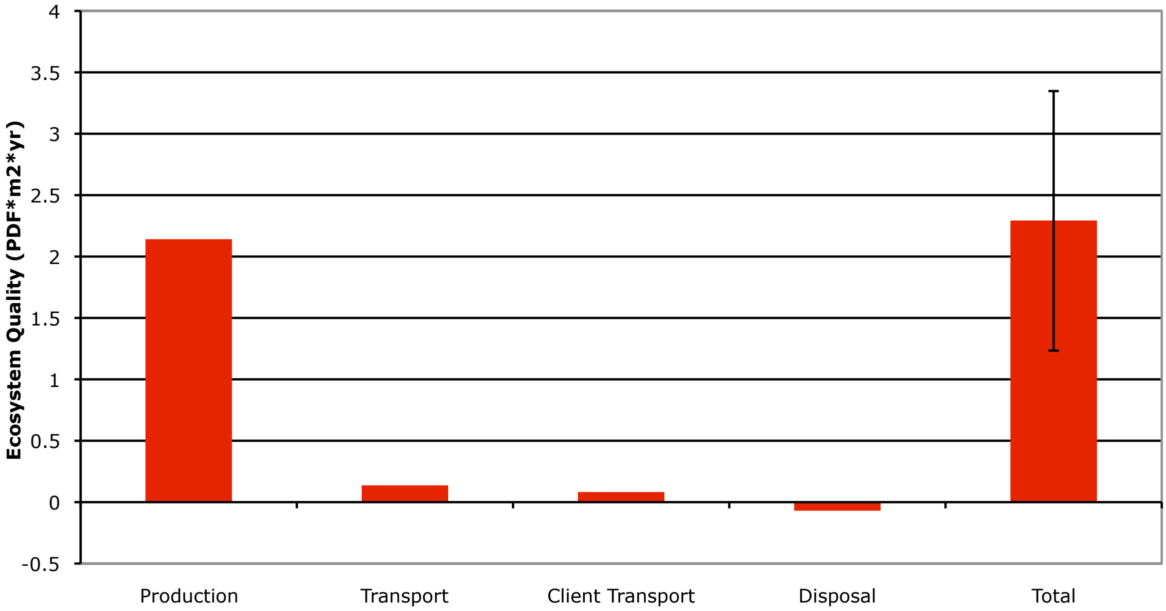

Figure 3.19 – Absolute impacts for Ecosystem Quality per life cycle stage for an artificial tree with a life span of six years, used during one year.

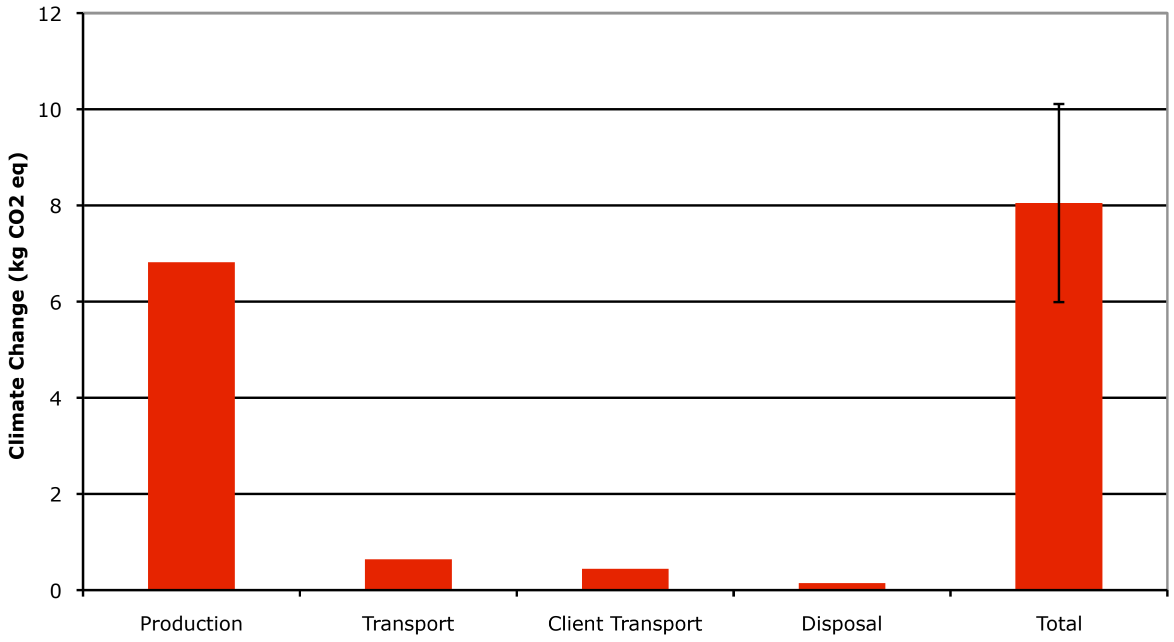

Figure 3.20 – Absolute impacts for Climate Change per life cycle stage for an artificial tree with a life span of six years, used during one year.

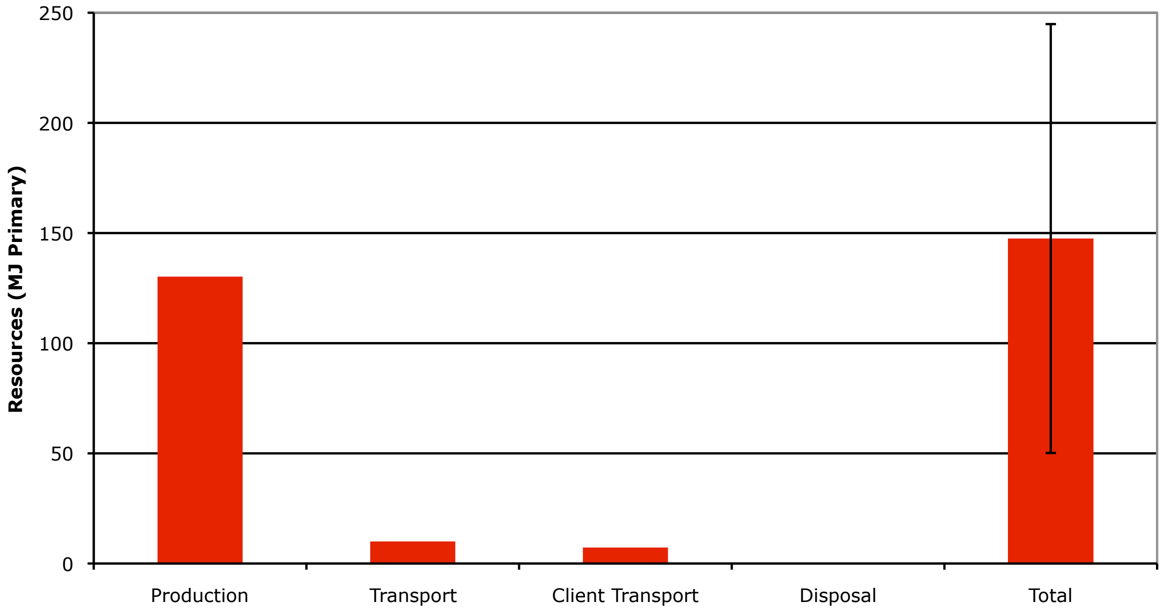

Figure 3.21 – Absolute impacts for Resource Depletion per life cycle stage for an artificial tree with a life span of six years, used during one year.

The process contribution for the three most important impact categories for the artificial tree was also analysed: respiratory inorganics, global warming and non-renewable energy (Table 3.2). The respiratory inorganics impacts primarily come from the transport from China (operation of ship and train). Then, the processes involved in steel production create respiratory impacts: iron ore, sinter iron, molybdenum, hard coal coke, ferrochromium, blasting). The global warming impacts primarily come from pig iron involved in steel production and PVC manufacturing for the branches. Passenger car and train transports are also important contributors and the other contributors are related to steel manufacturing and metal working. The non-renewable energy impacts primarily come from PVC manufacturing, then from hard coal, uranium, and natural gas (inputs to electricity production for steel working), as well as lignite (input to the cardboard box).

Table 3.2 - Process contribution of the artificial tree for the three major mid-point impact categories Process names were directly taken from the ecoinvent database.

Mid-point category	Process	Unit	Total
Respiratory inorganics	Operation, transoceanic freight ship/OCE U	%	9.9
	Operation, freight train, diesel/RER U	%	8.95
	Iron ore, 46% Fe, at mine/GLO U	%	6.50
	Sinter, iron, at plant/GLO U	%	6.29
	Molybdenum concentrate, couple production Cu/GLO U	%	4.95
	Polyvinylchloride, suspension polymerised, at plant/RER U	%	4.30
	Hard coal coke, at plant/RER U	%	4.16
	Ferrochromium, high-carbon, 68% Cr, at plant/GLO U	%	4.11
	Blasting/RER U	%	3.51
	Molybdenum concentrate, main product/GLO U	%	3.18
Global warming	Pig iron, at plant/GLO U	%	14.9
	Polyvinylchloride, suspension polymerised, at plant/RER U	%	10.6
	Sinter, iron, at plant/GLO U	%	4.49
	Operation, passenger car, petrol, fleet average/RER U	%	3.98
	Operation, freight train, diesel/RER U	%	3.72
	Natural gas, burned in industrial furnace >100kW/RER U	%	3.70
	Lignite, burned in power plant/DE U	%	3.54
	Natural gas, burned in industrial furnace low-NOx >100kW/RER U	%	3.32
	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	%	3.07
Non-renewable energy	Polyvinylchloride, suspension polymerised, at plant/RER U	%	19.1
	Hard coal, at mine/EEU U	%	9.65
	Uranium natural, at underground mine/RNA U	%	7.14
	Hard coal, at mine/WEU U	%	6.22
	Natural gas, at production onshore/RU U	%	6.00
	Lignite, at mine/RER U	%	5.17
	Uranium natural, at open pit mine/RNA U	%	4.8
	Crude oil, at production onshore/RME U	%	4.46
	Crude oil, at production offshore/NO U	%	3.58
	Crude oil, at production onshore/RAF U	%	3.15
	Natural gas, at production onshore/DZ U	%	3.13

Finally, to verify the previous analysis with *Impact 2002+*, it is possible to evaluate the mid-point impacts using *TRACI2*. Figure 3.22 shows the mid-point impacts for the entire life cycle of the natural tree using this North American method. The relative contribution of the various phases of the life cycle is similar to the contributions from *Impact 2002+*. The disposal of the artificial tree seems more important with *TRACI2* than with *Impact 2002+*.

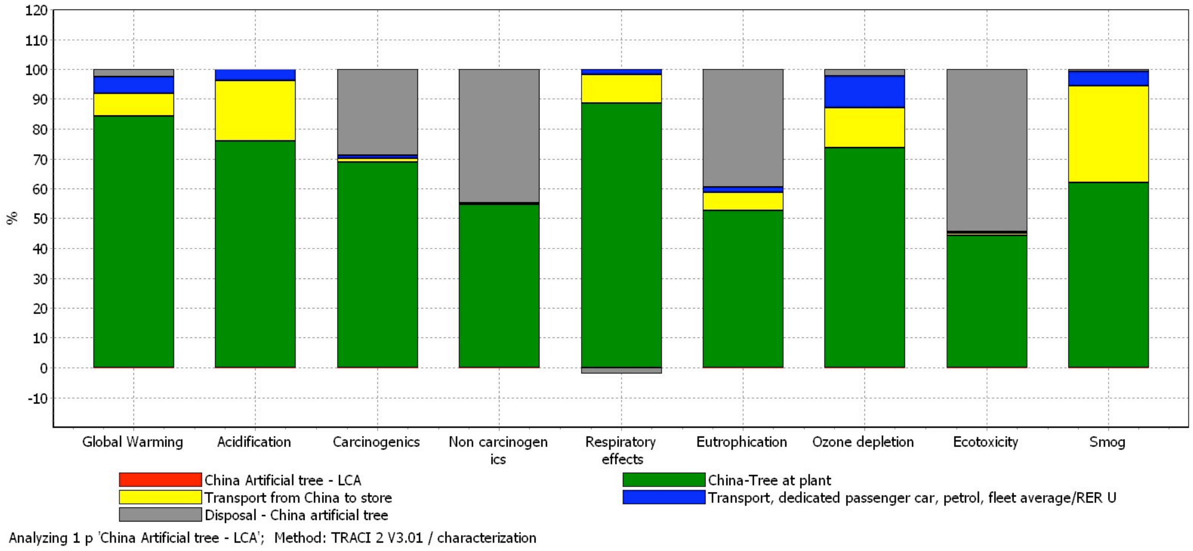

Figure 3.22 – Mid-point impacts for the life cycle of one artificial tree using TRACI2.

3.3. Natural and Artificial Tree Comparison

When comparing the two models for the use of one 7-foot high natural tree to one 7-foot high artificial tree having a life span of six years (Figure 3.23), the environmental impacts are similar (within 80% of each other) for four mid-point categories: non-carcinogens, respiratory inorganics, respiratory organics and aquatic acidification. Six categories are in favour of the artificial tree and five are in favour of the natural tree.

The following graphs do not include uncertainties because of correlation factors between the two models, i.e. variables are dependent between models.

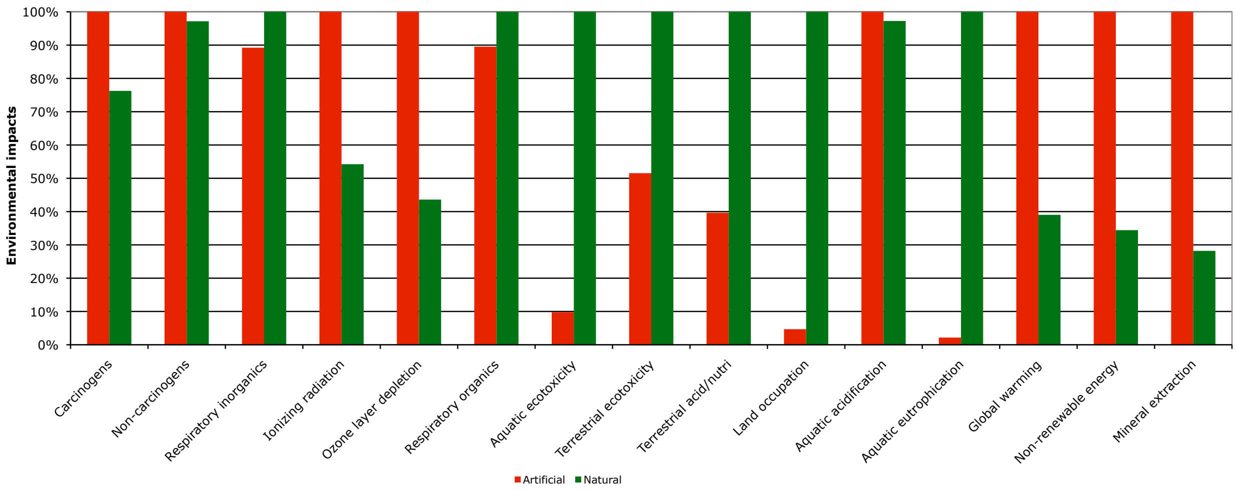

Figure 3.23 – Comparison of the mid-point impacts from one artificial tree with a life span of six years and one natural tree.

When aggregating the data in damage categories, the results show that the impacts for human health are approximately equivalent for both trees, that the impact for ecosystem quality are much better for the artificial tree, that the impacts for climate change are much better for the natural tree, and that the impacts for resources are better for the natural tree (Figure 3.24). This figure will be used as the basis for the sensitivity analyses.

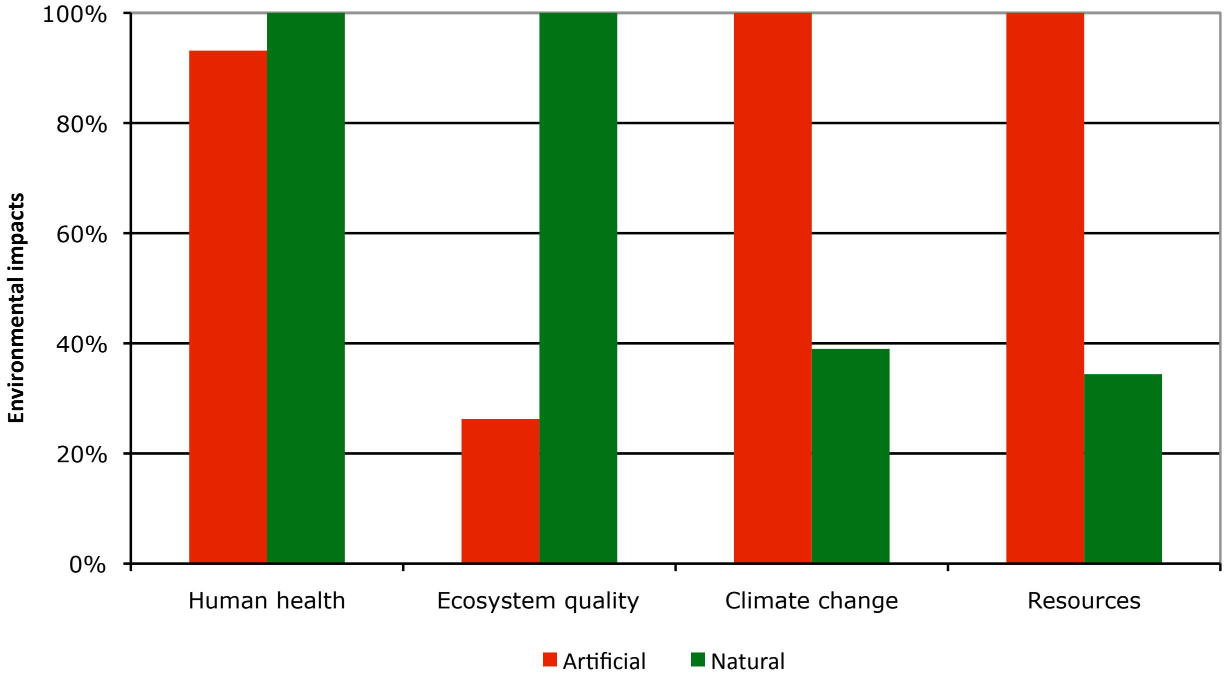

Figure 3.24 – Comparison of the damage impacts from one artificial tree with a life span of six years and one natural tree.

4. Interpretation

4.1. Sensitivity Analysis

4.1.1. Recycling and special disposal rates

The recycling and special disposal rates were modified as per Table 4.1. It is hypothesized that the consumers buying natural and artificial trees have the same recycling habits. Therefore, the recycling rates should vary in unison. They may, however, affect both types of trees differently since the amounts to be recycled differ. This hypothesis also holds for the natural tree producers who deal with packaging for their fertilizers, seeds, and peat moss. The manufacturing process of the artificial tree was modelled without packaging because the packaging is deemed negligible for metal and plastic components. Note that the steel from the branches is deemed too difficult to separate from the PVC needles for recycling; its recycling rate remains at 0%.

Table 4.1 - Recycling and special disposal rates for sensitivity analysis

Recycling & disposal parameter	Simulation			Applicable model
	Original value	High recycling	Low recycling	
Steel recycling	20%	50%	10%	Artificial tree & stand of natural tree
Steel recycling for branches	0%	0%	0%	Artificial tree
Cardboard box recycling	50%	75%	20%	Artificial tree
PE recycling	20%	50%	10%	Natural tree: fertilizer and seed bags
PP re-use	72%	90%	50%	Natural tree: packaging of trees in nursery
Proportion of burned trees (the rest is sent to a landfill)	50%	75%	20%	Natural tree

Figure 4.1 shows the results of the three simulations. The artificial tree from the original simulation was taken as the reference, i.e. 100% of the impacts for each category.

The simulation with increased recycling values exhibits similar trends compared to the simulation with original values. This is true even if only the proportion of burned trees is increased and with all other recycling rates unchanged (not shown). Knowing that the major process contributors for the natural tree include the cogeneration from wood and associated heavy oil which is avoided, the other recycling parameters play a minor role in the overall life cycle. The human health and ecosystem categories for the natural tree are more impacted with respect to the artificial tree and in a more decisive manner than for the original simulation. This indicates that burning the wood has negative impacts for these damage categories. Climate change and resources are less impacted for the natural tree than for the artificial tree, and in a more decisive way compared to the original simulation. This indicates that burning wood is a good method for these categories, contradicting the results for the previously mentioned categories.

The simulation with reduced values shows the opposite trends when compared to the simulation with increased values. In fact, the impacts on climate change now become negative. This is due to a lesser amount of avoided heavy oil at the Kruger facility.

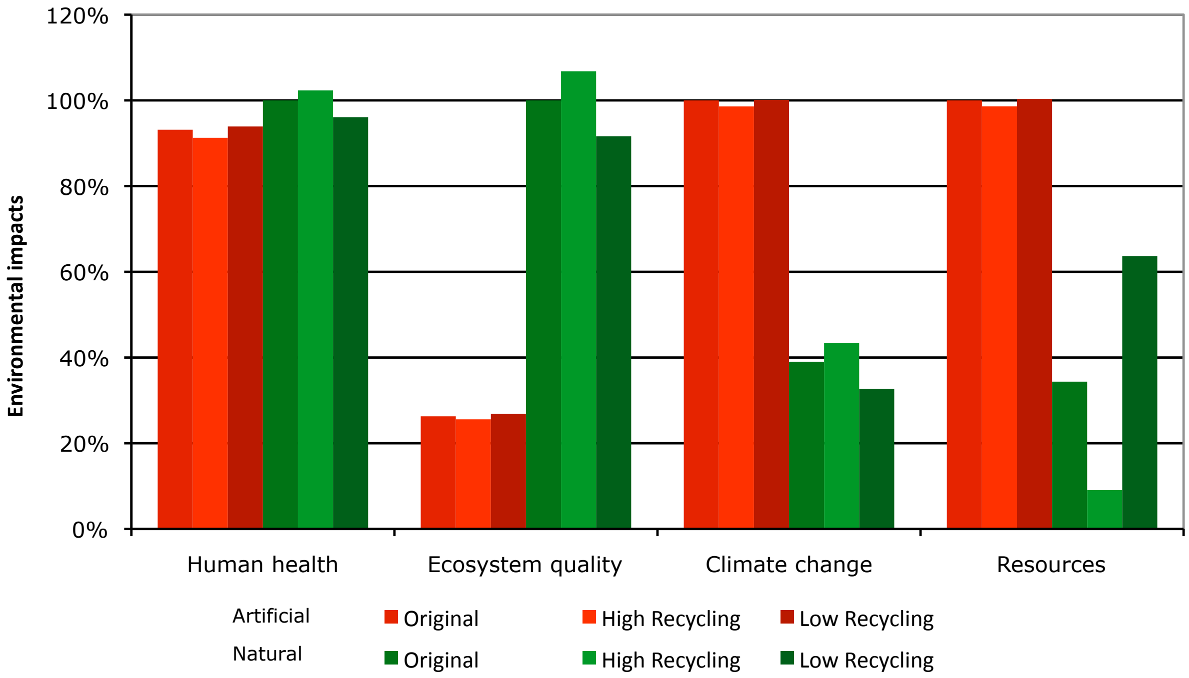

Figure 4.1 - Sensitivity analysis: Impacts from the original simulation, increased and reduced recycling and special disposal rates.

4.1.2. Transport distances

The distances in North America (NA) are relatively well known since primary data was collected and Google Maps was used. They were therefore varied slightly, while the values in China were varied considerably. Two simulations were conducted: 1) the values that primarily affect the artificial tree production were increased while the ones for the natural tree were decreased; 2) values that primarily affect the natural tree production were increased while the ones for the artificial tree were decreased (Table 4.2). Note that some processes such as Stop & Go collection for recycling and landfill is used for both types of trees. It therefore influences the results in similar manners. Also note that the consumer transport is not included in this first sensitivity analysis.

Table 4.2 - Transport distances sensitivity analysis

Distances	Simulation		
	Original value (km)	China increased (km)	NA increased (km)
Stop & go by recycling and landfill collection	10	5	15
Highway transport for recycling & landfill collection	30	20	40
Stop & go by natural tree collection	20	10	30
Rivière-du-Loup to Coop	450	405	495
Montreal to Coop in Sherbrooke	157	140	175
Coop to nursery in Cookshire	38	25	50
Coop to field in Ayer's Cliff	38	25	50
Nursery in Cookshire to field in Ayer's Cliff	50	25	75
Great lakes to Coop in Sherbrooke	1,500	1,300	1,700
Montreal to Bromptonville for wood combustion	165	150	180
Montreal to Trois-Rivières for wood combustion	135	115	155
Plastic manufacturer to moulding or calendering	100	500	50
Secondary supplier to tree manufacturer in Beijing	100	500	50
Beijing to port of Xanging	180	250	100
China to Vancouver by ship	9,000	10,000	8,000
Vancouver to Montreal by train	5,000	5,000	4,500
Train station to stores in Montreal	30	50	20

The simulations with increased values for China distances and increased values for North America distances exhibit almost the same results (Figure 4.2). Hence, both types of trees are not sensitive to transport distances.

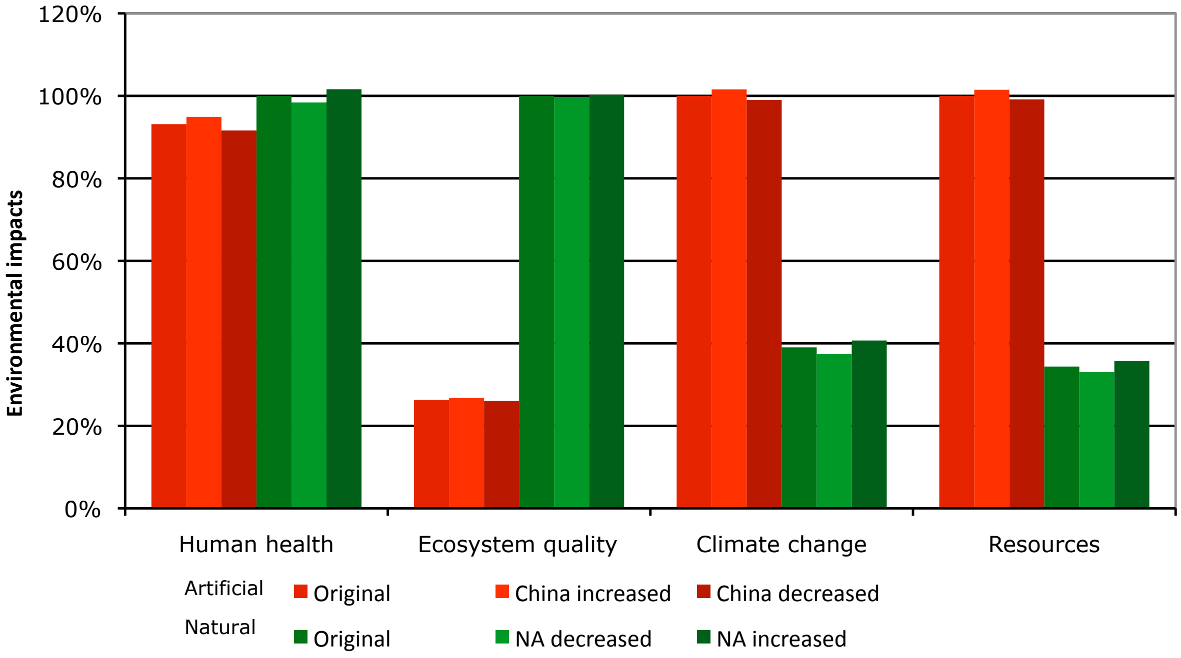

Figure 4.2 - Sensitivity analysis: Impacts from increased transport distances in China or North America (NA), compared with the original simulation.

A second sensitivity analysis was performed, this time on the consumer proximity to the point of purchase of the trees (artificial and natural). The distance was increased from 5 km one way to 16 km one way. For the Montreal area, 16 km is likely a worst-case scenario for most people. At this distance, however, because the consumers who purchase the natural trees use their car every year, the impacts on climate change become more important for the natural tree than for the artificial tree - which includes only one transport. The results from this study therefore greatly depend on the distance between the consumers home and the store location.

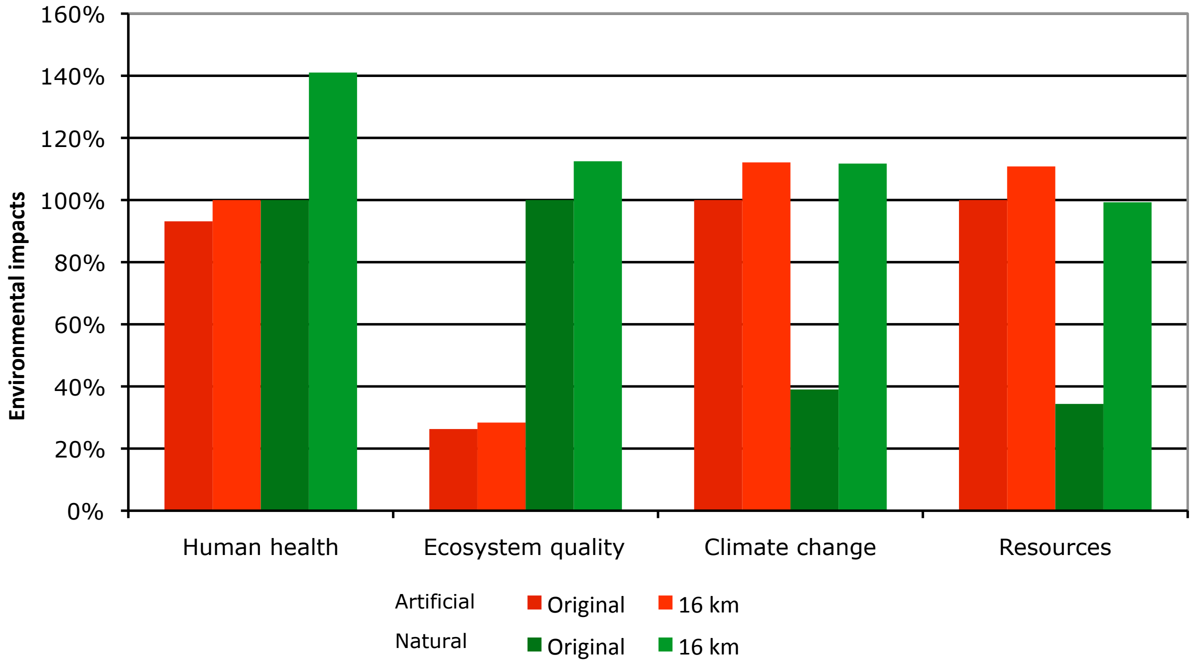

Figure 4.3 - Sensitivity analysis: Impacts of a 16 km distance to purchase the trees compare to the original simulation (5 km).

4.1.3. Tree weights

A sensitivity analysis on tree weight was performed for changes of 10% in the opposite directions. For the natural tree, the stand weight was kept constant for all simulations and the CO_2 sequestration was linearly varied with tree weight. For the artificial tree, all components were varied by 10%.

When adding 10% of weight to the natural tree (12.496 kg) and, at the same time, reducing the weight of the artificial tree by 10% (9.494 kg), the results for the damage categories are similar to the results of the original study (Figure 4.4). When the opposite weight changes are made (natural = 10.224 kg; artificial = 11.604 kg) , the results are also similar to that of the original study for all damage categories. The models are therefore relatively robust with respect to tree weights.

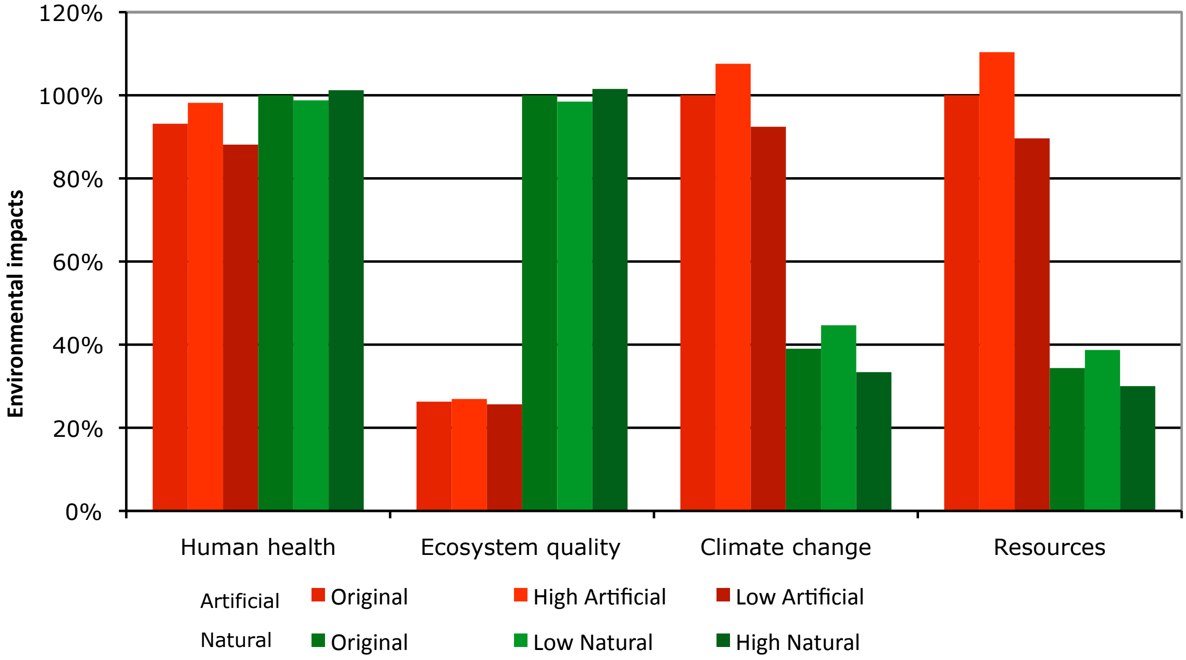

Figure 4.4 - Sensitivity analysis: Natural tree weight was increased by 10% and artificial tree weight was reduced by 10% and vice-versa, compared to the original simulation.

4.1.4. CO_2 sequestration

From the model developed in section 2.2.2.1, it appears that the data for CO_2 sequestration is highly variable. In fact, Gaboury et al. (2009) states that "the total amount of C per ha drops from 17 to 14 t C ha during the first 20 years following planting" and that "biological C balance [...| results in a net C emission during the first 20 years. Therefore, the low value for the CO_2 sequestration in this sensitivity analysis is changed from a sink to a source of 0.5 t CO_2/ha/yr. The high value for sequestered CO_2 is increased from 2 to 3 t CO_2/ha/yr. This happens to be the threshold at which the natural tree has positive impacts on climate change (Figure 4.5). This means that for 3 t CO_2/ha/yr, regardless of the number of years that the artificial tree is retained, the natural tree will always be better than the artificial tree. It also means that he more trees we produce, the better it is for climate change. However, when the plantation acts as a C source of 0.5 t CO_2/ha/yr, the benefits of the natural are erased and the overall impacts on climate change are worst than for the artificial tree. The threshold at which the natural tree starts being better for climate change than the artificial tree is for a C sink of 0.4 t CO_2/ha/yr (Figure 4.5). All other categories of impacts, however, are not modified by CO_2 sequestration.

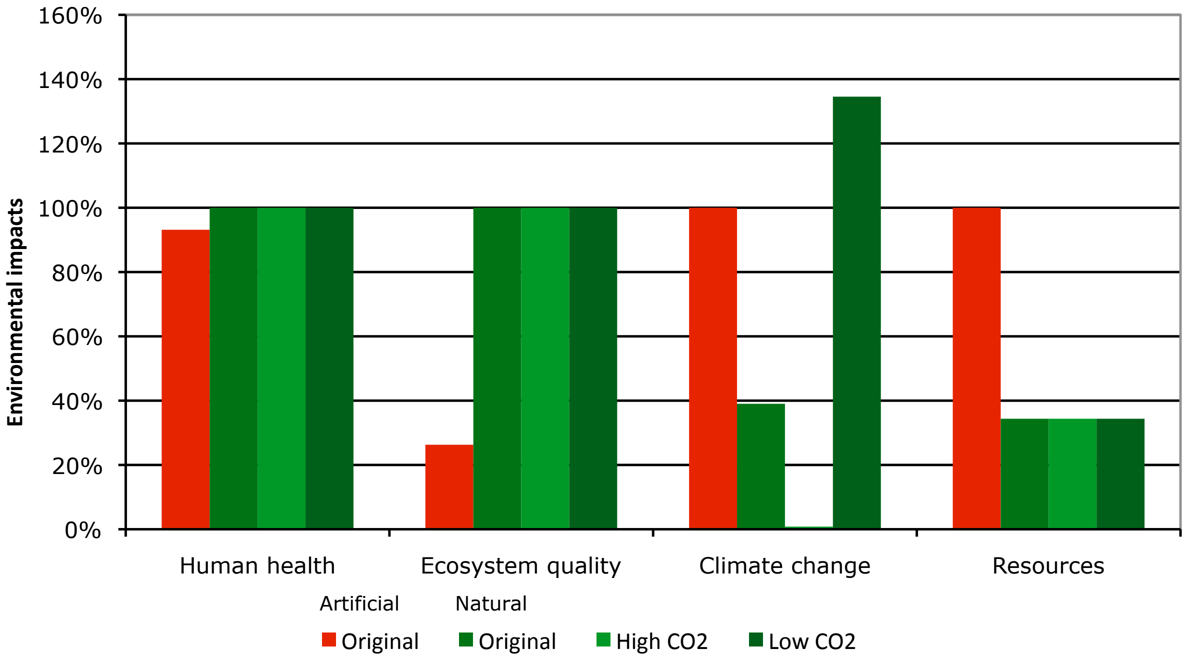

Figure 4.5 - Sensitivity analysis: Increased CO_2 sequestration to 3 t CO_2/ha/yr and decreased CO_2 sequestration to a C source of 0.4 t CO_2/ha/yr*, compared to the original simulation.*

4.1.5. Pesticide emissions

Pesticide emissions were modelled as if the total quantity of pesticides would be emitted in the soil. Although this is very unlikely, when no pesticide emissions are included in the study, the results are robust and do not vary except for three of the four damage categories (Figure 4.6). The changes seen in ecosystem quality, come from reduced ecotoxicities (aquatic and terrestrial) and a slight reduction for non-carcinogens impacts.

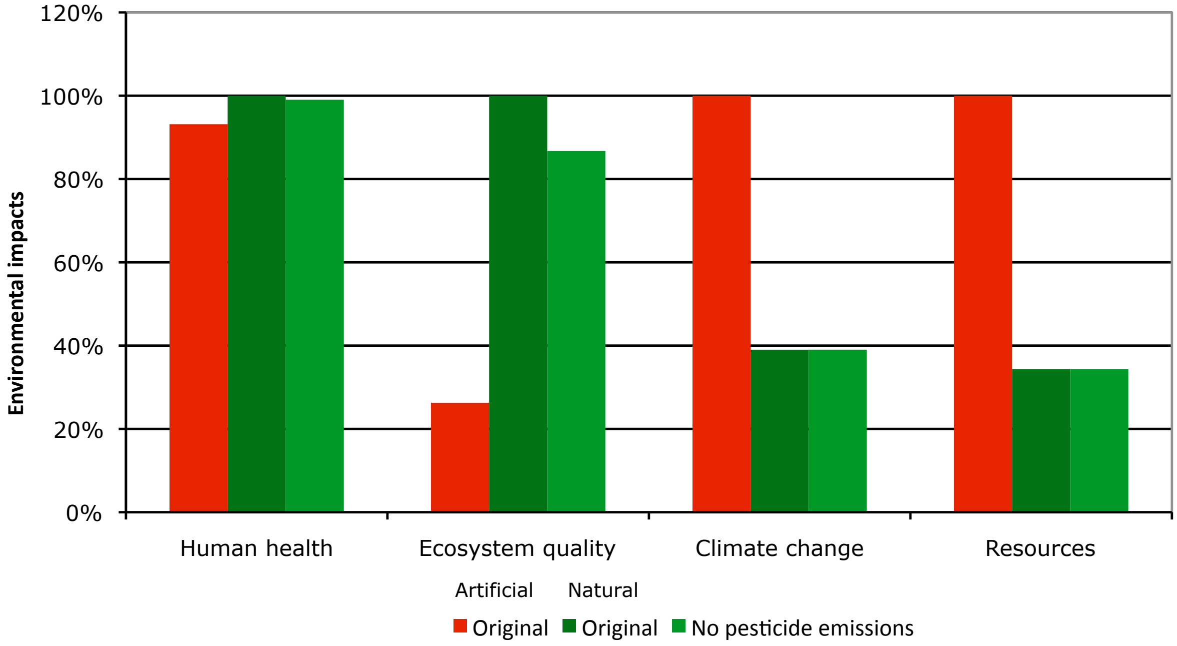

Figure 4.6 - Sensitivity analysis: Pesticide emissions equivalent to 0% of pesticide input mass compared to the original simulation (100% emitted to soil).

4.1.6. Fertilizer emissions

Fertilizer emissions were modelled as per section 2.2.2.1. The total quantity of fertilizer emissions is modified not produce emissions to air and water (0%). Although this is very unlikely, when no fertilizer emissions are included in the study, the results vary substantially for human health and climate change (Figure 4.7). It is important to note that aquatic acidification and eutrophication are not included in the damage category for ecosystem quality, as per the *Impact 2002+* method. The difference see on Figure 4.7 would likely be underestimated if these categories had been included in the impact assessment method.

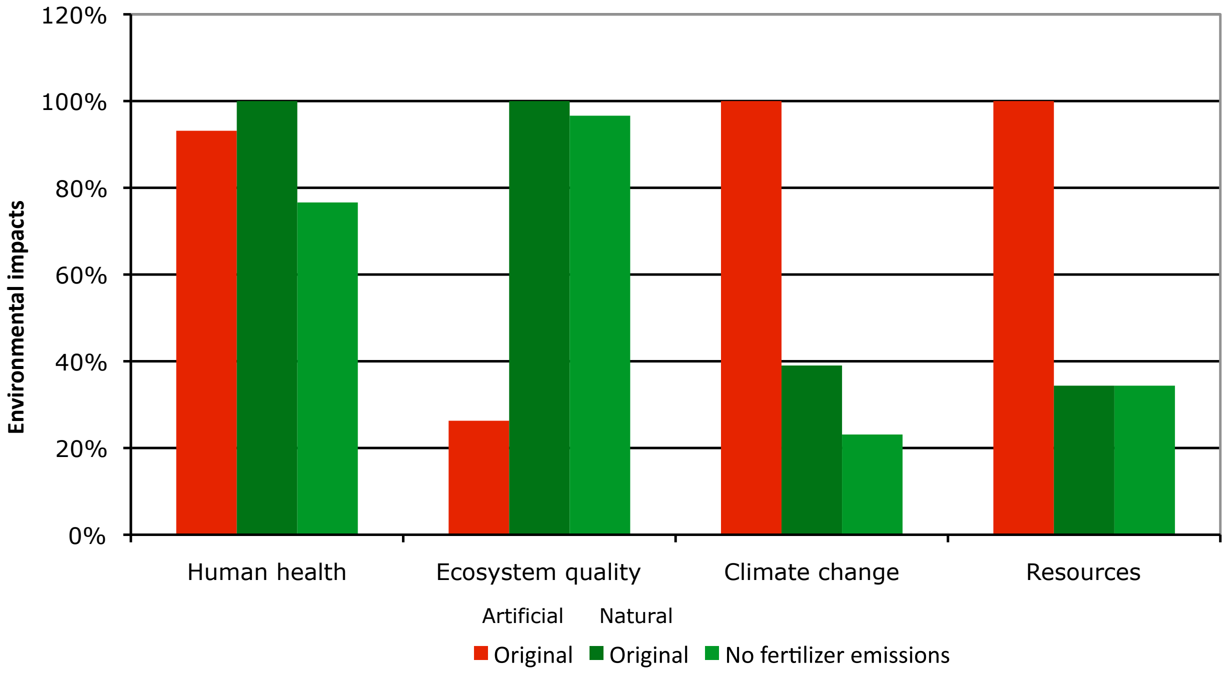

Figure 4.7 - Sensitivity analysis: Fertilizer emissions equivalent to 0% of fertilizer input mass compared to the original simulation.

4.2. Alternate Scenarios

4.2.1. PE tree

To determine if a tree made of PE is better than a tree made of PVC, PE was modelled using the same volume of PE as for PVC, in order to compare trees with the same look. The weight of PE was therefore reduced to 1.89 kg (PE density = 0.93 g/cm^3) compared to 2.808 kg for PVC (PVC density = 1.38 g/cm^3). Because no information was available regarding the type of PE used in artificial trees, low density PE (LDPE) and high density PE (HDPE) were modelled. For both models, the disposal was identical, i.e. the PE needles were sent to a landfill (Disposal, polyethylene, 0.4% water, to sanitary landfill/ CH U). Therefore, only the tree production differed in the type of material used: LDPE or HDPE.

The results for the damage categories with LDPE or HDPE in comparison with PVC and the natural tree show that there is no significant difference between both types of PE and PVC, although a small reduction for all damage categories can be seen (Figure 4.8).

When looking at the mid-point impact categories, however, the carcinogens category is approximately 40% and 16% more impacted by HDPE and LDPE than PVC, respectively (not shown). Differences are also seen for ozone layer depletion and mineral extraction. They are respectively more and less impacted. Despite these differences at the mid-point level, because of the small contribution of the carcinogens, ozone depletion and mineral extraction on the damage categories, only minor and non-significant differences between LDPE, HDPE and PVC can be seen for any damage category. The PE tree is therefore not a solution compared to the PVC tree.

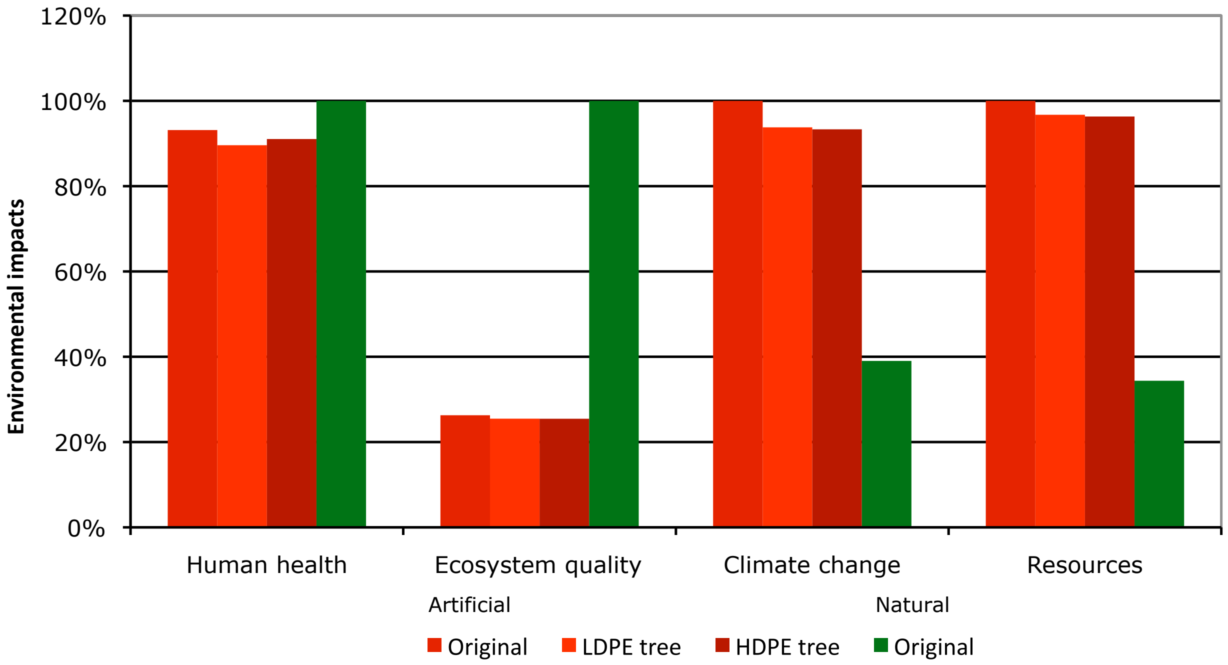

Figure 4.8 - LDPE needles and HDPE needles used for the artificial tree compared to the original simulation for the PVC artificial and natural trees for the damage categories.

4.2.2. Life time scenarios

To determine how long consumers should keep their artificial tree for its impacts to be equivalent to that of one new natural tree every year, several scenarios were calculated. The results are shown for each damage category separately for consumers living 5 km away from the point the purchase of the trees.

4.2.2.1. Human health

According to (Figure 4.9), a consumer needs to keep his artificial tree 6 years for the impacts on human health to be equivalent between the artificial tree and new natural trees every year.

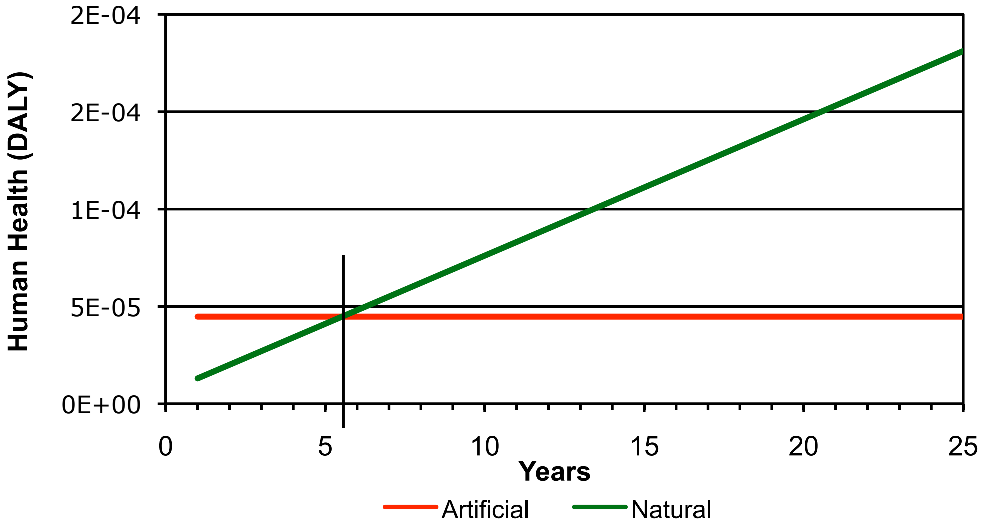

Figure 4.9 - Human Health impacts for one artificial tree and one new natural used annually.

4.2.2.2. Ecosystem quality

According to (Figure 4.10), a consumer needs to keep his artificial tree at least 2 years for the impacts on ecosystem quality to be equivalent between the artificial tree and new natural trees every year.

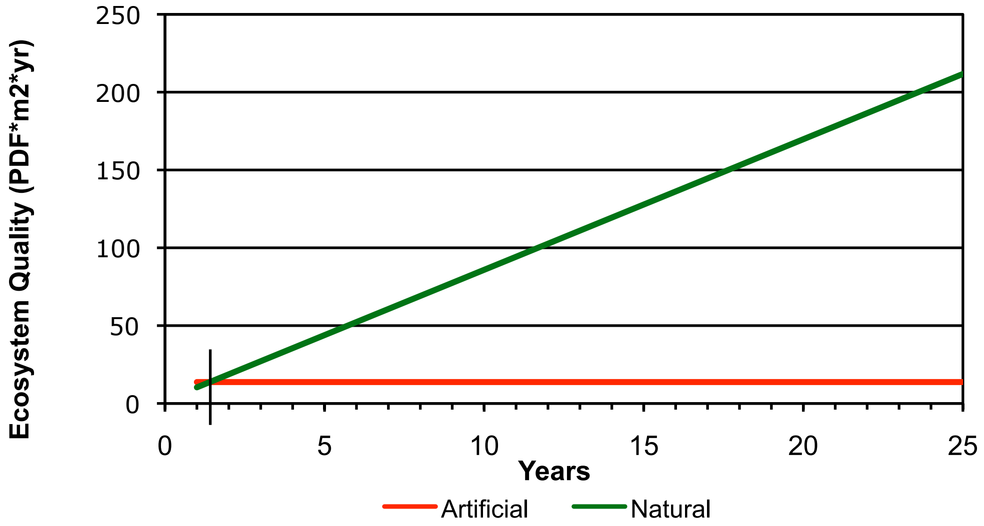

Figure 4.10 - Ecosystem Quality impacts for one artificial tree and one new natural used annually.

4.2.2.3. Climate change

For climate change, since the outcome highly depends on CO_2 sequestration and client transport, the values presented in Figure 4.12 could also vary. For the current situation (2 t CO_2/ha/yr and 5 km from store to home), one would need to keep his artificial tree for 20 years.

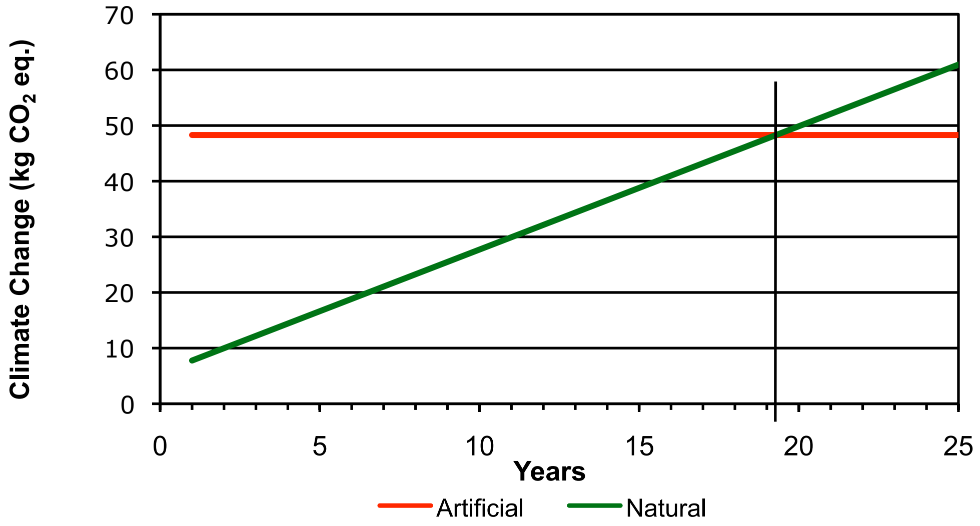

Figure 4.11 - Climate Change impacts for one artificial tree and one new natural used annually.

4.2.2.4. Resources

According to (Figure 4.12), a consumer needs to keep his artificial tree approximately 23 years for the impacts on resources to be equivalent between the artificial tree and new natural trees every year.

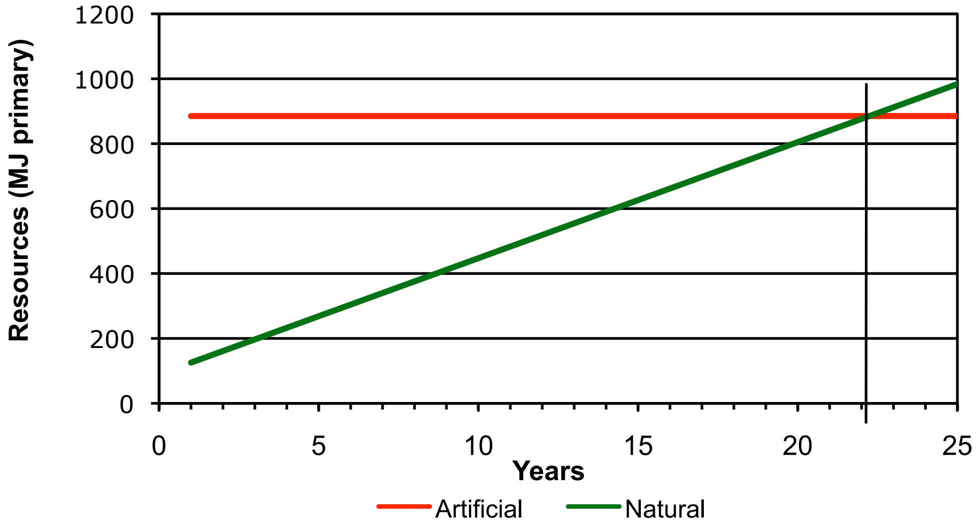

Figure 4.12 - Resources depletion impacts for one artificial tree and one new natural used annually.

4.2.3. Life time scenarios - problem categories

The figures presented above reflect well the number of years that one should keep the artificial tree for its impacts to be equivalent to a new natural tree every year. When looking at the problem-oriented categories, the required life span of the artificial tree reflects the findings above (Table 4.3). The mineral extraction, however, stands out. On would need to keep the artificial tree for 48 years for the environmental impacts of a new natural tree every year to be more important than the artificial tree.

Table 4.3 - Number of years that one needs to keep the artificial tree for its impacts to be equivalent to the impacts of a new natural tree every year.

Problem-oriented category	Nb years
Carcinogens	8.4
Non-carcinogens	6.2
Respiratory inorganics	5.3
Ionizing radiation	12.2
Ozone layer depletion	16.5
Respiratory organics	5.3
Aquatic ecotoxicity	0.5
Terrestrial ecotoxicity	2.8
Terrestrial acid/nutri	2.2
Land occupation	0.3
Aquatic acidification	6.2
Aquatic eutrophication	0.1
Global warming	19.3
Non-renewable energy	22.2
Mineral extraction	47.4

4.3. Completeness checks

The objective of a completeness check is to make sure that the data necessary to interpretation are available and complete. Missing data must be carefully looked at to verify whether they are required or not to meet the goal and scope of the study. In order to do this, a control list that includes emissions to air, water and soil and wastes for each process identified within the product system has been used. Table 4.4 presents a summary of the results for each tree.

Table 4.4 - Completeness checks

Life cycle stage	Natutral tree	Complete	Required action	Artificial tree	Complete	Required Action
Production	X	Yes	–	X	Yes	–
Client transport	X	Yes	–	X	Yes	–
Use	X	Yes	–	n.a.	–	–
Landfill	X	Yes	–	X	Yes	–
Heat generation	X	Yes	–	n.a.	–	–
X : data available	n.a. : not applicable					

The control list has been used in an iterative process: as the study progressed, the authors reviewed the list. This allowed for validation of missing data and improving the inventory. From this analysis, it appears that all data are complete compared as required by the scope of the study.

4.4. Consistency checks

The rules and assumptions defined in the scope of the study have been respected. Data source, age and geographical representativeness have been revised for their consistency. Overall, the consistency of data has been found to be adequate. However, a few inconsistencies need to be mentioned here.

One process from China, where the artificial tree is manufactured, has not been modelled with Chinese data due to lack of data. The Chinese grid-mix has been replaced by the average European grid-mix. Another case where the geographic boundaries has not been respected because of a lack of regional data is transport in Canada. Again, data from an average European car have been used, which can vary slightly compared to a vehicle used in Canada.

The impact assessment method *Impact 2002+* is incoherent with our geographical boundaries for some mid-point impact categories. Characterization factors used for regional impacts are based on Europe. This choice was deemed necessary since no Canadian impact assessment method has been published yet. The Canadian method LUCAS is still under development.

That being said, these inconsistencies do not affect the results since both systems have been compared using the same method.

4.5. Uncertainty analysis

An uncertainty analysis was performed with the Monte Carlo method for 100 iterations using SimaPro. Uncertainties for primary data were modelled with the triangular distribution when the data quality was good and with the rectangular distribution when the distribution was unknown. The normal and lognormal distributions were not used except in the ecoinvent data because the amount of collected data was generally insufficient to conduct systematic statistical analysis. Values for the limits of the triangular and rectangular distributions were attributed based on the best of our knowledge, which took data quality into consideration. Overall, circa 44% of the data was modelled with uncertainty. Most data with uncertainty came from sub-processes of the ecoinvent data.

The Monte Carlo uncertainty analysis shows that there is a significant difference ($p < 0.05$) between the natural and the artificial with respect to resources and ecosystem quality. The difference seen for human health and climate change, because of the uncertainty are not significantly different. There is a strong trend, however, that indicates that the natural tree is preferable with respect to climate change an a moderate trend that indicates that the artificial tree is preferable for human health.

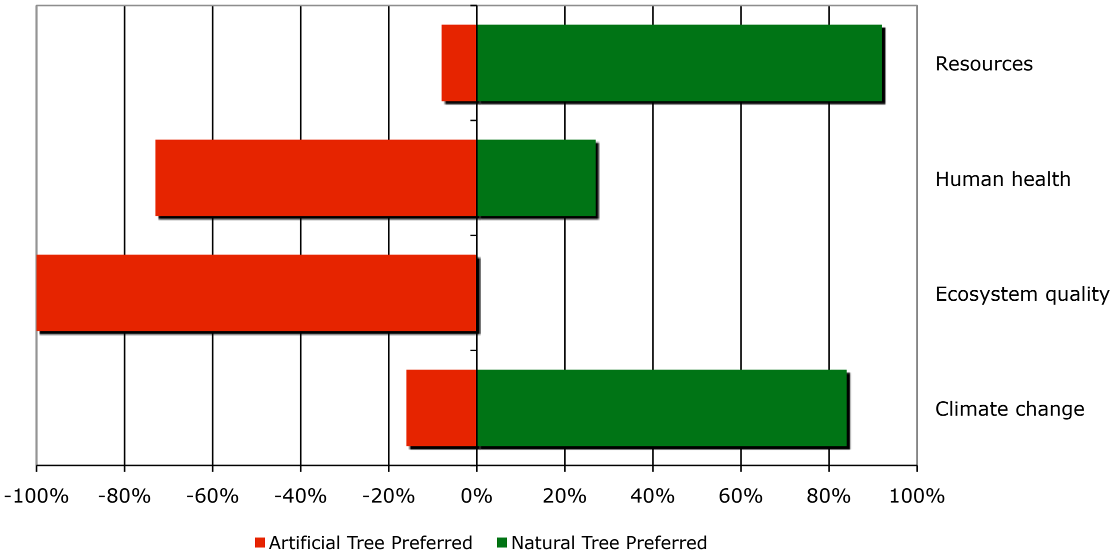

Figure 4.11 - Uncertainty results for a Monte Carlo analysis with 100 iterations.

4.6. Limits of the study

The current LCA study has limitations. It does not take into account noise, odour, human activities (eating, lodging, etc.), soil erosion that is avoided by the plantations, dioxin emissions from plastic in the artificial tree during use and disposal (that would occur in the unlikely event of a fire), impacts of fillers contained in PVC. Also, the electricity from China was mostly modelled with electricity from Europe. This is specifically applicable for cases where the amount of electricity involved in the process is not available through the ecoinvent database (e.g. Plastics such as PVC). In addition, the CO2 sequestration as well as fertilizer emissions can vary greatly with environmental conditions (soil content, sun exposure, rainfall, etc.) and add uncertainty to the results. Moreover, the client transport was modelled with a distance of 5 km. From the sensitivity analysis, it is obvious that this distance is critical because it tremendously affects the results. Finally, results are specific to Montreal and may vary depending on geographic location because of differences in processes such as travelled distances and the end of life of the natural tree.

5. Conclusion

The goal of this study was to position the artificial Christmas tree and the natural Christmas tree with respect to environmental impacts over their entire life cycles and compare the results between both types of trees. A Life Cycle Assessment was performed to guide the environmentally conscious consumers on their choice of Christmas tree. With the current data and analysis and following ISO 14044, it is possible to conclude within the following limits:

Consumers travel approximately 5 km to purchase their trees;

The natural tree is burned at the end of its useful life and this energy replaces heavy oil, which is the case in Montreal for the 2008 Christmas holidays;

Among the four damage categories of impacts, climate change is currently of prime importance for the general population in Quebec. The results for this impact category are clear: the natural tree is better than the artificial tree considering an average life span of six years for the artificial tree. This conclusion holds true for resource depletion as well.

The natural tree, however, is not a perfect solution as it results in important impacts on ecosystem quality. Clients who prefer using the artificial tree can reduce their impacts on all categories by increasing the life span of their tree, ideally over 20 years. Human heath impacts were also analysed, but no significant differences were found.

Due to the uncertainties of CO_2 sequestration and distance between the point of purchase of the trees and the customer's house, the environmental impacts of the natural tree can become worse. For instance, customers who travel over 16 km from their house to the store (instead of 5 km) to buy a natural tree would be better off with an artificial tree.

The emitted CO_2 over the entire life cycle are approximately 3.1 kg CO_2 per year for the natural tree and 8 kg CO_2 per year for the artificial tree. These CO_2 emissions roughly correspond to driving an average car (150 g/km) 125 km and 322 km, respectively. Therefore, carpooling or biking to work only one to three weeks per year would offset the carbon emissions from both types of Christmas trees.

Although the dilemma between the natural and artificial Christmas trees will continue to surface every year before Christmas, it is now clear from this LCA study that, regardless of the chosen type of tree, the impacts on the environment are negligible compared to other activities, such as car use.

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7. Appendix A: Quebec Electricity Mix

The electricity mix from Quebec was modelled according to the Hydro-Quebec production including imports from other provinces and the United States (Hydro-Quebec, 2007). This model is based on the UCTE electricity Mix both for the foreground and background processes. When electricity was required for the construction of an electrical plant, the same voltage level was input, but the grid mix was changed to reflect the Quebec situation instead of the UCTE portrait.

Table A.1 - Model of the Quebec electricity mix.

Model	Contribution (%)	Based on model...
Electricity, hydropower, at reservoir power plant, non alpine regions /RER U	50.04	
Electricity, hydropower, at run-of-river power plant /QC U	42.29	Electricity, hydropower, at run-of-river power plant /RER U medium voltage electricity of QC to build plant
Electricity, nuclear, at power plant pressure water reactor /QC U	2.97	Electricity, nuclear, at power plant pressure water reactor / US U medium voltage electricity of QC
Electricity, hard coal, at power plant/ UCTE U	1.06	
Electricity, industrial gas, at power plant/ UCTE U	2.43	
Electricity, oil, at power plant/ UCTE U	0.14	
Electricity, at wind power plant/ RER U	0.32	
Electricity, biowaste, at waste incineration plant, allocation price / CH U	0.75	
Electricity, high voltage, at grid/ QC U		Electricity, high voltage, production UCTE, at grid/ UCTE U
Electricity, medium voltage, at grid/ QC U		Electricity, medium voltage, production UCTE, at grid/ UCTE U
Electricity, low voltage, at grid/ QC U		Electricity, low voltage, production UCTE, at grid/ UCTE U

8. Appendix B: Natural Tree Economic Flows

Table B.1 - Tree in nursery economic flows

Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Tree in nursery	196,700	trees/ha	Nursery	
Seeds	130.3	kg/ha	Nursery / Seeds come from a tree plantation, which is the model described in this study.	Barley seed, IP, at regional storehouse/ CH U with Barley grains, IP, at regional storage /RER U" without the process "Barley grains IP, at farm/ CH U"
Sowing	1,686	kWh/ha	Nursery / 75$/wk @ 0,069$/kWh, 84 kg/wk ($4{,}2x10^6$ seeds/wk @ 50,000 seeds/kg)	Electricity, low voltage, at grid/ QC U
PE bags	120	g/40kg	Estimate / HDPE bags transported from Great Lakes area (1500 km, truck)	Polyethylene, HDPE, granulate, at plant/ RER U + Extrusion, plastic film/ RER U + Transport, lorry, >32t, EURO3/ RER U
Bag recycling	50	%	In Mtl	Recycling HDPE, see Table B-5
Bag landfilling	50	%	In Sherbrooke	PE landfilling, see Table B-5
Peat moss	30,000	kg/ha	Nursery / Peet moss with same HDPE bags as for seeds Estimate / 750 bags of 40 kg	Peat, at mine/ NORDEL U
Peat moss transport	450	km	Estimate / From Rivière-du-Loup to producer	Transport, lorry, >32t, EURO3/ RER U
	1	km	Nursery / Transport to area of use	Transport, tractor and trailer/ CH U
Transport	38	km	Seeds from Coop to producer	Transport, lorry 7.5-16t, EURO 3/ RER U
Fertilizing	4,062	kg/ha	Nursery	All fertilizers were modeled based on:
11-41-8	760	kg/ha	Raymond, 2008 / All fertilizers were modeled using: - MAP to fulfill P_2O_5 requirements, from Florida (2600 km, train) - CAN or Urea to fulfill N requirements, from American midwest (2000 km, truck) - KCl or K_2SO_4 to fulfill K_2O requirements, from Saskatoon (3000 km, train)	MAP: 11% MAP, as N, at regional storehouse/ RER U; 52% MAP, as P_2O_5 at regional storehouse/ RER U + Transport, freight, rail, diesel/ US U CAN or Urea: CAN or Urea, as N, at regional storehouse/ RER U + Transport, lorry >32t, EURO 3/ RER U KCl or K_2SO_4: Potassium Chloride or Sulfate, as K_2O, at regional storehouse/ RER U + Transport, freight, rail, diesel/ US U
12-2-14	720	kg/ha		
15-0-0	239	kg/ha		
34-0-0	192	kg/ha		
8-20-30	182	kg/ha		
20-8-20	302	kg/ha		
46-0-0	47	kg/ha		
10-11-16+Mg	700	kg/ha		
27-0-0	260	kg/ha		
10.3-16.6-33.2	700	kg/ha		
NH_3 emitted	57.8	kg/ha	Based on corn, at farm/US	Ammonia
N_2O emitted	27.7	kg/ha	Based on corn, at farm/US	Dinitrogen oxide
NO_x emitted	15.7	kg/ha	Based on corn, at farm/US	Nitrogen oxides
NO_3 emitted	1,260	kg/ha	Based on corn, at farm/US	Nitrate
P emitted	10.7	kg/ha	river compartment	Phosphorus
	0.9	kg/ha	groundwater compartment	Phosphorus
PE bags	5	kg/ton	Estimate / HDPE bags transported from Great Lakes area (1500 km, truck) 50% recycled, 50% landfilled, as for sowing.	Polyethylene, HDPE, granulate, at plant/ RER U + Extrusion, plastic film/ RER U + Transport, lorry, >32t, EURO3/ RER U See Table B-5
Applications	33	Appl./ha		Application of plant protection products, by field sprayer/ CH U
Transport	195	km	From Mtl to Coop to producer	Transport, lorry, > 32t, EURO 3/ RER U
Pesticides	70.4	kg/ha	Nursery	All pesticides come from Europe, all at regional storehouse/RER U except where mentioned
Simazine	7.5	kg/ha	100% emitted to soil	Triazine compounds / emissions = Simazine
Venture	2	kg/ha	100% emitted to soil	Phenoxy-compounds / emissions = Fluazifop-P-butyl
Lontrel	1.5	kg/ha	100% emitted to soil	Pesticides, unspecified / emissions = Clopyralid
Goal	4	kg/ha	100% emitted to soil	Pesticides, unspecified / emissions = Oxyfluorfen
Gallery	2	kg/ha	100% emitted to soil	Pesticides, unspecified / emissions = Isoxaben
Cygon 480	8.3	kg/ha	100% emitted to soil	Organo-phosphorus compounds / emissions = Dimethoate
Roundup	6.6	kg/ha	100% emitted to soil	Glyphosate / emissions = Glyphosate

Senator 70WP	3.3	kg/ha	100% emitted to soil	Benxo[thia]diaxole-compounds / emissions = Thiabendazole
Ridomil	6	kg/ha	100% emitted to soil	Acetamide-anillide-compounds / emissions = Metalaxil
Devrinol	27	kg/ha	100% emitted to soil	Acetamide-anillide-compounds / emissions = Napropamide
Decree	2.2	kg/ha	100% emitted to soil	Acetamide-anillide-compounds / emissions = Acetamide
Applications	24	Appl./ha	Nursery	Application of plant protection products, by field sprayer/ CH U
Packaging	380	g/10L	Estimate / PVC container transported from Europe with pesticide, 100% landfilled in Sherbrooke	See Table B-5 for disposal
Transport	6,000	km	From Europe to Mtl	Transport, transoceanic freight ship/ OCE U
	157	km	Mtl to Coop to producer	Transport, lorry, > 32t, EURO 3/ RER U
	38	km		Transport, lorry, 7.5-16t, EURO 3/ RER U
Irrigating	2,103	m3/ha	Nursery	Irrigating/ US U
Extraction and replanting	24	kWh/ha	Nursery & estimate / conveyor	3 kW, 25% max power, 32 hrs
Storage, cold	606	kWh/ha	Nursery / Cold room, 1/2 full (1.2M trees) 2 wks @10,780 kWh/ 8 wks	Electricity, low voltage, at grid/QC
	262,300	trees/ha	Trees in rows	Electricity, low voltage, at grid/QC
Replanting	1	ha	Nursery / Disposal in field	Sowing/ CH U
Peat moss removal	30,000	kg/ha	Nursery / Peet moss removal	
	1	km	Nursery / Removed and dumped elsewhere on farm	Transport, tractor and trailer/ CH U
	2,100	kg/ha	Micales and Skog, 1997 / as newspaper: 0.157 g C released as CH_4 /kg C content (average paper) This gives 40% of C emissions as CH_4	Methane, biogenic, to air compartment in low population
	8,635	kg/ha	Micales and Skog, 1997 / as newspaper: 0,105 g C released as CO_2 /kg C content (average paper) This gives 60% of C emissions as CO_2	Carbone dioxide, biogenic, to air compartment in low population
Harvesting	1	ha	Nursery	Harvesting, by complete harvester, potatoes/ CH U
Packaging	196.7	kg/ha	Nursery / 100 trees/bag, 100 g/bag	Polypropylene, granulate, at plant/ RER U + Extrusion, plastic film/ RER U
PP bag	3.5	kWh/ha	Nursery & estimate / Conveyor 1A * 110V * 32h	Electricity, low voltage, at grid/QC
PP re-use	141.6	kg/ha	Nursery / 80% are re-used 10 times, on average, 20% are sent to a landfill. 20% + 1/10 of 80% are therefore sent to a landfill, leaving 72% effective re-use	See Table B-5 for re-use
Storage	1,104	kWh/ha	Nursery / Cold room, half full (240k trees) 1 wk @10,780 kWh/ 8 wks	Electricity, low voltage, at grid/QC
	196,700	trees/ha		
Transport	50	km	Nursery to field	Transport, lorry, 16-32t, EURO 3/ RER U
	49,175	kg/ha	Nursery / 0.25 kg/tree before losses* 196,700 trees	
Land occupation	4	ha*a	4 years	Occupation, arable

Table B.2 - Tree in field economic flows

Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Tree in field	2,910	trees/ha	CRAAQ, 2007	
Tree in Nursery	3,483	trees/ha	CRAAQ, 2007 / Includes losses	
Sowing	1	ha	CRAAQ, 2007	Sowing/CH U

Fertilizing	3,650	kg/ha	Raymond, 2008 / All fertilizers were modeled using:	All fertilizers were modeled as per fertilizers for tree in nursery
8-24-12	400	kg/ha	- MAP to fulfill P_2O_5 requirements, from Florida (2600 km, train)	
12-8-14	1,450	kg/ha	- CAN or Urea to fulfill N requirements, from American midwest (2000 km, truck)	
15-8-14	1,350	kg/ha		
5-20-20	450	kg/ha	- KCl or K_2SO_4 to fulfill K_2O requirements, from Saskatoon (3000 km, train)	
NH_3 emitted	48.8	kg/ha	Based on corn, at farm/US	Ammonia
N_2O emitted	23.4	kg/ha	Based on corn, at farm/US	Dinitrogen oxide
NO_x emitted	13.3	kg/ha	Based on corn, at farm/US	Nitrogen oxides
NO_3 emitted	1,065	kg/ha	Based on corn, at farm/US	Nitrate
P emitted	7.5	kg/ha	river compartment	Phosphorus
	0.7	kg/ha	groundwater compartment	Phosphorus
PE bags	5	kg/ton	Estimate / HDPE bags transported from Great Lakes area (1500 km, truck), 50% recycled, 50% landfilled, as for tree in nursery	Polyethylene, HDPE, granulate, at plant/RER U + Extrusion, plastic film/RER U; Transport, lorry, >32t, EURO 3/ RER U See Table B-5 for disposal
Applications	9	Appl./ha	CRAAQ, 2007	Fertilising, by broadcaster/CH U
Transport	195	km	From Mtl to Coop to producer	Transport, lorry, > 32t, EURO 3/ RER U
Pesticides	56.25	kg/ha	Nursery	All pesticides come from Europe, all at regional storehouse/RER U except where mentioned
Simazine	4.5	kg/ha	Nursery	Triazine compounds / emissions = Simazine
Lontrel	3	kg/ha	Nursery	Pesticides, unspecified / emissions = Clopyralid
Roundup	23	kg/ha	Nursery	Glyphosate / emissions = Glyphosate
2,4-D	8.75	kg/ha	Nursery	2,4-D / emissions = 2,4-D
Diazinon	17	kg/ha	Nursery	Organo-phosphorus compounds / emissions = Diazinon
PVC container	380	g/10L	Estimate / PVC container transported from Europe with pesticide, 100% landfilled in Sherbrooke	See Table B-5 for disposal
Applications	32	Appl./ha	CRAAQ, 2007	Application of plant protection products, by field sprayer/ CH U
Transport	6,000	km	From Europe to Mtl	Transport, transoceanic freight ship/ OCE U
	157	km	From Mtl to Coop	Transport, lorry, > 32t, EURO 3/ RER U
	38	km	From Coop to producer	Transport, lorry, 7.5-16t, EURO 3/ RER U
Grass	14	kg/ha	CRAAQ, 2007	Grass seed, IP, at regional storehouse/ CH U with default transportation
PE bags	120	g/40kg	Estimate / HDPE bags transported from Great Lakes area (1500 km, truck) 50% recycled, 50% landfilled, as for other seeds	Polyethylene, HDPE, granulate, at plant/RER U + Extrusion, plastic film/RER U; Transport, lorry, >32t, EURO 3/ RER U See Table B-5 for disposal
Sowing	1	Appl./ha		Sowing/ CH U
Transport	38	km	From Coop to producer	Transport, lorry 7.5-16t, EURO 3/ RER U
Lime	4,500	kg/ha	CRAAQ, 2007	Lime, algue, at storehouse/CH U with default transportation
Packaging	0		bulk	
Application	1	Appl./ha		Fertilising, by broadcaster/ CH U
Transport	195	km	From Mtl directly to producer	Transport, lorry 16-32t, EURO 3/ RER U
Tree cutting	negl.		CRAAQ, 2007 / Manually done, negligeable	
Packaging	0.059	kg/tree	Standish, 2008	Polyethylene, LDPE, granulate, at plant/ RER U + Extrusion, plastic film/ RER U
Disposal	50	%	Recycled in Mtl	See Recycling LDPE in Table B-5
	50	%	Landfilled in Sherbrooke	See Table B-5
Transport	800	km	From NJ, USA to Cookshire, QC	Transport, lorry, >32t, EURO 3/ RER U
	38			Transport, lorry, 7.5-16t, EURO 3/ RER U
Mowing	5	Appl./ha	CRAAQ, 2007 / once per year for 5 years	Mowing, by motor mower/ CH U
Tillage	2	Appl./ha	CRAAQ, 2007 / 2 passes	Tillage, harrowing, by spring tine harrow/ CH U
Stone removal	1	ha	CRAAQ, 2007	Tillage, ploughing/ CH U

Stump removal	1.19	kg/tree	Peichl et al., 2007 / Stump is 45% of root system	
	0.0206	kg/tree	Micales and Skog, 1997 / CH_4 emissions, 19 gC/kg => 25gCH4/kg	Methane, biogenic, to air compartment in low population
	0.0829	kg/tree	Micales and Skog, 1997 / CO_2 emissions, 13 g/kg => 48gCO_2/kg	Carbone dioxide, biogenic, to air compartment in low population
	1	km	Pettigrew, 2008 / buried on field	Transport, tractor and trailer/ CH U
Transport in field	33.1	tkm/ha	Lemieux, 2008 & estimate / 2910 trees over 1 km * 11.36 kg/tree	Transport, tractor and trailer/ CH U
Loading	0.41	m^3/tree	Estimate / Pi * 0.252 * 2.1 m	Fodder loading, by self-loading trailer/ CH U
Pickup use	5,000	km/yr	CRAAQ, 2007 / general pickup use for tree activities for 50 ha * 11 years	Passenger car, petrol, fleet average/RER U
Transport	195	km	From producer directly to Mtl	Transport, lorry, 16-32t, EURO 3/ RER U
CO_2 sequestration	17.9	t/ha	Villeneuve, 2003; Tremblay et al., 2006 / 2 t CO_2/ha/yr for 8.95 years	Carbon dioxide, in air to biotic sub-compartment
Land occupation	9.95	ha*a	year 8 (30%), 9 (45%) and 10 (25%) + 1 yr	Occupation, forest
	1	ha	CRAAQ, 2007	Transformation, to forest

Table B.3 - Home use economic flows

Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Stand	1.5	kg	Estimate / Same tree stand as for the artificial tree + reservoir to hold at least 4 L of water. All processes proportional to weight	See Table C-1
Truck	180	km	Estimate / Beijing to port Xingang	Transport, lorry > 32t, EURO 3/ RER U
Ship	9,000	km	Freight ship from China to Vancouver	Transport, transoceanic freight ship/ OCE U
Train	5,000	km	Diesel train from Vancouver to Montreal	Transport, freight, rail, diesel/ US U
Truck	30	km	Estimate / Train station to stores	Transport, lorry > 32t, EURO 3/ RER U
Water	65	L/year	PEI, 2008 / 3L/day for 15 days + 2L/ day for 10 days	Tap water, at user/ RER U
Transport home	10	pkm/yr	Estimate / Dedicated car 5 km both ways	Transport, passenger car, petrol, fleet average/ RER U with car operation set to 1 km/km

Table B.4 - Disposal economic flows

Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Stand	1.5	kg	Estimate / See home use above	See home use above
Disposal	20	%	Estimate / Recycled	Avoided products = Pig iron, at plant/ RER U Inputs = Iron scrap, at plant, RER U
	80	%	Estimate / Landfilled	Disposal, inert material, 0% water, to sanitary landfill/CH U
Transport	10	km	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
	30	km	Estimate / Highway to landfill or recycling facility	Transport, lorry, 16-32t/ RER U
Tree	11.36	kg/yr	Lemieux, 2008 & estimate	
Disposal	50	%	Estimate / combusted in QC to produce heat and electricity. This includes Bromptonville and Trois-Rivières in equal proportions	
	50	%	Estimate / landfilled near Mtl	Disposal, wood untreated, 20% water, to sanitary landfill/ CH U
	50	%	Estimate / Proportion going to Bromptonville, the rest goes to Trois-Rivières	
Combustion Bromptonville	0.371	kWh/kg	Hamel, 2008; / Electricity = 14%, avoided products Energy densities, 2008 / Energy density = 2.639 kWh/kg, 50% moisture content Estimate / Wood density=450 kg/m^3	Wood chips, burned in cogen ORC 1400kWth/ CH, without wood input, transport to plant and waste heat Avoided: Electricity mix/ QC U

	8.17	MJ/kg	Hamel, 2008; / Heat = 86%, avoided products Energy densities, 2008 / Energy density = 9.5 MJ/kg, 50% moisture content Estimate / Wood density=450 kg/m^3	Wood chips, burned in cogen ORC 1400kWth/ CH, without wood input, transport to plant and waste heat Avoided: Heavy fuel oil, burned in industrial furnace 1 MW, non-modulating/ RER U, which uses 40 MJ/kg
Combustion Trois-Rivières	9.50	MJ/kg	Hamel, 2008; / Heat = 100% See above for other details	Heat, softwood chips, from industry, at furnace 1000 kW/ CH U, without wood input and transport to plant. Electricity, low voltage, at grid/ QC U instead of CH U Avoided: Heavy fuel oil, burned in industrial furnace 1 MW, non-modulating/ RER U, which uses 40 MJ/kg
Heat waste	3.3	MJ/kg	Hamel, 2008 / lost or unused	Heat, waste, in low population sub-compartment
Transport	20	km/yr	Estimate / To CESM, Mtl, for incineration	Municipal waste collection, lorry 21t/ CH U
	165	km/yr	Hamel, 2008 / Kruger in Brompton	Transport, lorry > 32t, EURO 3/ RER U
	135	km/yr	Hamel, 2008 / Kruger in Trois-Rivières	Transport, lorry > 32t, EURO 3/ RER U
	10	km/yr	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
	30	km/yr	Estimate / Highway to landfill	Transport, lorry, 16-32t/ RER U
Packaging	negl.		0.5% of total tree mass, energy and impacts	

Table B.5 - Packaging disposal economic flows

Component	Sub-component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Recycling HDPE	Avoided product	1	kg/kg	SimaPro suggestion for recycling	Polyethylene, HDPE, granulate, at plant/RER U
	Energy	0.6	kWh/kg	SimaPro suggestion for recycling	Electricity, medium voltage, at grid/ QC U
	Transport	10 30 157 30	km	Stop & go transportation + To sorting facility + To Mtl+ To recycling facility	Municipal waste collection, lorry 21t/ CH U Transport, lorry, 16-32t/ RER U Transport, lorry, >32t, EURO 3/ RER U Transport, lorry, >32t, EURO 3/ RER U
Recycling LDPE				Same as for Recycling HDPE	Instead of HDPE material, use: Polyethylene, LDPE, granulate, at plant/ RER U
Re-use PP	Avoided product	72	%	SimaPro suggestion for recycling Re-use also avoids plastic extrusion	Polypropylene, PP, granulate, at plant/ RER U Extrusion, plastic film/ RER U
PE landfilling	Transport	10 30	km	Stop & go transportation + To landfill	Municipal waste collection, lorry 21t/ CH U Transport, lorry, 16-32t/ RER U
	Disposal	100	%	Landfilling of PE	Disposal, polyethylene, 0.4% water, to sanitary landfill/ CH U
PVC disposal	Transport	10 30	km	Stop & go transportation + To landfill	Municipal waste collection, lorry 21t/ CH U Transport, lorry, 16-32t/ RER U
	Disposal	100	%	Landfilling of PVC	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/ CH U,
PP landfilling	Transport	10 30	km	Stop & go transportation + To landfill	Municipal waste collection, lorry 21t/ CH U Transport, lorry, 16-32t/ RER U
	Disposal	100	%	Landfilling of PP	Disposal, polypropylene, 15.9% water, to sanitary landfill/ CH U

9. Appendix C: Artificial Tree Economic Flows

Life cycle steps	Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
Tree production		10.549	kg		
	PVC needles	2.808	kg	Levasseur et al., 2007: 387,360 needles. Number is extrapolated from measurements.	
	PVC	2.845	kg	Includes 0.3% loss due to calendering, 1% loss due to cutting	Polyvinylchloride, suspension polymerised, at plant/ RER U
	Tin	0	kg	Gibb, 2008 / Approx 1.5% as stabilizer This was removed according to explanation following the critical review	Tin, at regional storage/ RER U
	Green pigment	3.8E-0	kDKK99	Inortech chimie, 2008; Money conversion, 2008; Banque du Canada, 2008 / costs 10$ in China, brought back to 1999, then to DDK using average of 1st and last day conversion rates of 1999: 37.73 DKK, 1% of PVC mass	proxy: Dyes, pigments, organic basic chemicals, DK
	Sheet forming	2.845	kg	US manufacturer & Gibb, 2008	Extrusion, plastic film/ RER U Calendering, rigid sheets/ RER U
	PCV cutting	1.50	kg	US manufacturer / Needles are punched. Estimate / Amount is 53% of process based on densities: Al: 2.64 g/cm^3, PVC: 1.4 g/cm^3, Input qty = 2.808 kg * 1.01 = 2.836 kg * 53%	proxy: Deformation stroke, cold impact extrusion, aluminium/ RER U using electricity from China: Electricity, low voltage, at grid/ CN U
	Transport	200	km	Estimate / From PVC plant to calendering plant and to Christmas tree manufacturer.	Transport, lorry > 32t, EURO 3/ RER U
	Branches	4.74	kg	Levasseur et al., 2007 / OD = 5 mm, 8 branches x 8 brackets = 64 branches of various lengths: 7 to 24 in.	
	Steel	4.74	kg	Estimate	Steel, low-alloyed, at plant/ RER U without iron scrap in sub-processes (pig iron instead)
	Forming	4.74	kg	Estimate	proxy: Wire drawing, steel/ RER U
	Wire twisting	4.74	kg	Estimate	proxy: Steel product manufacturing, average metal working/kg/RER U
	Coating	0.483	m^2	Levasseur et al, 2007 & estimate / OD=5 mm, Mass=4.74 kg, Density=7.85 g/cm^3, giving a length of 30.75 m	Powder coating, steel/ RER U
	Transport	100	km	Estimate	Transport, lorry > 32t, EURO 3/ RER U
	Trunk	0.782	kg	US manufacturer / 2 sections, 33 inches long, 24 gauge, OD = 1.25 inch. They wedge into each other	
	Steel	0.782	kg	Estimate	Steel, low-alloyed, at plant/ RER U without iron scrap in sub-processes (pig iron instead)
	Coating	0.167	m^2	Estimate / Area calculation for above trunk	Powder coating, steel/ RER U
	Welding	1.676	m	Linear weld to close tube (2*33 in)	proxy: Welding, arc, steel/ RER U
	Folding & swa	0.782	kg	Folding of steel sheet, and swaging of ends to fit into each other	proxy: Steel product manufacturing, average metal working/kg/RER U
	Transport	100	km	Estimate	Transport, lorry > 32t, EURO 3/ RER U
	Stand	1.190	kg	US manufacturer & estimate / 4 legs, 32 cm, 7/16 in OD, 1/8 in thick + center piece (equiv. to 2 legs), density=7.85 g/cm^3	
	Steel	1.190	kg	Estimate	Steel, low-alloyed, at plant/ RER U without iron scrap in sub-processes (pig iron instead)
	Forming	1.190	kg	Estimate	proxy: Cold impact extrusion, steel, 1 stroke/ RER U

Life cycle steps	Component	Qty	Unit	Source / Hypothesis	Ecoinvent model data
	Coating	0.067	m^2	US manufacturer & estimate / Area calculations for above stand	Powder coating, steel/ RER U
	Rubber feet	negl.	kg	Estimate / neglected < 0.5% & low impacts	
	LDPE bag	negl.	kg	Estimate / neglected < 0.5% & low impacts	
	Transport	100	km	Estimate	Transport, lorry > 32t, EURO 3/ RER U
	Brackets for branches	0.100	kg	Levasseur et al., 2007: 100 g for 8 brackets with 8 branches per bracket 5 mm OD	
	Steel	0.101	kg	Estimate / Loss from hole drilling	Steel, low-alloyed, at plant/ RER U without iron scrap in sub-processes (pig iron instead)
	Forming	0.101	kg	Estimate	proxy: Deformation stroke, cold impact extrusion, steel/ RER U
	Drilling	0.010	kg	Levasseur et al., 2007 & estimate / 64 holes, 1 mm deep through bracket depth, OD=5 mm, density=7.85 g/cm^3	Drilling, conventional, steel/ RER U
	Transport	100	km	Estimate	Transport, lorry > 32t, EURO 3/ RER U
	Packaging - cardboard	0.929	kg	US manufacturer / 2 boxes 40 in x 20 in x 20 in: shipping, client storage, density = 150g/m^2 Estimate / 20% cardboard overlap for joints	Packaging, corrugated board, mixed fiber, single wall, at plant/ RER U with mixed fiber replaced with fresh fibers
	Transport box	100	km	Estimate	Transport, lorry > 32t, EURO 3/ RER U
Transport from China to Mtl	Truck	180	km	Estimate / Beijing to port Xingang	Transport, lorry > 32t, EURO 3/ RER U
	Ship	9,000	km	Freight ship from China to Vancouver	Transport, transoceanic freight ship/ OCE U
	Train	5,000	km	Diesel train from Vancouver to Montreal	Transport, freight, rail, diesel/ US U
	Truck	30	km	Estimate / Train station to stores	Transport, lorry > 32t, EURO 3/ RER U
Client transport		10	pkm	Dedicated car 5 km one way for a total of 10 km	Transport, passenger car, petrol, fleet average/ RER U with car operation set to 1 km/km
Disposal	Steel (brackets, trunk, stand)	2.072	kg	Estimate / see stand above	See stand above
	Disposal	20	%	SimaPro suggestion / Avoided products Estimate / Recycled proportion	Avoided products = Pig iron, at plant/ RER U Inputs = Iron scrap, at plant, RER U
		80	%	Estimate / Landfilled	Disposal, inert material, 0% water, to sanitary landfill/CH U
	Transport	10	km	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
		30	km	Estimate / Highway to landfill or recycling facility	Transport, lorry, 16-32t/ RER U
	Steel (branches)	4.74	kg	100% landfilled, steel is too difficult to separate from PVC for recycling	Disposal, inert material, 0% water, to sanitary landfill/CH U
	Transport	10	km	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
		30	km	Estimate / Highway to landfill	Transport, lorry, 16-32t/ RER U
	PVC	2.808	kg		
	Disposal	100	%	Landfilling of PVC, PVC is too difficult to separate from steel for recycling	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/ CH U,
	Transport	10	km	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
		30	km	Estimate / Highway to landfill	Transport, lorry, 16-32t/ RER U
	Cardboard	0.929	kg		
	Disposal	50	%	SimaPro suggestion / Avoided products Estimate / Recycled proportion	Avoided products = Core board, at plant/ RER U Inputs = Corrugated board, recycling fiber, single wall, at plant, RER U
		50	%	Estimate / Landfilled	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/ CH U
	Transport	10	km	Estimate / Stop & go	Municipal waste collection, lorry 21t/ CH U
		30	km	Estimate / Highway to landfill or recycling facility	Transport, lorry, 16-32t/ RER U

10. Appendix D: Independent Critical Review (16 pages)

Pascal Lesage, Eng.
Sylvatica, Montreal office
7379 St-Hubert
Montreal, Qc. Canada
H2R 2N4

December 8, 2008

Ellipsos Inc.
c/o Mr. Jean-Sébastien Trudel
1030 Beaubien E., Suite 305
Montreal, Qc. Canada
H2S 1T4

Critical Review of the LCA study "Comparison of Natural and Artificial Christmas Trees (Report 1043-RF1-08)"

Dear Mr. Trudel and co-authors,

You will find herein the comments of the critical review panel I chaired and that reviewed your LCA study entitled "Comparison of Natural and Artificial Christmas Trees". The other two panel members were Jean-François Ménard, Eng. of Ecointesys Life Cycle Systems and Prof. Claude Villeneuve of the Chaire en Éco-conseil at Université du Québec à Chicoutimi.

Save the exceptions outlined below, the peer reviewers agree that the general modeling approach and data choices for both product systems is appropriate to meet the goals of the study. However, given that the study is meant to support comparative assertions that will be made public, we feel that omissions in the interpretation phase of the LCA will need to be corrected before making the results of the study public. You should have no problem addressing the issues outlined below, and we trust you will be able to have an ISO 14044 compliant study for communication with the Quebec market in time for the holiday season.

1 Goal and scope

1. It was unclear to the panel why the **functional unit** did not refer to one single Christmas holiday season, which would have made it simpler and more effective in subsequent communications. The number of years the tree could be reused would therefore simply be a key parameter. This was suggested in the intermediate report review. In any case, the wording of the functional unit is not very clear, implying that natural trees can be reused for 6 years, which of course is not the case.

   ellipsos: The adjustments suggested by the reviewers has been implemented. The functional unit refers to one Holiday season. The durability of the artificial tree and stand of the natural tree remain six years.

2. The description of the **system boundaries** was generally clear and acceptable to meet the goal of the study. However, two statements in the text should be revisited by the authors:
   a. It is stated in Section 2.2.1.3 that the cut-off criteria "can be modified according to an iterative process". Although this is very true, this report is a final report, and so it should be stated what final cut-off criteria was actually used. Details should also be given if these final criteria are different from what was planned at the beginning of the study.

ellipsos: The statement regarding the iterative process was removed. The 3% cut-off criterion was kept as planned initially.

b. It is stated in Section 2.2.2.2 that "A bag is included because the stand is deemed outsourced by the tree manufacturer." It is unclear what outsourcing has to do with the setting of system boundaries.

ellipsos: The US manufacturer stated that their stands came from China and that they came in PE plastic bags. The same assumption was taken for the trees manufactured in China. However, the bags were finally removed from the study since their mass, energy and impacts were below the 3% cut-off criterion mentioned above (1.2.a).

2 Aspects specific to the natural tree model

1. Several issues have been identified relating to the overall carbon balance. In addition to the comments below, we will send two articles and one figure that should be of some help to you in revising this aspect of the model.
   a. A distinction between carbon sequestered in trees (which is only temporarily sequestered) and carbon sequestered in soil and litter should be made. Both should be treated differently in the model.

   ellipsos: See details below (1.1.c)

   b. We estimate that, overall, the sequestration rate assumed in this study (2 t CO_2/ha) seems reasonable. However, we recommend a sensitivity analysis considering 0.5 t CO_2/year, which is the lower limit. For informative purposes, we would like you to consider the following:
      - White spruce trees, in the earlier stages of growth, resemble fir trees more than do black spruce trees. A study on white spruce estimates a sequestration total of 5,5t CO_2/ha over 50 years, not considering roots (Tremblay et al., 2006; see attached). Hence, the 2 ton CO2/ha seems reasonable.
      - The black spruce data that was used for the report (Gaboury et al., 2006) is for trees grown in Nordic conditions, with a very slow growth rate during the 15 first years – fir trees therefore actually have a higher growth rate than that considered during these years. Also, the Gaboury et al. study removes from its balance the sequestered carbon associate with the initial harvesting of 30 m^3 of wood initially on the site. Furthermore, that study accounts for fire and disease risks. Given all this, the assumption that the fir tree plantation sequestration will be higher than that cited in the Gaboury et al. study seems justified.
      - The CO2FIX model used by Gaboury et al. (2009) indicates that the carbon accumulation is mostly done in the wood and leaf sections of the tree (approximately 65%), with the rest occurring in soil (approximately 15% in roots). We have sent you (see attached) a figure on carbon sequestration rates for a plantation where trees are harvested every 20 years. In it, you will be able to observe the amount of carbon stored in different compartments.
      - The amount of carbon that can be sequestered depends on the C/N ratio. Since the Christmas tree plantation is fertilized, carbon sequestration is favoured.

   ellipsos: See details below (1.1.c)

   c. It will be necessary to document your assumptions regarding the carbon that is sequestered in soil and litter, stating especially whether you assume this sequestration can be assumed as definitive. One of the reviewers states that the sequestration in soil can last for hundreds of years, above the lifetime of a

CO_2 molecule emitted today. The assumed fate of the litter would have to be discussed in your report. If roots are removed after harvest, the fate of these roots will have to be described and modeled as well.

ellipsos: Based on the reviewers' comments, the authors have revised the C sequestration model as follows:
The reviewers mention that we, the authors, are using a sequestration rate above that of Gaboury (2006). In fact, Gaboury reports a sequestration rate of 1.2 t C/ha/yr, which would give 4.6 t CO_2/ha/yr. Therefore, the value of 2 t CO_2/ha/yr that we have chosen is lower than that of Gaboury. The reviewers also mention that Tremblay et al. (2006) report a value of 5.5 t CO_2/ha/yr for white spruces. This data is over a 50-year period. Since Christmas trees are usually cut after 12 to 14 years, we prefer to use the data from Tremblay et al. for the mean CO_2 sequestration over 22 years: 2 t CO_2/ha/yr.

From Tremblay et al, 2006, we also understand that for the first 22 years, the aboveground C storage is, on average, 1.8 t C/ha/yr, litter accumulation is negligible, and C content from the soil decreases by 1.3 t C/ha/yr. Tremblay et al. have neglected the root compartment. This data indicates that the tree plantation is a C sink of 0.5 t C/ha/yr (2 t CO_2/ha/yr). However, Gaboury et al. (2009) also state that "the total amount of C per ha drops from 17 to 14 t C ha during the first 20 years following planting" and that "biological C balance [...] results in a net C emission during the first 20 years. Therefore, the low value for the CO_2 sequestration in the sensitivity analysis was reduced from a sink of 1 t CO_2/ha/yr to a source of 0.5 t CO_2/ha/yr, increasing the sensibility span compared to the reviewers' recommendation.

From Gaboury et al. (2009), we assume that 60% of C sequestration occurs in the aboveground compartment (stem, foliage and branches) and that the belowground compartment sequesters 40% of C (soil, 26%; roots, 14%). We assume that this data for 70 year-old trees also holds for the Christmas tree plantation at harvest, which likely underestimate the roots proportion. Finally, from Peichl et al. (2007), who gives data for white pines at 15 years afforestation, we assume that the stump and major roots represent 45% of the root system. This weight proportion is considered when the stumps are removed from the field. They are then transported by trailer to another area on the plantation and buried. Their emissions follow the calculations from Micales and Skog (1997) with the proportion of carbon emitted as methane (19 g CH_4/kg wood) and carbon dioxide (13 g CO_2/kg wood). See below for more details.

Finally, we assume that the soil and root compartments left in the soil do not contribute to emissions in air or water and that they stay in the soil indefinitely.

d. In terms of carbon sequestered in the trees, Figure 4.4 hints that there may be a problem with the current modeling approach. We would expect that a 10% increase in the mass of the natural tree would significantly increase the calculated climate change benefits of the natural tree, as more carbon would be sequestered in the tree itself. The very slight effect seems to indicate that only avoided CO_2 emissions (avoided electricity, avoided combustion of fossil fuels) at the combined heat and power plant are affected.

ellipsos: The assumption made by the reviewers is correct. For a tree weight increase or decrease, the amounts of sequestered CO_2 are now adjusted linearly with weight, for the aboveground and belowground compartments.

e. Generally, it will be necessary to better document the fate of the carbon temporarily stocked in the tree at end-of-life. Part of the carbon will be released during the combustion (recovered portion of trees). For the portion of trees sent to a landfill, part of the carbon will be sequestered on the long term in the landfill itself. There will be a formation of methane at the landfill, but it could be assumed that it will be captured and flared. Values for each of these fractions should be documented, and the source of information used to quantify these should be given. For your information, the fraction of carbon that can be considered permanently stored following landfilling is approximately 30% (ICF consulting 2005).

ellipsos: Micales and Skog (1997) have calculated the proportion of carbon emitted as methane (CH4) and CO2 from wood in landfills, using 15% moisture in wood. They give 0 to 19 g CH4/kg wood and 0 to 13 g CO2/kg wood. These numbers are low compared the reference from the reviewers

(ICF consulting, 2005). The IFC data refers to various types of paper emissions and not wood. Micales and Skog (1997) also recognizes this important difference between paper products and forest products, stating that the former falls into the "moderately decomposable waste" category and the latter falls into the "slowly decomposable waste" category. Micales calculates that 30% of the carbon from paper and 0-3% of the carbon from wood are ever emitted as landfill gas. His conclusions are thus similar to those of IFC. The data from Ecoinvent "Disposal, wood untreated, 20% water, to sanitary landfill/ CH U" refers to 20% moisture in wood and emits 2.39 g CH4/kg and 15.7 g CO2/kg. The value for methane falls within the limits found by Micales and Skog. The value for CO2 falls slightly outside the interval found by Micales and Skog, but the authors are still using this data for its completeness regarding the other emissions.

f. The CO_2 sequestration value given in the report per hectare. This relies on the assumption that the plantation densities (trees/ha) are the same between those studied in the cited references and those under study in this study. If this assumption was indeed made, then it should be documented.

ellipsos: The assumption that the plantation density is the same as those cited in reference has been documented in section 2.2.2.1.

g. The value for carbon sequestration at the plantation is given twice in Table 2.1. It should only be presented for the "Tree in field" section.

ellipsos: The value for carbon sequestration in Table 2.1 for the tree in the nursery was removed.

2. Concerning the use of the tree in a combined cogenerator at end of life:

a. The report says that only the Bromptonville plant is included "since it includes both electricity production and heat production". Why does that fact that the Trois-Rivières only produce heat exclude it from the study? It seems a better option would have been to obtain (or assume) data on the portion of trees going to each of the plants.

ellipsos: We changed the model to include equal amounts of wood going to Trois-Rivières and Bromptonville. Both plants were modelled and the text reflects this new model. We hypothesize that both plants use the same technology and have the same proportions of waste heat.

b. The calculations of the energy (electricity, heat and heat loss) produced in the cogenerator should be better documented/explained, with a presentation of the different assumptions. At a minimum, the assumed heat content of wood needs to be given.

ellipsos: The data comes from the Kruger company and is better explained in the Table of Appendix B. Wood energy density was changed from 5.5556 MJ/kg (Hamel, 2008), which included wood, paper and other residues to 9.5 MJ/kg for wood only (Energy densities, 2008). The authors assume that the needles have the same energy density as wood.

c. The choice of unit processes to model the combustion of the wood chips in the cogenerator at the Kruger plant should be better documented and justified. The unit processes chosen are the energy allocated ones ("Electricity, at cogen ORC 1400 kWth, wood, allocation energy/CH" and "Heat, at cogen ORC 1400 kWth, wood, allocation energy/CH"). There is a unit process in the ecoinvent database that corresponds to the unallocated combustion of 1 MJ of wood in a cogenerator ("Wood chips, burned in cogen ORC 1400kWth/CH") that seemed a more appropriate choice, since the amount of wood was the variable precisely known.

ellipsos: The unallocated combustion of wood in a cogenerator (Wood chips, burned in cogen ORC 1400kWth/CH) was selected as per the reviewer suggestion. The data was still divided into electricity and heat production to reflect the reality in Bromptonville and Trois-Rivières.

   d. Table B-4 supplies a value for waste heat. However, the ecoinvent processes also consider waste heat. Was the waste heat n the ecoinvent model removed?

      ellipsos: The waster heat from the ecoinvent model is now removed, favoring our primary data.

   e. Finally, the contribution analysis presented in Table 3.1 has ecoinvent “allocation correction” unit processes that seem to indicate that wood inputs to the cogenerating processes were not removed from the cogenerating boiler processes used. If this is the case, the model has a major double counting issue (the life cycle of the Christmas tree and of the generic combusted tree are included).

      ellipsos: The wood inputs had in fact been accounted twice. The wood input for the Wood chips, burned in cogen ORC 1400kWth/CH) was removed, as well as the default transportation, again, favoring our primary data.

3. The use of “Grass from meadow” for Peat moss production is not adequate. Grass production is a net carbon sequestrating activity, while peat moss extraction results in the emission of methane. The dataset “Peat, at mine/kg/NORDEL” would be more appropriate.

   ellipsos: The nursery was contacted to clarify the nature of the peat moss used; it is Sphagnum or decayed, compacted Sphagnum moss, which can be used as a soil additive to increase the soil's capacity to hold water and nutrients. The model was changed to use Peat, at mine, kg, NORDEL, as per the reviewers' suggestion, using 1 kg of peat as 1 kg of peat moss. This significantly increases the relative contribution peat moss in the sowing process, for the category non-renewable energy. For the overall tree life cycle, this is not significant.

4. Why has the peat moss removal process not been modelled? First, because of its important mass (30 t/ha), it is bound to be a significant activity. What is more, the end of life of peat moss emits GHG that may in part offset the apparent climate change benefits of natural tree cultivation.

   ellipsos: The nursery was contacted to clarify this issue. Pots are filled with peat moss and seeds are sown with an electrical sowing machine. The pots are then laid on the ground for two years. After the tree extraction, the peat moss is transferred to a trailer and dumped in a pile further on the field. This is a manual activity, which is neglected.

5. The land occupation type attributed to the tree plantation is not clearly stated in the report. However, it appears that a land occupation type akin to agricultural land may have been used. If this is the case, this choice may overestimate land use impacts. Indeed, a tree plantation does not resemble an agricultural ecosystem, at least not in terms of intensity of impacts. The number and intensity of interventions are lower, and there is no annual harvest. As a consequence, the territory continues to have value for fauna (forest cover, production of grass). As a matter of fact, the Master’s study by François Villeneuve at the Université de Moncton (2007) showed that one can find fauna comparable to what can be found in natural habitats (jackrabbits, ruffed grouse, small rodents, foxes and prey birds).

   ellipsos: Land occupation for the tree in the nursery and in field had not been modeled in the initial revision of this final report, presuming that the ecosystem disruption would be minimal, as the reviewers have mentioned. The model was modified as follows. For the years in nursery, the land occupation is close to an agricultural use. In fact, the production can be done on an irrigated land, which is the case in our model. The land occupation was therefore modeled with “Occupation, arable” for four years. For the tree in field, it is not entirely true that the habitat in a plantation is identical to that of a real forest. For example, the number of floral species is likely smaller and the forest density is reduced. The authors would have liked to model this land occupation with “Occupation, forest, intensive, short-cycle”, but the Impact 2002+ method does not take this occupation into account. The land occupation was therefore modeled as “Occupation, forest” for 11 years in the field. This process has land occupation impacts in Impact 2002+ that are approximately 10% of the impacts of an arable land.

6. The data for the fertilizers used in the nursery do not add up to the indicated total and is the exact nature of the fertilizers used is not clear (are the numbers in the first column the CAS numbers of the fertilizers?). The unit processes from the ecoinvent database used to model them should also be clearer.

   ellipsos: The numbers in the first column of Tables B-1 and B-2 represent the N, P (P2O5) and K (K2O) contents of the fertilizer in percentage, as they are usually ordered by the producers. The fertilizer models follow the advice of Guy Raymond from the Institut de Technologie Agroalimentaire. The explanations in the Tables as well as in the text have been improved (section 2.2.2.1).

7. The process chosen for “Sowing in nursery” seems inadequate, as the chosen data represents sowing in field (including, for example, the use of tractors). Electricity consumption of the electric sowing machine should have been used.

   ellipsos: The sowing process had originally been chosen, but it was replaced in the model by the amount of electricity for the machinery performing the sowing action. The data in the Table B-1 was overlooked when this change occurred. The model is correctly implemented and the information in the table was corrected.

8. Why was the tree seeds production modelled with the unit process “Barley seed IP, at regional storage/ RER U”? Approximately 92% of the impact (single score, but similar results are obtained for each impact category) comes from the cultivation of the barley that generates the seeds (a cycle is thus created from plant to seeds and back to plant) which is probably very different than for Christmas trees. However, from what is shown for barley, a ratio could have been estimated to the rest of cultivation system for the trees.

   ellipsos: The ecoinvent process for barley seeds was kept. However, in this data the process for “Barley grains, IP, at regional storage /RER U” was removed because the seeds come from a plantation of trees, which is the model of interest here. Therefore, only the building occupation and inputs specific to seed preparation are left in the barley data. This reduces the environmental impacts of the seeds, but has low impacts on the overall model.

9. The report does not mention that fertilizer used in tree plantations are mostly of the granular type, and so that very little actually lixiviates to the aquatic ecosystem. What is more, trees protect against erosion, much in the same way regenerating forest ecosystems do. These aspects should be mentioned in the report.

   ellipsos: Since the first revision of this report (1043-RF1-08), the fertilizer emissions have been included. At the nursery, fertilizers are sprayed, while in the field, they are spread in granular form. The model at the nursery was changed from “Fertilising, by broadcaster/ CH U” to “Application of plant protection products, by field sprayer/ CH U”. For both the nursery and the field, fertilizer emissions were added according to the model for Corn, at farm/US of the Ecoinvent database, which uses fertilizers in the granular form. Details about this model have been added to section 2.2.2.1 as well as the qualitative assessments regarding erosion. Erosion, however, is not taken into consideration in the impact assessment methods. This constitutes a limit of this study.

10. In Tables 2.1, B-1 and B-2, the values for the economic flows for the nursery and the growth in the field are per ha, which does not correspond to the functional unit. Table 2.1 should show the economic flows normalised to the functional unit. Tables B-1 and following should show the data used for the economic flows normalisation, the associated calculations with some explanations (assumptions) and the exact unit process used to render these economic flows. Not indicating the values associate with the actual unit processes used also makes verifying the modelled system impossible.

    ellipsos: The data in Tables B-1 and B-2 was kept per hectare. Normalization to one natural tree is feasible with the given data. The numbers shown allow for complete reproduction of the results. However, the authors prefer to leave the numbers per hectare since the primary data was obtained per hectare. In this format, the data can be quickly checked for anomalies. It also allows the various stakeholders of this study to understand the forestry processes involved with the natural tree. Finally, given time constraints, the authors prefer to act on more serious issues outlined by the reviewers.

11. The assumption that the transport of peat moss is from Montreal is very unlikely. Indeed, peat moss production in Quebec is a rural activity, occurring for example in the Bas-St-Laurent region.

    ellipsos: The peat moss is now modeled to come from the Rivière-du-Loup area as was mentioned by the nursery.

12. Section 2.2.2.1 states that the pots were excluded because it they are reused many times. This in itself is not an appropriate reason for excluding the pots. It should be made clear that it is actually assumed that the mass, energy and impacts associated with the use of these pots is under the stated cut-off criteria.

    ellipsos: The suggestions has been implemented. The sentence now reads: The pots are neglected since they are re-used several times and their mass, energy and impacts associated are under 3%.

13. It is not clear how the 72% effective re-use value for the PP bag at the nursery was calculated and how it was used in calculating the amount of bags (kg of PP) per functional unit.

    ellipsos: PP bags are returned to the nursery in 80% of the cases, 20% are presumably sent to a landfill. After 10 re-uses by the nursery, the bags need to be sent to a landfill because they are not re-usable. Therefore, we have an additional percentage of PP bags that are sent to a landfill: 1/10 * 80% = 8%. This gives an effective re-use proportion of 72%, while 28% are sent to a landfill. In the re-use scenario, the raw material "Polypropylene, PP, granulate, at plant/ RER U" and the extrusion process "Extrusion, plastic film/ RER U" are avoided by re-using the PP bags (the latter is now incorporated in the model). Per hectare, 196.7 kg are produced and a credit for 141.6 kg is given. Per tree, this gives 1 g of PP required and a credit of 0.72 g.

14. Section 2.2.2.1 states that all flows were multiplied by six "except for the stand, which is used for the entire duration of the life cycle". It s not clear what the term "life cycle" refers to. It may be clearer to simply write that you assume the stand lasts six years.

    ellipsos: The sentence was corrected as per the reviewer suggestion. It now reads: Since the reference flows of this study require six natural trees, the inventory is multiplied by six, except for the stand, which lasts six years.

15. The fact that stumps are manually removed is surprising.

    ellipsos: The stumps are extracted from the ground with mechanized equipment. This has been modeled as per the information from Pettigrew, 2008 with the processing unit process "Tillage, harrowing, by spring tine harrow/ CH U" used twice. Once they have been extracted, they are manually removed from the field.

3 Artificial tree model

1. There is a discrepancy between the PVC manufacturing process indicated in Table 3.2 (Polyvinylchloride, suspension polymerized, at plant/RER) and in Appendix C (Polyvinylchloride, bulk polymerized, at plant/RER). A search on the internet, primarily in the PlasticsEurope website (whose data was included in the ecoinvent database), indicates that "Suspension PVC is the general purpose grade and is used for most rigid PVC applications such as pipes, profiles, other building materials and hard foils. It is also plasticised and used for most flexible applications"; and that "Suspension PVC accounts for more than 80% of the PVC market. The market share for emulsion PVC is approximately 10% and for bulk PVC, 5%". However, there is a note in the Levasseur et al. report indicating that the PVC for the trunk cannot be from emulsion or suspension polymerisation. The choice of process used in the model is not clear and should be better documented and coherent throughout the report.

ellipsos: The chosen process is Polyvinylchloride, suspension polymerized, at plant/ RER. Appendix C contained a transcription error. The report from Levasseur et al. (2007) does not state its source for not choosing the suspension method and the authors do not agree with their PVC selection. The authors agree with the reviewers and the most predominant type of PVC was chosen (suspension).

2. Section 2.2.1.4 indicates that electricity production only accounts for less than 0.3% of overall environmental impacts. However, this low contribution is the result of an artefact of the ecoinvent database, namely that the plastics datasets are “system terminated” (they represent cradle-to-grave elementary flows from which it is impossible to evaluate the impact of individual inputs, such as electricity). Had it been possible to evaluate the share of impacts attributable to electricity production in the plastics datasets, the 0.3% value would undoubtedly been much higher. This should be discussed both in this section and also in the interpretation phase.

   ellipsos: This is now discussed in the interpretation phase as one of the limits of this study.

3. The exclusion of pigments should not only be based on mass criteria but also on environmental relevance. A quick check, assuming pigments to be “undefined organic chemicals” suggest that the impact of producing pigments could be environmentally significant. Indeed, the impacts of producing 1 kg of undefined organic chemicals are higher than those of producing 1 kg of PVC in 12 of 15 impact categories (IMPACT 2002+), higher by a factor of 550 for ozone layer depletion and 68 for carcinogen impacts. Also, pigments often contain metals, and therefore the production or use of pigments could result in the emission of metals to the environment. The exclusion of pigments from the study based on mass terms only therefore seems misguided to the reviewers.

   ellipsos: Green pigments are usually made of Phtalocyanine Based Organic Pigments (Pigment green, 2008; Wikipedia, 2008; Wijdekop et al., 2008). This chemical, however, cannot be found in the ecoinvent database. The process “Dyes, pigments, organic basic chemical, DK” from the Denmark Input Output Database 99 was used. Inortech chimie (2008) provided the cost of green dies in China (10 CDN$/kg). This value was brought back to the value in Canadian dollars for 1999 (CDN$ 8.18). It was then converted to Danish Krones using the average exchange rate between the rates on the first day of 1999 and the last day of 1999, giving 0.3773 DKK99. The results for this model were comparable to the results obtained by the reviewers. Differences of a factor four were seen, for carcinogens, ionizing radiation and ozone depletion. The authors prefer to use a chemical specific to color pigments than an undefined unit process.

4. In Section 2.2.2.2, a general description of the structure of the tree (how the different elements: trunk, brackets, branches and needles are organised) would have made understanding the calculations easier. Also, the modelling of the economic flows would be clearer if all the data used was indicated and the calculations presented in the appendix. For example, the trunk consists of two steel tubes of gauge 24 thickness and 33 inch length, however the diameter is missing.

   ellipsos: The diameter of the trunk was added in the appendix. In addition, the various tables include more data used in the calculations in order to make the report more transparent. A section in the text (section 2.2.2.2) was added to describe the tree construction.

5. There is a mistake in the total number of needles on the tree; the Levasseur et al. report indicates 387’360 and not 387’600 (Section 2.2.2.2):.

   ellipsos: The typographical mistake was corrected to 387,360 needles.

6. In section 2.2.2.2, paint, rubber feet and a plastic bag are mentioned in the text in regards to the tree stand, however these are not indicated in Table 2.2. Further, in Appendix C, the paint becomes a powder coating, and

the rubber feet and plastic bag are considered negligible since they are supposed to be <0.5%. This should be clearer in the text.

ellipsos: The rubber feet and plastic bag were initially meant to be incorporated in the tree, but their mass and environmental impacts were below the 3% established threshold. They were then removed from the model, but the text had not been changed. The text regarding these two items was modified to reflect the model.

7. It is unclear if the itinerary selected for the artificial tree is realistic, considering that Levasseur et al. indicated that Los Angeles is the most important port on the west coast of North America for products from Asia.

   ellipsos: We contacted the Montreal Port Authority (Matta, 2008) and the Shipping Federation of Canada (Gravel, 2008) regarding routing of merchandise to Montreal. They said that for Canadian goods coming from Asia to Montreal, the route generally went through Vancouver and not through Los Angeles. Reference to the above communications is now made in the report.

8. In Table 2.2, there seems to be a mistake in the value for the mass of the branches. Levasseur et al. indicate a value of 4.74 kg without any loss due to the manufacturing process. In Table 2.2, it is indicated that a 1% loss factor is considered, but the 4.74 kg value is still there (should be 4.79 kg if there is a 1%). Also, the source of information for the 1% loss factor should be given.

   ellipsos: The added losses for the various steel working processes were removed. The 1% loss that had been included was a basic estimate from a local metal shop. As the reviewers pointed out (see 3.11), the ecoinvent processes already include loss factors that are far more accurate than the 1% estimate. The Tables in Appendix C now use the ecoinvent processes without further loss factors. The same reasoning has not been applied to the PVC in the needles. Proxy processes were used to model punching the needles and a 1% loss was maintained. Note: the process used to simulate needle punching was changed from "Cold impact extrusion, aluminium, 1 stroke/ RER U" to "Deformation stroke, cold impact extrusion, aluminium/ RER U" with the electricity from China.

9. It is stated that "To stabilize the PVC, nowadays, approximately 1-2% of tin is used instead of 2-5% of lead (Gibb, 2008)." It is unclear how this information affected the model, especially knowing that the PVC data used is a system terminated dataset (i.e. inputs into the production of PVC cannot be varied). Please provide more detail.

   ellipsos: From the discussion with Gibb (2008), the authors understand that, for PVC, resins are produced but they cannot be used as is. Various fillers need to be added to form a usable compound. These fillers can reach a large proportion of the compound mass (up to 50%). The authors first wanted to include the primary PVC stabilizer to the ecoinvent process, thinking that the ecoinvent process represented the resin alone. By looking at the database, it is now unclear if the Ecoinvent data represents the PVC resin alone or the PVC compound. By adding tin or lead to the PVC material unit process, the effect could be: 1) the tin or lead is double counted or 2) only tin or lead would be taken into account, leaving all other fillers out of the model. In addition, in the case where the tin or lead fillers are added, only the impacts from their production would be taken into account. The emissions from these fillers are rather difficult to compile during the use of the tree and for the end of its life. Knowing that the concerns regarding lead are primarily related to its use and its end of life, the data would be even more incomplete. In fact, in the first revision of this final report, the scenario substituting tin for lead did not affect the results. The authors therefore decided to remove the tin and lead fillers from the study. This constitutes a limit of the study.

10. For some of the "processing" unit processes (e.g. Extrusion, plastic film/ RER U), there is a loss factor indicated in the documentation. These factors seem to have been taken into account for the amount associated with the processing unit processes itself, but not with the resin production process (i.e. the amount of resin produced needs to be higher than contained in the end product).

    ellipsos: The factors have been taken into account for the processing unit processes and the materials unit processes. The appendix only stated the amount of materials in the needles obtained from Levasseur et al. (2.808 kg). This material includes a larger amount of PVC from suspension polymerisation by 1.3% (2.845 kg), processing unit processes for extrusion and calendering (2.845 kg), as well as an amount larger by 1% for the cutting process (2.836 kg). The Table in the Appendix now explains these numbers.

11. The process “Steel product manufacturing, average metal working/kg/RER U” considers a loss factor of 22.7%, compensated by the included steel production unit process “Steel, low-alloyed, at plant/RER U”. It is unclear whether this was considered in the overall loss factor of 1% indicated for the branches and the trunk.

    ellipsos: The added losses for the various steel working processes were removed. The 1% loss that had been included as basic estimate from a local metal shop. As the reviewers pointed out here, the ecoinvent processes already include loss factors that are far more accurate than the 1% estimate. The Tables in Appendix C now use the ecoinvent processes without further loss factors, except for needle punching, where the 1% figure was kept.

12. There seems to be no transport considered between the production sites and the Christmas tree manufacturer for the stand and the brackets. Please explain this assumption.

    ellipsos: Transport was included for the brackets from the bracket manufacturer to the tree manufacturer (100 km). For the stand, however, this transport had been omitted and was added (100 km). In addition, the type of transport was made uniformed for all transportation between suppliers in China (Transport, lorry > 32t, EURO3/RER U).

13. There seems to be no processing modelled for the steel brackets. The reviewers consider this an omission.

    ellipsos: Two processes were added: forming (Cold impact extrusion, steel, 1 stroke/ RER U) and drilling (Drilling, conventional, steel/ RER U).

14. There seem to be mistakes (i.e. an over-estimation) in both surface area calculations for the trunk and stand for the coating unit process. The details of the calculations would have helped in their verification.

    ellipsos: The calculations were verified and found to have been doubled. For the trunk, we have now have: pi*OD*L*2, where pi=3.1416, OD=1.25 in, L=33 in, 2=number of sections. This calculation gives 259 in^2 = 0.167 m^2. For the stand, the calculations include 4 legs, structural rods and a center piece. The stand calculations were verified and corrected (factor 2). The stand is simplified as having 6 legs: pi*OD*L*6, where pi=3.1416, OD=7/16 in = 1.11 cm, L=32 cm, 6=4 legs + parts equivalent to 2 legs. This gives 670 cm^2 = 0.067 m^2. In addition, coating was added for the branches. The calculations are included in the Table in appendix C. Coating of the brackets was neglected.

15. Is the unit process “Disposal, steel, 0% water, to inert material landfill/CH U” the most appropriate to model the landfilling of steel products in a sanitary landfill? Couldn’t the unit process “Disposal, inert material, 0% water, to sanitary landfill/CH U” be adapted to better simulate this process? The waste treatment unit process used to model the landfilling of the steel branches is not indicated, but it could be the same as for the landfilled stand, trunk and brackets.

    ellipsos: The unit process from Ecoinvent was changed for all steel components of the artificial and natural tree as per the recommendation: Disposal, inert material, 0% water, to sanitary landfill/CH U

16. The report states that the plastics recycling unit processes are from ecoinvent: actually, they are from the SimaPro software developers.

    ellipsos: Correction made to identify SimaPro as the source for the recycling processes.

17. The choice of the “processing” unit processes in the ecoinvent database to model the manufacturing of the different tree elements is not documented, explained or justified in Annex C. Are they estimated proxies or were they identified by the American tree manufacturer, as may be indicated in the table?

ellipsos: In general, these processes are proxies. Primary data was very difficult to obtain because manufacturers prefer not to disclose their manufacturing processes. However, a brush manufacturer was visited to better understand how the needles were attached to the branches (this is how the first trees were made, by brush manufacturers). The word "proxy" is now mentioned in Tables of Annex C, where applicable.

4 Interpretation of the results

4.1 General conclusions

1. Section 2.2.5 describes the interpretation phase of LCA, but the description is incomplete. Indeed, no mention was made of the completeness checks and the consistency checks required by ISO. Furthermore, no mention is made of uncertainty and data quality analyses, also required by ISO for comparative assertions.

   ellipsos: Completeness checks, consistency checks, uncertainty analysis and data quality analysis were included in the report. Details are given below for each of these additions.

2. The report also states, in Section 2.2.7, that "A complete evaluation of the quality of results, according to Phase 4 of the ISO 14044 standard, will allow for a better understanding of these limits." This complete evaluation and some text explaining the better understood limits are missing from the report.

   ellipsos: Limits of the study have now been incorporated in the study in the interpretation section (section 4). They namely include the following topics: noise, odour, human activities (eating, lodging, etc.), soil erosion that is avoided by the plantations, dioxin emissions from plastic in the artificial tree during use and disposal, impacts of fillers contained in PVC. Also, the electricity from China was mostly modeled with electricity from Europe. In addition, the CO2 sequestration as well as fertilizer emissions can vary greatly with environmental conditions (soil content, sun exposure, rainfall, etc.) and add uncertainty to the results. Finally, the results may vary if the analysis is transposed elsewhere since the end of life of the natural tree was modeled according to the specificity of Montreal. The authors believe that, even with these limitations and given the data sensitivity, the conclusion of this study is valid for other locations.

4.2 Impact assessment

1. All the presented results are in relative terms only. It would have been pertinent to give, perhaps in a table, the actual results (in the relevant units). This lack of quantified results impaired the review process.

   ellipsos: The absolute results have been included in the study. In fact, meaningful conclusions were added to the study with respect the results in absolute terms.

2. It is not mentioned in the text that two impact categories are not included in the damage indicators (aquatic acidification, aquatic eutrophication).

   ellipsos: The mention has been added in section 2.2.5. The sentence reads: It is important to note that the problem-oriented impacts for aquatic acidification and aquatic eutrophication are not included in the damage category for ecosystem quality. This results in an underestimation of the impacts for ecosystem quality.

3. It would have been useful to better comprehend the limits of the study to be presented with a table indicating the number of reuses necessary for the artificial tree to be environmentally preferable to the natural tree *per midpoint impact category*.

   ellipsos: A table per midpoint categories was added in section 4.2.3 of the report.

4.3 Coherence analysis

1. In the interpretation phase, ISO recommends a coherence analysis that looks at how the compared systems were modelled, especially were they modelled in a similar and coherent way. Although the systems seemed coherent to the reviewers, a formal coherence analysis is missing from the report.

4.4 Contribution analysis

1. In the contribution analysis of the natural tree life cycle, it is mentioned that uranium is used by multiple unit processes. The review panel finds this surprising, as it would have been expected that uranium is only used in the production of electricity in nuclear power plants. More information should be provided here.

   ellipsos: The reviewers are correct when saying that uranium is only used in the production of electricity in nuclear power plants. Since electricity is called by multiple processes involved in the natural tree life cycle, uranium appears as one of the important contributors to non-renewable energy impacts. The statement "input to multiple processes » was changed for « input to electricity used in multiple processes ».

2. The inclusion of "allocation correction" processes in the contribution table will not be understood by readers of the report who do not have a good understanding of the ecoinvent database. Also, we have no information on where in the natural tree life cycle these processes show up. These processes are associated with wood harvesting in ecoinvent, but the report makes clear that the carbon sequestration is quantified with primary data. Without further information, it is assumed here that there is an error in the model. The error may be that the process used for cogeneration at tree end of life was not stripped of its wood inputs.

   ellipsos: There was indeed an error in the model. The authors thank the reviewers for pointing it out. The wood had been double counted in the model. This was corrected as described above (2.2.e).

4.5 Sensitivity analysis

1. In section 4.1.1, it is stated that "the recycling rates should affect both types of trees at the same rate". Although this is directionally true, the actual quantified rate will be different for both types of trees since the rate is proportional to the mass being recycled and the mass of recycled materials is different for both tree types.

   ellipsos: The sentence now reads: Therefore, the recycling rates should vary in unison. They may, however, affect both types of trees differently since the amounts to be recycled differ.

2. Legends for the figures in the sensitivity analysis section are difficult to interpret, especially since all have mention black bars which are never included in the actual graphics.

   ellipsos: The black bars in the legend do not appear on our screens when viewing the .pdf file. The authors will ensure that this situation does not happen again.

3. The wrong figure was pasted in place of Figure 4.1.

   ellipsos: All figures have been replaced with graphs made outside of SimaPro to improve the graph quality. Figure 4.1 was therefore pasted with the appropriate figure.

4. In the "lead as stabilizer" scenario, it should be mentioned that the apprehended human health impacts of lead as a stabiliser, likely to occur in the use or disposal phase of the product, are not included in the analysis. Had they been included, the counter-intuitive results shown in this section might have been reversed.

ellipsos: See above explanation to question on PVC stabilization (3.9).

5. Section 2.2.6 mentions that, despite the difference in density between PE and PVC, the total mass of needles was kept constant. Section 4.2.2 states the opposite, saying the total mass of needles was brought down to 1.89 kg (PE) from an original 2.808 kg (LDPE).

   ellipsos: The text in section 2.2.6 is an omission. The total mass of PE was indeed reduced to 1.89 kg to compare trees with the same look.

6. The graphic titles should be revised in Section 4.2.3. It is unclear what is meant by "X natural trees used annually".

   ellipsos: Only "Natural tree" now figures in the graphic tile.

7. A sensitivity analysis on emissions from pesticides use for the natural tree system would have been important.

   ellipsos: The emissions from pesticides have now been incorporated in the model. All pesticides are 100% emitted to soil, such as for the "Corn, at farm/ US U" material unit process. See section 2.2.2.2 of the report for details. A sensitivity analysis has been conducted and shows that if no emissions are taken into account, 13% of the impacts on ecosystem quality are omitted. The sensitivity analysis was included in section 4.1.

8. There is some confusion as to the definition of the sensitivity analysis simulations on the recycling rates. In Table 4.1, do steel recycling and cardboard recycling refer to the artificial tree system; and do PE recycling, PP re-use and proportion of incinerated trees refer to the natural tree?

   ellipsos: The recycling rate for steel apply to all steel components except branches. It therefore applies to the artificial tree as well as the stand for the natural tree. The cardboard recycling refers to the artificial tree. The PE recycling rate refers to all PE used for the natural tree: fertilizer and seed bags. It does not apply to PE used for the branches of the artificial tree because this PE is deemed to difficult to separate from the branches' steel. The PP re-use refers to the natural tree. A column in Table 4.1 was added to clarify this simulation.

9. In Section 4.1.3, the results for the High artificial simulation for human health are similar for both systems but are reversed to the original simulation (higher impact for the artificial tree).

   ellipsos: With the changes made to the models, the results for human health are similar for both systems, regardless if the tree weights are varied in one direction or another (±10%). This question does therefore does not apply anymore.

4.6 Uncertainty analysis

No uncertainty analysis was conducted, despite the fact that ISO 14044 (Section 4.4.5) clearly states that "An analysis of results for sensitivity and uncertainty shall be conducted for studies intended to be used in comparative assertions intended to be disclosed to the public."

ellipsos: An uncertainty analysis was included in the report. It is based on the Monte Carlo analysis included in SimaPro. Uncertainties for primary data were modeled with the triangular distribution and uncertainties for estimates were modeled with the rectangular distribution. Values for the limits of these distribution were attributed based on the best of our knowledge, which took data quality into consideration. Results are shown for Mean ± 2SD, which corresponds to a 95% confidence interval.

4.7 Data quality assessment

No data quality assessment was presented in this report. Data quality assessments are crucial both for understanding and for reporting the limits of LCA studies. Particularly, in this study, a data quality analysis would have been very useful considering: 1) the fact that a good part of the quantitative data for the artificial tree (needles, branches and brackets) comes from a student project and measurement errors were indicated as a possibility; and 2) there are a lot of proxies used in the natural tree model (operations at the nursery and in the field for example).

ellipsos: Data quality was addressed in section 2.2.3 of the report. Data quality was evaluated with the Weidema method, adapted by Toffel (Toffel et al., 2004; Weidema et al., 1996).

Please do not hesitate to contact me if you need clarifications on any of the points above. We look forward to receiving your updated report as well as a letter explaining how each of these issues was addressed.

Sincerely,

Pascal Lesage, Eng.

Thank you for your thorough review of our LCA study. It is greatly appreciated. We hope that our answers will match the quality of your review.

ellipsos inc.

Pascal Lesage, Eng.
Sylvatica, Montreal office
7379 St-Hubert
Montreal, Qc. Canada
H2R 2N4

December 15, 2008

Ellipsos Inc.
c/o Mr. Jean-Sébastien Trudel
1030 Beaubien E., Suite 305
Montreal, Qc. Canada
H2S 1T4

Final statement from the critical Review panel of the LCA study "Comparison of Natural and Artificial Christmas Trees (Report 1043-RF2-08)"

Dear Mr. Trudel and co-authors,

The reviewers were glad that you were able to address the issues that we had identified in our letter dated December 8 and feel that the quality of the study has been significantly improved. We consider the study and the approaches and data used therein to be appropriate to meet the goal of the study and support the use of the study for communication to the public on the relative environmental impacts of natural and artificial trees.

There were, however, some details that the reviewers wanted to bring to the author's attention. None imply changing anything to the actual model, but rather affect the way the results are discussed or interpreted:

1. The panel still believes that it would have been more transparent to present the economic flows in Table 2.1 on a "per functional unit" basis.

2. The interpretation of normalized impacts is not entirely correct. The text implies that normalized impact scores can be directly compared to each other, and that e.g. a normalized score of 10 for one impact category would be twice as "important" as a normalized score of 5 for another impact category. Although normalized scores have the same unit (pers-yr in the case of IMPACT2002+), such a direct comparison is not appropriate: normalization factors are based on observed yearly impacts for a given region, not on perceived relative importance of different impact categories. To directly compare the categories, one needs to proceed to the weighting step, which is of course not allowed, according to ISO, for public comparative studies.

3. It is not clear how the +- 2 sd shown on figures 3.8-3.11 and 3.18-21 were calculated, not if or how the DQI presented in Table 2.4 were translated to uncertainty factors for the uncertainty analysis.

4. Section 4.2.3, mentioned in your answer to our first set of comments, is missing.

5. Section 4.6 mentions the emission of dioxins from plastic tree use. It should be clear that this would occur only in the unlikely event of a fire.

6. On Page 23, it should be clearer what the negative contribution to climate change are associated with.

7. The graphs, because of the chosen colour schemes and size of the police, are hard to read.

8. It should be mentioned in the interpretation phase that aquatic acidification and eutrophication are not included in ecosystem quality damage category. This should especially be reminded to the readers when discussing the sensitivity analysis relating to fertilizers emissions.

In closing, I wish to congratulate you on an interesting study and, especially, on your success in reaching so many people with it.

Sincerely,

Pascal Lesage, Eng.

For the critical review panel composed of:

Pascal Lesage, Eng., Ph.D. (Sylvatica, Montreal office)

Jean-François Ménard, Eng. (Ecointesys Life Cycle Systems)

Claude Villeneuve (UQAC)