LIFE CYCLE ASSESSMENT OF OIL PALM SEEDLING PRODUCTION (Part 1)

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ABSTRACT

The oil palm nursery is the first link in the palm oil supply chain where oil palm seedlings are produced for the cultivation of palms in plantations. One seedling is the defined functional unit. This article outlines the environmental impacts, identified using life cycle assessment (LCA), associated with the production of a single seedling, and the proposed mitigation measures. LCA is a cradle-to-gate study which starts at the pre-nursery stage, proceeding to the main nursery before subsequent transplantation of the seedlings in the plantation. An audit on electricity, diesel, fertilizers, pesticides, polybags and water consumption was carried out using data obtained from a questionnaire on the life cycle inventory of seedling production. The information obtained was then verified by follow-up site visits. The life cycle impact assessment (LCIA) was carried out for a single seedling produced, using the SimaPro software version 7.1 and the Eco indicator 99 methodology. Polyvinylchloride (PVC) pipes were also included in the study. Ecotoxicity was found to be the major impact category followed by fossil fuel and respiratory inorganics.

Keywords: nursery, seedling, life cycle inventory, environmental input, life cycle impact assessment.

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INTRODUCTION

The life cycle inventory (LCI) is the most important resource-intensive phase when conducting a life cycle assessment (LCA). LCA is a process tool to evaluate the environmental impacts associated with a product, process or activity by identifying and quantifying energy and materials used as well as waste released into the environment. LCA subsequently evaluates opportunities to effect environmental improvements. A full LCA includes the entire life cycle of a product, process or activity; encompassing extraction and processing of raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal (Birkved and Hauschild, 2006; Yusof and Hansen, 2007; Avraamides and Fatta, 2008).

The oil palm nursery is the starting link in the palm oil supply chain. In 2006, 2007, 2008 and 2009, the average production of germinated oil palm seeds in Malaysia was 66.7, 65.2, 88.2 and 86.4 million, respectively (http://econ.mpob.gov.my). The productivity of an oil palm plantation depends on many factors, and the most important starting point is the quality of the oil palm seedlings derived from cross pollination of selected parent palms for use in planting. The production of high quality oil palm seedlings is very much dependent on good nursery management and practices.

A nursery stage is required because palms require constant close attention during the first 10 to 12 months of their growth and development. A nursery will enable closer supervision over a smaller area, and will facilitate pest control and the culling of undesirable oil palm seedlings.

There are two types of nursery practice – single-stage and double-stage. The technique of raising

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seedlings in large polythene bags (polybags) before transplanting them to the field is known as a single-stage nursery system. However, currently most of the oil palm nurseries are practicing the double-stage nursery system. A double-stage nursery consists of a pre-nursery and a main nursery. In the pre-nursery, seeds are sown in small polybags in which the seedlings are maintained until they are approximately three to four months. These seedlings in the small polybags are kept under shade to protect them from direct sunlight. Later in the main nursery, the seedlings are transplanted into larger polybags and grown without protective shade until they are 10 to 12 months old and are ready for planting in the plantation (Corley and Tinker, 2003; Esnan *et al*., 2004). This practice ensures that well-developed seedlings with optimum vigour at the time of field planting can quickly establish in the field so that the field immature period is minimized and high early yields are obtained.

For the pre-nursery stage, polybags of size 15 cm × 23 cm (6″ × 9″) and of 250 gauge (0.0625 mm) thickness are used. Germinated seeds are planted in these polybags which are placed close to one another so that the young seedlings can be easily managed. This entails easier maintenance in comparison to seedlings in a single-stage nursery. The polybag size used in the main nursery is 30 cm × 38 cm (12″ × 15″) or 38 cm × 45 cm (15″ × 18″) with a thickness of 500 gauge (0.125 mm). These polybags are arranged at 0.9 m × 0.9 m × 0.9 m, or 0.75 m × 0.75 m × 0.75 m, measured centre to centre, to achieve an equal triangular spacing. All seedlings should get sufficient water of 0.5 litre per polybag per day in the pre-nursery, and 1.5-2.5 litre per polybag per day in the main nursery. Watering is normally done twice daily, before 11.00 am and after 4.00 pm (Anon., 2009).

OBJECTIVES

There are two main objectives to this LCA study and they are as follows:

- to identify the potential environment impacts associated with the production of seedlings from cradle-to-gate, and ultimately when linked to the plantation, mill, refinery and production of palm biodiesel in a later part of the study; and
- to use this assessment for evaluating opportunities to mitigate the potential impacts.

The LCA study is outlined in different parts, namely, Parts 1-5. Specific to this article is the use of LCA to identify the stages in the oil palm nursery that could contribute to the environment load.

FUNCTIONAL UNIT

The relevant functional unit of the system was used to provide the seedling with links to upstream plantation, midstream and downstream processing of food and non-foods products. Therefore, the appropriate functional unit for this LCA study of the nursery is a single oil palm seedling.

ALLOCATION OF CO-PRODUCTS

More often than not, a system will yield more than one product. In such cases, allocation must be made for input and output flows for each product. In oil palm seedling production, no allocation is required because the present system produces only one product, *i.e.* a seedling.

SYSTEM BOUNDARY

This LCA study has a cradle-to-gate system boundary, beginning with the transportation of the germinated seeds to the nursery and ending with the transportation of 12-month-old seedlings in big polybags to the plantation. The system boundary includes the production of pre-plantation inputs, *i.e.* the oil palm seedlings in the nursery. The boundary determines which unit processes should be included or excluded in an LCA study. In this study, all processes are considered relevant unless excluded based on the exclusion criteria shown in *Table 1*. *Figure 1* shows the supply chain in oil palm seedling production.

Items Excluded from the Study

Buildings and machinery, road works, road lighting, workers and the production of top soil were not considered.

METHODS

Life Cycle Inventory (LCI)

Foreground data which describe the specific production sub-systems include the production of seedlings. These data for each unit process were collected directly from oil palm nurseries through the use of questionnaires. The input data for each unit process were validated by on-site visits, telephone conversations, on-site measurements, and communication via e-mail and fax.

Life Cycle Impact Assessment (LCIA)

The system boundary for LCIA starts from the germinated seed until the transportation of the

TABLE 1. SYSTEM BOUNDARY DEFINITION CRITERIA

Processing category	Included	Excluded		
		Insignificant environmental impact	Difficult to obtain representative data	Not directly relevant to scope and goal of study
Production of polyvinylchloride for pipes	✓	-	-	-
Production, maintenance and replacement of capital equipment	-	✓	✓	-
Transportation of capital goods	-	✓	✓	-
Production of agricultural inputs, *e.g.* polybags, fertilizers, insecticides, herbicides and fungicides	✓	-	-	-
Disposal of small polybags (15 cm × 23 cm)	-	✓	✓	-
Transportation of polybags, fertilizers, insecticides, herbicides and fungicides	✓	-	-	-
Water supply	✓	-	-	-
Agricultural activities, *e.g.* application of fertilizers, insecticides, herbicides and fungicides; use of polybags	✓	-	-	-
Transportation of germinated seeds to nursery	✓	-	-	-
Land occupation by nursery	-	✓	✓	-
Transportation of seedlings to plantation	✓	-	-	-
Electricity generation	✓	-	-	-
Diesel for running water pump	✓	-	-	-
Production of top soil	-	-	✓	-
Partitioning of pesticides in different compartments	✓	-	-	-
Emissions from the application of pesticides	✓	-	-	-

seedling to the nursery. Modelling of environmental impact was carried out using the software SimaPro version 7.1. Background data for the inputs were sourced from inventory databases, notably the Ecoinvent database developed by the Swiss Centre for Life Cycle Inventory which is included in this software. The LCA methodology used was Eco-indicator 99. This methodology uses the damage-oriented approach or end-point approach for impact assessment. Impact categories considered in this methodology include carcinogens, respiratory organics and inorganics, climate change, ionizing radiation, ozone layer depletion, ecotoxicity, acidification or eutrofication, land use, mineral and fossil fuels. The Eco-indicator set of impacts were used because it comprises a comprehensive set of impacts to meet the requirements of ISO for a range of impact categories.

Co-product

There is no co-product in the production of seedlings.

Capital Goods

In this study, capital goods such as machinery, *e.g.* the water pump for irrigation of the seedlings, had been excluded in the production of seedlings. However, the polyvinylchloride pipes used to

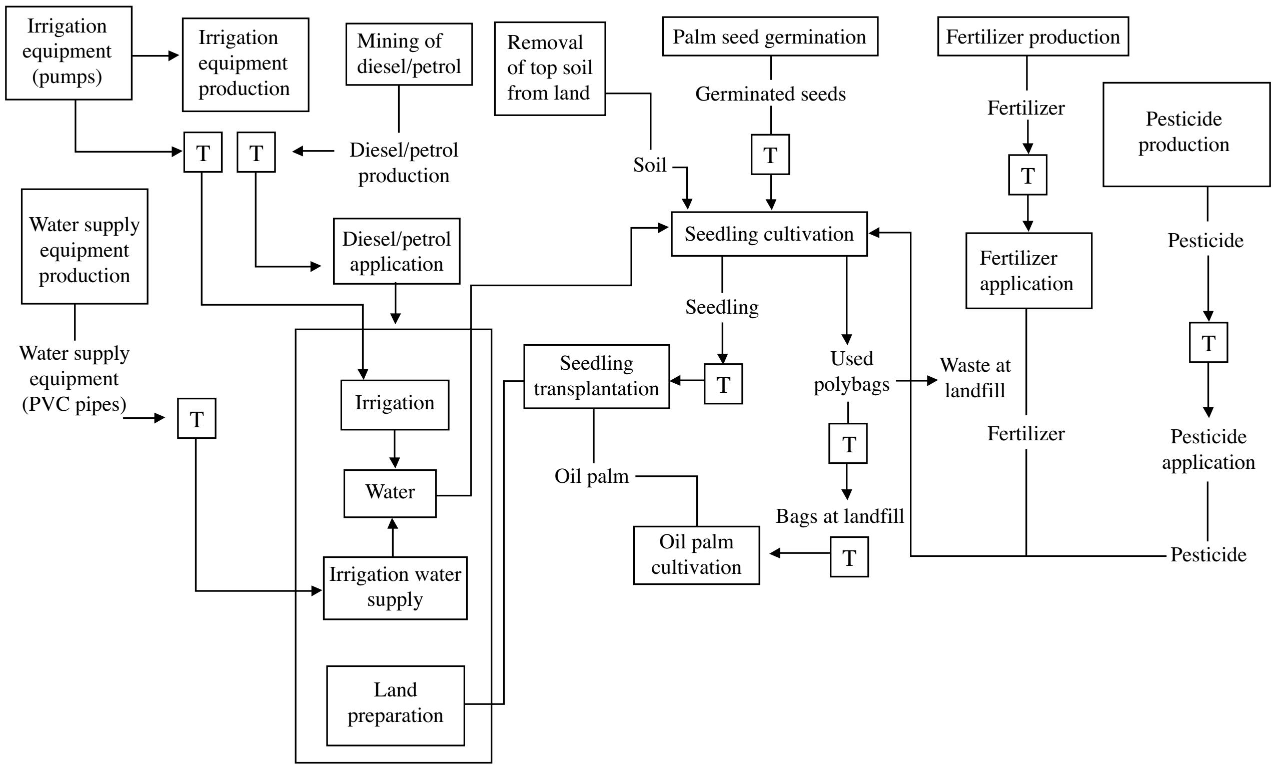

Figure 1. Flow chart for cultivation of oil palm seedlings.

transfer water for watering the seedlings were included in this study.

RESULTS

Life Cycle Inventory (LCI)

Twenty-one oil palm nurseries licensed by the Malaysian Palm Oil Board (MPOB) were selected for collection of inventory data for the production of oil palm seedlings in nurseries. These oil palm nurseries, located in Peninsular Malaysia, practised the double-stage nursery system. Questionnaires were posted to the operators of the nurseries and one selection criterion, based on the average value of a 25-year economic life for one cycle of an oil palm tree (Corley and Tinker, 2003), was adopted. Inventory data were collected from the oil palm nurseries over a period of four years (from 2004 to 2007).

Annual inventory data collected from the identified 21 nurseries over a four-year period were analyzed. One of the most time-consuming exercises is the LCI data collection, and this was carried out with the co-operation of nursery owners and stakeholders (Sime Darby Sdn Bhd, United Plantation Sdn Bhd, FELDA, *etc.*). *Table 2* shows the averaged inputs for a single seedling based on

TABLE 2. AVERAGED LIFE CYCLE INVENTORY (LCI) FOR THE PRODUCTION OF A SINGLE SEEDLING

Input	Amount
Electricity (kWhr)	0.006 (0.22 MJ)
Diesel (litre)	0.004 (0.15 MJ)
Polybag (kg)	2.10E-03
Water (litre)	1.5
Fertilizers	
N (kg)	5.10E-04
P_2O_5 (kg)	2.60E-04
K_2O (kg)	2.10E-04
Pesticides	
Thiocarbamate (kg)	1.12E-05
Pyrethroid (kg)	3.54E-06
Organophosphate (kg)	2.00E-05
Dithiocarbamate (kg)	9.61E-05
Unspecified pesticide (kg)	1.35E-06
Urea/sulfonyl urea (kg)	2.17E-05
Glyphosate (kg)	8.90E-06
Transportation (tkm)	6.47E-09
Van (< 3.5 t) B250	
Capital good	
Polyvinylchloride (kg) for pipes	0.000713

data obtained from the 21 oil palm nurseries. Input energy such as electricity and fossil fuel, materials (polybags), plant nutrition (fertilizers) and plant protection chemicals (herbicides, fungicides and insecticides) were considered. Energy used for machinery to water the seedlings, transportation of germinated seeds to the nursery, transportation of the seedlings to the plantation, transportation of fertilizers, insecticides, herbicides, fungicides and polybags from the port to the nursery were included in the inventory.

Table 2 shows the transportation required for the production of an oil palm seedling. In the computation of the environmental burden for seedling production, all distances were considered as half of a round trip, and the delivery van (<3.5 t) loads were considered full load weights. Data on delivery van weights and distances were obtained through responses to the distributed questionnaires and also through dialogues with stakeholders.

Electrical energy (electricity) from the national grid and fossil fuel (diesel) were used as power sources to run the pump for watering the seedlings in the oil palm nurseries. According to the inventory data, the amount of diesel and electricity needed to produce one seedling was 0.004 litre and 0.006 kWhr, respectively. The inventory data also revealed that the amount of polybags needed to produce one seedling was 2.10×10^{-03} kg. Most insecticides, herbicides and fungicides are only applied in oil palm nurseries during the time of specific pest attacks. From this LCA study, we found that the major infestation in the oil palm seedlings was by fungi. The commonly used fungicides in the oil palm nurseries were mancozeb, thiram, carbendazim, maneb and dithane (collectively classified under dithiocarbamates). The other pesticides used in order of frequency were sulfonylurea urea (herbicide) and organophosphates (insecticide). The total quantity of pesticides used was very low at 1.63×10^{-04} kg per seedling. For the production of one seedling, the nurseries used 9.8×10^{-04} kg of NPK fertilizers.

Materials such as fertilizers, insecticides, herbicides, fungicides and polybags are transported to the nursery for the production of the single oil palm seedling. Transportation includes delivery of the germinated seeds to the nursery, of the seedlings to the plantation, and of fertilizers, insecticides, herbicides, fungicides and polybags from the port in Malaysia to the nursery. The total amount was found to be 6.47×10^{-09} tkm. In general, the sum total of inputs needed to produce one seedling from the nursery was quite low.

According to the data obtained through the distribution of questionnaires and confirmed by evidence collected during on-site visits, water, fertilizers and pesticides were required to produce healthy oil palm seedlings. Among the pesticides used, dithiocarbamates were the most commonly used in the oil palm nursery. Fertilizers were manually applied. However, some nurseries used a drip system for supplying seedlings (less than four months old) with a pre-mixed fertilizer solution. Water for seedlings was mostly sourced from nearby rivers with catchment ponds. When rainfall was sufficient (enough to wet the soil in the polybag), watering was not carried out. Irrigation was by sprinklers powered by diesel pumps or electric pumps using electricity from the grid.

Table 3 shows the data type and source in the nursery system for transportation and production of fertilizers, polybags, pesticides, seedlings and water. The table also shows where the input data were obtained, and whether they were from background or foreground data sources, and whether they were taken from the Ecoinvent database or from the Malaysian data base (SIRIM). Foreground data for each unit process were collected directly from the oil palm nurseries through the questionnaires. The input data for each unit process were validated by on-site visits, telephone conversations, on-site measurements, and communication via e-mail and fax. Foreground data included information on field electricity generation and diesel used to run pumps, and consumption of water for irrigation of the oil palm seedlings in the nursery. Direct pesticide application, oil palm seedling cultivation and transportation were considered foreground data. Transportation of raw materials such as fertilizers, insecticides, herbicides, fungicides and polybags to nurseries were also included in the nursery stage as foreground data.

Background data which included information on generic materials were collected from published sources or proxies, *i.e.* the same operation but in another country. Some of the data were obtained from literature and public databases, or calculated using published models. Generally, data on the production of raw materials such as fertilizers, insecticides, herbicides and fungicides for the inputs were obtained from the Ecoinvent database, while data on the application of the raw materials were obtained from the questionnaires. However, electricity and polybag production were from Malaysian-based (SIRIM) data. It is to be noted that some inflows and outflows were not included in this system boundary because of difficulty in quantification, and these have been shown in *Table 1*.

The LCI data for the nursery were reviewed by the LCA Technical Working Group, the LCA Technical Committee and the National Committee on LCA Studies for the Oil Palm Industry which comprises representatives of the stakeholders, SIRIM Berhad and the MPOB LCA team. These review meetings checked the quality of the

TABLE 3. DATA SOURCE FOR NURSERY SYSTEM

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*)/ Data source
Electricity production	Mining and extraction of fossil fuels	Energy conversion	Distribution to the grid at the point of use	B/Malaysian data from SIRIM
Irrigation water supply	Water from surface water	Physical	Water at nursery	B/site specific data
Irrigation	Water at nursery	Physical	Water applied to germinated seeds/seedlings	F/site specific data
Fertilizer production N, P_2O_5 and K_2O	Acquisition of raw materials	Chemical processing	Fertilizers at the production unit gate	B/Ecoinvent database
Transportation of fertilizers N, P_2O_5 and K_2O to nurseries (includes intermediate storage and retailing)	Collection of fertilizers from port in Malaysia to nursery	Physical	Delivery of fertilizers to nursery	F/site specific data
Application of fertilizers N, P_2O_5 and K_2O (includes incorporation into soil at the recommended dosage)	Fertilizers stored at nursery	Physical	Fertilizers into soil	F/site specific data
Production of insecticides thiocarbamate, pyrethroid and organophosphate	Acquisition of raw materials	Chemical processing	Pesticides at the production unit gate	B/Ecoinvent database
Transportation of insecticides thiocarbamate, pyrethroid and organophosphate to nurseries (include intermediate storage and retailing)	Collection of pesticides from port in Malaysia to nursery	Physical	Delivery of pesticides to nursery	F/site specific data
Application of insecticides thiocarbamate, pyrethroid and organophosphate (including preparations for application at the recommended dosage)	Pesticides stored at nursery	Physical	Pesticides applied to seedlings	F/site specific data
Herbicide production; unspecified herbicide (glufosinate ammonium, urea/sulfonylurea and glyphosate)	Acquisition of raw materials	Chemical processing	Herbicides at the production unit gate	B/Ecoinvent database
Transportation of herbicides; unspecified herbicide (glufosinate ammonium, urea/ sulfonylurea and glyphosate) to nurseries (includes intermediate storage and retailing)	Collection of herbicides from port in Malaysia to nursery	Physical	Delivery of herbicides to nursery gate	F/site specific data

TABLE 3. DATA SOURCE FOR NURSERY SYSTEM (continued)

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*)/ Data source
Application of herbicides; unspecified herbicide (glufosinate ammonium, urea/sulfonylurea and glyphosate) (including preparations for application at the recommended dosage)	Herbicides stored at nursery	Physical	Herbicides applied to soil	F/site specific data
Fungicides production: dithiocarbamate	Acquisition of raw materials	Chemical processing	Fungicides at the production unit gate	B/Ecoinvent database
Transportation of fungicides; (dithiocarbamate) to nurseries (includes intermediate storage and retailing)	Collection of fungicides from port in Malaysia to nursery	Physical	Delivery of fungicides to nursery gate	F/site specific data
Application of fungicides (dithiocarbamate) (including preparations for application at the recommended dosage)	Fungicides stored at nursery	Physical	Fungicides applied to soil	F/site specific data
Polybag production	Acquisition of raw materials	Chemical processing	Polybags at the production unit gate	B/SIRIM database
Transportation of polybags to nurseries (includes intermediate storage and retailing)	Collection of polybags from port in Malaysia to nursery	Physical	Delivery of polybags to nursery gate	F/site specific data
Use of polybags	Polybags stored at nursery	Polybags stored at nursery	Polybags used at nursery	F/site specific data
Top soil supply	Acquisition from land	Physical	Soil for seedling cultivation	B/literature (Turner and Gillbanks, 2003)
Transportation of top soil to nurseries (includes intermediate storage and retailing)	Collection of top soil from estate or contractor to nursery	Physical	Delivery of top soil to nursery gate	F/site specific data
Oil palm seedling cultivation	Acquisition of oil palm germinated seeds	Biological	10- to 12-month-old oil palm seedlings for planting in plantations	F/site specific data

Note: *B/F = background/foreground.

data before the subsequent phases of LCIA and improvement analysis.

Life Cycle Impact Assessment (LCIA)

Figures 2 and *3* show the weighted and characterized results of LCIA for the production of a single seedling. Ecotoxicity was found to be the major impact category, followed by fossil fuel and respiratory inorganics. The ecotoxicity impact was mainly due to emissions from pesticides used for the control of fungi, insects and weeds infesting oil palm seedlings at the nursery stage.

Therefore, the use of bio-pesticides may have the potential to reduce this impact and should be further assessed as an alternative. The other hot spot in the production of seedlings was the use of diesel for irrigating the seedlings, and this is reflected in the impact from fossil fuel and respiratory inorganics.

CONCLUSION

In general, the production of seedlings in the nursery has an insignificant impact on the

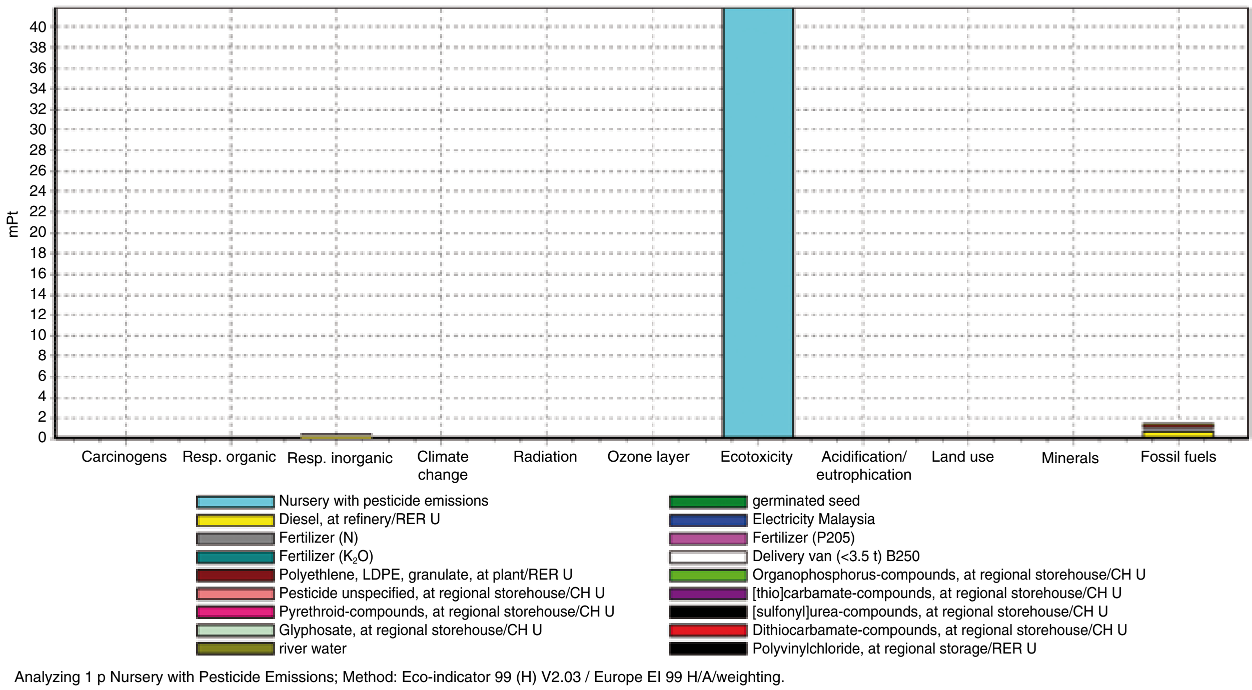

Figure 2. Weighted results in life cycle impact assessment (LCIA) for the production of a single seedling.

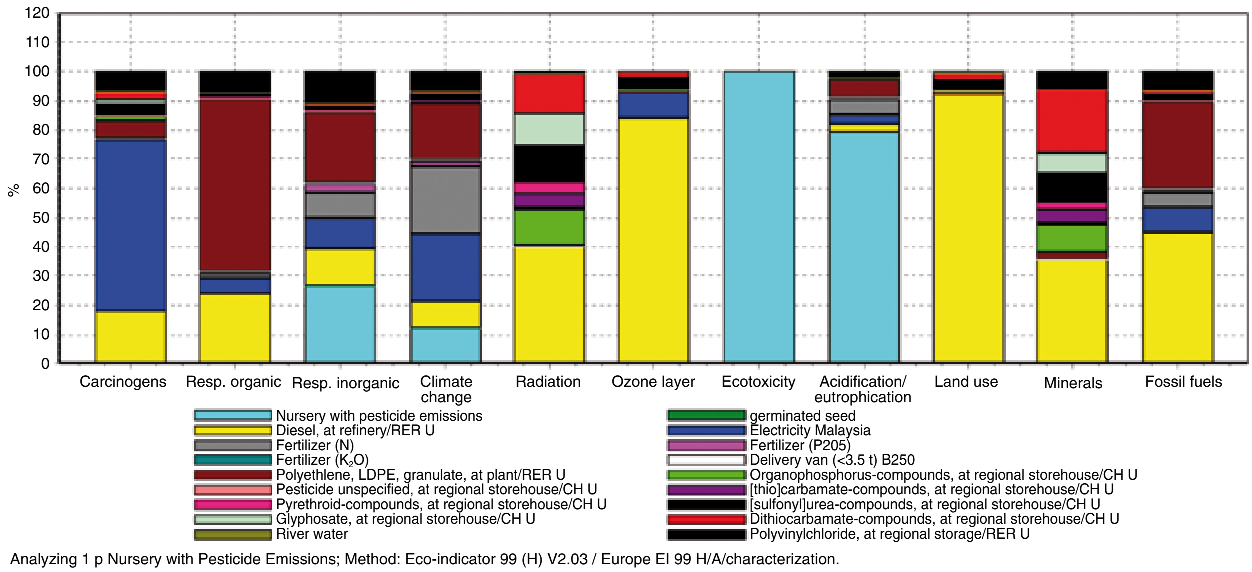

Figure 3. Characterized results in life cycle impact assessment (LCIA) for the production of a single seedling.

environment. It is to be noted that land occupation by the nursery has been not been modelled into this LCA study.

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