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Life Cycle Assessment in the production of young budding of rubber in Peninsular Malaysia

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A study on the life cycle assessment (LCA) for the production of two whorl young budding in polybag (TWYBP) was carried out to compile an inventory of materials and energy balance as well as to identify and quantify the environmental impact associated with it. The study was conducted using LCA methodology involving 32 rubber nurseries in Peninsular Malaysia. The life cycle impact assessment (LCIA) study was conducted using Simapro Software version 7.3.3 with Eco-indicator 99 as the selected LCIA methodology. Production of diesel was found to be the main contributor to the ozone layer, land use and fossil fuels characterisation impact categories with contribution percentage of 85.7%, 61.1% and 54.9% from the total impact of the respective characterisation results. Fossil fuels impact category recorded the highest impact for the weighing results, followed by respiratory inorganic, carcinogens and climate change. Fossil fuels recorded 63.2% while another seven impact categories i.e. *acidification/eutrophication, land use, ecotoxicity, minerals, radiation, respiratory organics and ozone layer recorded less than 1% each from the total value of the 11 weighting impact categories. Production of diesel and polybags were the two processes that contribute greatly toward the total environmental impact in the production of TWYBP. The diesel and polybag consumption in the production of TWYBP can be reduced by increasing the bud-grafting success rate in the form of training on the correct bud-grafting technique for the rubber nursery workers, proper selection of good quality seedlings from recommended clones and selection of good quality bud-patches from recommended clones to be grafted to young rootstocks.*

Keywords: Young budding in polybag; rubber bud-grafted; rubber nursery; life cycle assessment; life cycle impact assessment

Life cycle assessment (LCA) is an environmental management tool that enables quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity[1]. LCA has been widely used to quantify environmental loads and their impacts on the environment and to identify significant activities and inventory items that cause stress on the environment occurring in the entire life cycle of a product[2]. LCA can be used to trace the direct impacts as well as impacts associated with a product throughout the entire life cycle from cradle to grave in order to get a holistic overview of the environmental burden associated with the products[3]. LCA is also one of the essential environmental management tools for developing and implementing strategies towards overall process optimisation, preservation of environment, environmental labels and design for the environment[4].

LCA will be a very important methodology in the near future due to the general public and industry awareness on the sustainability issues related to the product that they consume and with the introduction of more stringent environmental laws worldwide. In the Europe, LCA is a cornerstone of the European Integrated Product Policy, the Thematic

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Strategy on the Prevention and Recycling of Waste and the Sustainable Use of Natural Resources[5].

The government of Malaysia in its Ninth Malaysia Plan (2006-2010) has mandated the Standards and Industrial Research Institute of Malaysia (SIRIM) to develop a National Life Cycle Inventory Database for primary industries and activities to facilitate efforts by industries to develop LCAs in their productions and manufacturing processes, leading to the promotion of environmentally sound technologies and adaptation of self-regulatory measures[6].

A rubber nursery can be considered as a factory producing planting materials for transplanting into the field[7]. As of March 2011, there are 159 licensed rubber nurseries in Peninsular Malaysia and 103 of these licensed rubber nurseries are actively producing planting materials with a total combined area of 1431.6 hectares[8]. The commonly produced planting materials by the rubber industries are in the form of young buddings in polybags (YBP), bare root budded stumps, budded stump in polybags and green budsticks[8,9]. A total of 19.367 million polybags were produced by rubber nursery operators in Malaysia for 2011 and young buddings in the polybags are the most popular form of planting materials representing 69.8% from the total production of polybags[8].

In line with the global awareness on climate change and in order to achieve the goal of sustainability in the Malaysian rubber industry, the Malaysian government through Malaysian Rubber Board (MRB) has formulated a strategy to promote the green image of Malaysian natural rubber through promoting LCA methodology as one of the strategies in the One Nation Rubber Strategy[10]. The objective of this strategy is to make sure that by 2020 the national average data on LCA will be available for the whole sectors to be used as a guide in formulating strategies to reduce environmental impacts from the whole sectors of the rubber industry[10].

The study on LCA for the whole sectors of rubber industry in Malaysia is important in order to enhance the competitiveness of the Malaysian rubber industry. It is important as Malaysian rubber industry is an export based industry. The current business trends especially in the developed countries market which emphasise on green credentials and certain regulations that require full disclosure of products environmental impact are also on the rise worldwide. With this in mind, the LCA study on the production of young buddings will be the first step towards the overall goal of quantifying the environmental impacts from all sectors of the Malaysian rubber industry.

The LCA methodology is relatively a new approach and the study on the LCA for the production of two whorl young budding in polybags (TWYBP) by the rubber nurseries will be the first study conducted in Malaysia with the objective to compile an inventory of materials and energy balance as well as to identify and quantify the environmental impact from the production of TWYBP.

MATERIALS AND METHODS

A total of 32 rubber nurseries in Peninsular Malaysia took part in this study and these respondents represent 29.1% from the total number of licensed rubber nurseries in Peninsular Malaysia. The LCA study for this work was carried out according to *ISO 14040* and *ISO 14044*. The scope of this study was to perform a gate to gate approach on the production of TWYBP within the boundaries of the rubber nurseries and the defined system boundary for this study is simplified in *Figure 1*.

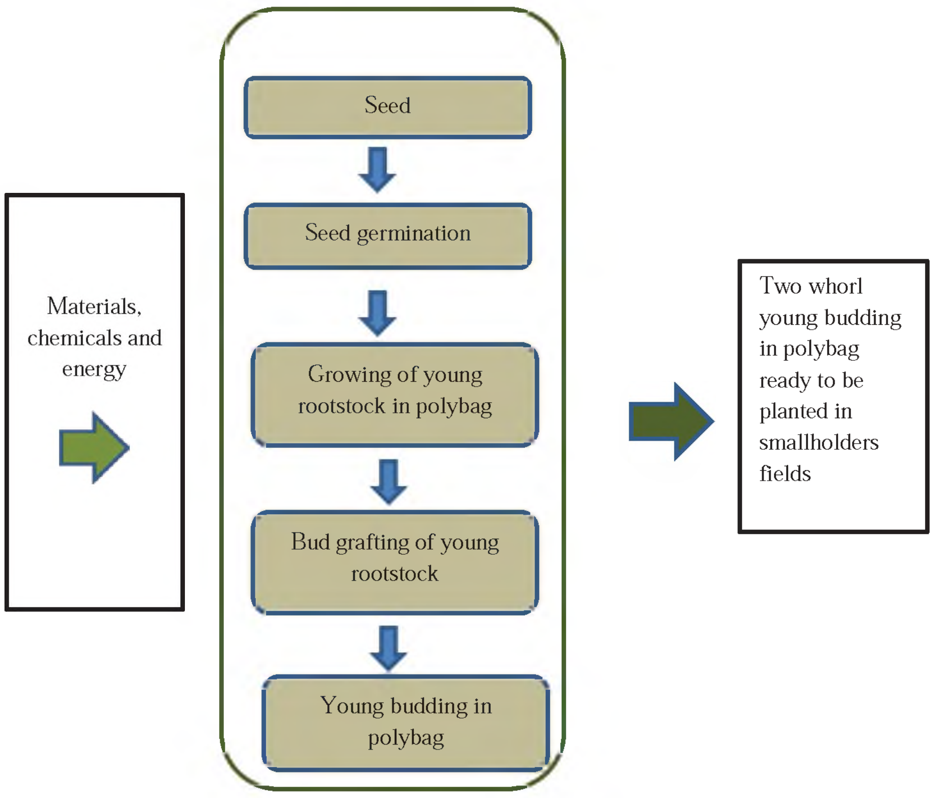

Figure 1. The define system boundary for the production of two whorl young buddings in polybags.

The functional unit for this LCA study *i.e.* the quantified performance of a product system for use as a reference unit as defined by International Standard Organisation[11] was based on the quantity of the TWYBP produced by the rubber nurseries ready to be planted at small holders' field. For this study, it was assumed that there was no significant quality differences of the TWYBP produced from all the respondents that took part in this study. The two types of data involves in this study are foreground and background data. The foreground data for this study were collected directly from the rubber nursery operators through a detailed questionnaire survey. The foreground data cover the information on the agronomic practices, fertilizers and plant protection application, diesel consumption for running water pump and water consumption for irrigation. The foreground data from the survey were verified during the site visits to the majority of the respondents. For rubber nurseries which were not visited during this study, the foreground data were verified through email and telephone communication. The verified foreground inventory data from the survey were then analysed and summarised into Life Cycle inventory (LCI) table based on the production of one polybag of TWYBP. Life Cycle Impact Assessment (LCIA) study was conducted using Simapro version 7.3.3 software with Eco-indicator 99 as the selected LCIA methodology using data from the LCI table. Background data for the inputs for this study were sourced from Ecoinvent database version 2.2, Industrial Data 2.0 database and LCA Food DK database which is embedded within the Simapro software and also from

TABLE 1. DATA SOURCES FOR THE PRODUCTION OF TWYBP

Process	Data type	Data source	Process description	
			Start	End
Application of fertilizers based on standard operating procedure	Foreground	Site specific data	Fertilizer stored at the nursery	Fertilizer added into top soil in the polybags
Production of N fertilizer	Background	LCA Food DK database	Raw materials and energy inputs	N fertilizer at the production unit process
Production of P205 fertilizer	Background	LCA Food DK database	Raw materials and energy inputs	P205 fertilizer at the production unit process
Production of K20 fertilizer	Background	LCA Food DK database	Raw materials and energy inputs	K20 fertilizer at the production unit process
Production of Phosphate rock as P205	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Phosphate rock as P205 at the production unit process
HDPE Resin E production	Background	Industry Data 2.0 database	Raw materials and energy inputs	HDPE Resin E at the production unit process
Production of Magnesium oxide at plant	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Magnesium oxide at plant at the production unit process
Application of fungicide/insecticide based on standard operating procedure	Foreground	Site specific data	Fungicide/ insecticide stored at nursery	Fungicie/insecticide applied to planting material
Active ingredients for the fungicide/ insecticide and its percentage	Background	Publicly access government database by Pesticide Board Malaysia[12].	Identification of fungicide/ insecticide brand name	Identification of fungicide/insecticide active ingredients and its percentage.
Production of mancozeb	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Mancozeb at the production unit process
Production of chlorothalonil	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Chlorothalonil at the production unit process
Production of insecticide	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Insecticide at the production unit process
Production of diesel	Background	Ecoinvent version 2.2 database	Raw materials and energy inputs	Diesel at the production unit process

Pesticide Board, Department of Agriculture Malaysia online database[12]. The data types and sources for this work are summarised in *Table 1* based on template by Halimah *et al.*[13] while the list of activities excluded from this study is shown in *Table 2*.

RESULTS

Life Cycle Inventory

The LCI table quantifying the average inputs values for the production of one polybag of TWYBP for this study is shown in *Table 3*.

Life Cycle Impact Assessment (LCIA)

LCIA assesses the life cycle inventory results based on a specific goal and scope with the aim of improving understanding on their potential environmental significance. In general LCIA can be classified into two steps *i.e.* mandatory steps which include elements of classification and characterisation and optional step which include elements of normalisation, grouping and weighting[11].

In the characterisation step, the inventory data within each impact category will be multiplied by a characterisation factor to

TABLE 2. LIST OF ACTIVITIES EXCLUDED FROM THE SYSTEM BOUNDARY

Activities	Reasons for exclusion
1. Land clearing for nursery establishment	i) It is a one-off activity involving some elements of fuel through the use of machineries but difficult to quantify the amount. ii) The amount of fuel used is insignificant as only one time land clearing is needed and the nurseries can be used for many years. iii) Considered as capital goods as defined by Sumiani[3].
2. Construction of rubber germination bed	i) The construction of germination beds consist of a very simple and basic structure containing layer of sawdust on top of a layer of sand which can be reused many times. ii) Considered as capital goods as defined by Sumiani[3].
3. Extraction of top soil to fill up the polybags and transportation of top soil from the source to nurseries.	i) Difficult to obtain data and considered as outside of the scope of this study. ii) Considered as an environmentally insignificant as it can be translated as a process of transferring the top soil from the source to the nurseries and finally moved from the nurseries and buried permanently at the smallholders holdings together with the young buddings.
4. Air emissions from diesel combustion engine use to run water sprinkler system in the nurseries	i) Difficult to obtain data due to unavailability and inaccessibility of specific equipment during the study and the amount is predicted to be insignificant towards environmental impact based on literature data of oil palm seedlings by Halimah *et al.*[14].
5. Production of bud patches used in the bud grafting process	i) The weight of bud patch was less than 0.05% from the total weight of young rootstock and cut off criteria was applied for the bud patch used in the bud grafting process of young rootstock as allowed in ISO[15].
6. Production of transparent polyethylene tape used to wrap bud patches to young rootstocks in the bud grafting process.	i) The weight of transparent polyethylene tape was less than 0.05% from the total weight of young rootstock and cut off criteria was applied for the transparent polyethylene used in the bud grafting process of young rootstock as allowed in ISO[15].

TABLE 3. LCI TABLE FOR THE PRODUCTION OF ONE POLYBAG OF TWYBP.

Input	Unit	Average value
Polybag	Kg	0.0130
N fertilizer	Kg	0.0042
P205 fertilizer	Kg	0.0042
K20 fertilizer	Kg	0.0039
Rock Phosphate fertilizer	Kg	0.0790
Magnesium oxide from Yellow NPK Compound fertilizer	Kg	0.0010
Fungicide with 80% w/w mancozeb as active ingredient	Kg	0.0009
Fungicide with 50% w/w chlorothalonil as active ingredient	Kg	0.0002
Insecticides (various active ingredients)	Kg	0.0003
River water	M3	0.2227
Diesel	L	0.0399

differentiate the substances based on their severity[16]. The characterisation result for the production of one polybag of TWYBP is shown in *Figure 2*.

Production of diesel was the highest and second highest contributor to 9 out of 11 characterisation impact categories as shown in *Figure 2*. Production of diesel was found to be the main contributor to the ozone layer, land use and fossil fuels impact categories with contribution percentage of 85.7%, 61.1% and 54.9% from the total impact of the respective impact categories. Diesel production also contribute significantly towards the respiratory organics, respiratory inorganics, climate change, radiation, ecotoxicity, acidification/ eutrophication and minerals impact categories as shown in *Figure 2*. In the production of TWYBP, diesel was used to run refurbished vehicle diesel engine. This refurbished diesel engine is used to pump water from the river into the nursery water sprinkler system for watering the planting material at various stages of growth.

HDPE resin E production was the major contributor to two characterisation impact categories *i.e.* carcinogens and respiratory organics with contribution of 72.8% and 49.0% respectively. The production of HDPE resin E also contributed significantly to climate change and fossil fuels impact categories at the rate of 23.2% and 30.9% respectively. HDPE resin E in this study represents the raw material used in the production of the polybags as their production was not available in the Simparo 7.3.3 databases. Polybag is an essential item in the production of TWYBP as the germinated seeds are planted in the polybags containing top soil before they grow into TWYBP.

Production of rock phosphate fertilizer was a major contributor to the radiation and respiratory inorganic characterisation impact categories at 33.4% and 27.9% respectively (*Figure 2*). Rock phosphate fertilizer was also the second biggest contributor to land use impact category at 34.3% from the total impact. Based on the survey data, only 37.5% from the total number of rubber nurseries in this study used rock phosphate in their standard operating procedure. This fertilizer was mixed with the top soil in bulk before the mixture was filled into the polybags which were then ready to receive germinated rubber seeds. This fertilizer is considered as an extra because many rubber nursery operators think

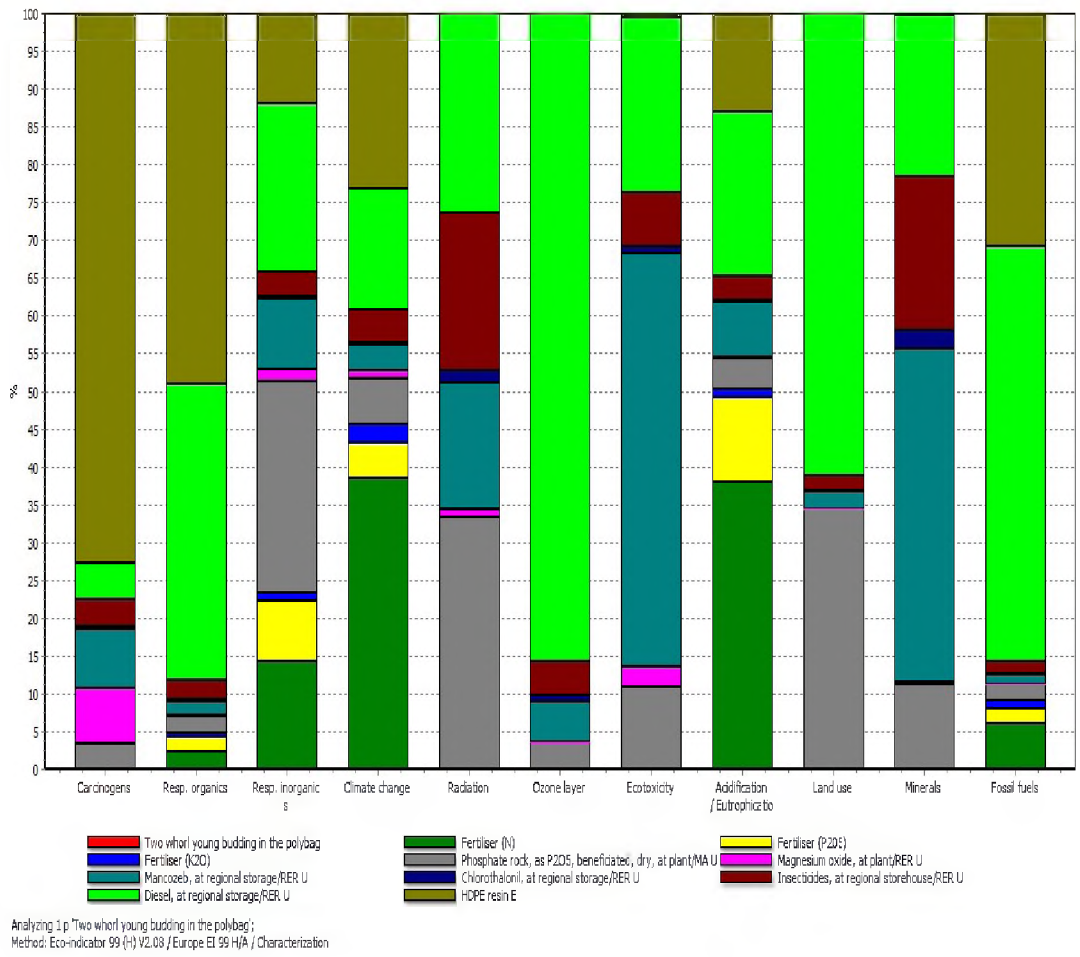

Figure 2. Characterisation results in LCIA for the production of one polybag of TWYBP.

that they can do without it since the nutrients in the top soil plus the NPK fertilizers are adequate. The use of this extra fertilizer may incur an additional cost to the rubber nursery operators.

Fertilizer N production is the biggest contributor to the climate change and acidification/eutrophication impact categories with contribution of 38.6% and 37.9% of the respective impact categories (*Figure 2*). All rubber nurseries in this study used NPK compound fertilizer as the main fertilizer in their standard operating procedure. There are two types of NPK compound fertilizer used by the rubber nurseries in this study with 27 rubber nurseries using NPK green compound fertilizer while the rest used NPK yellow compound fertilizer in their operation.

Mancozeb production was the main contributor to ecotoxicity and minerals impact categories (*Figure 2*). Mancozeb production contributes 54.6% from the total impact of ecotoxicity and 44.1% from the total impact of minerals. A total of 27 rubber nurseries in this study used fungicide with 80%w/w mancozeb as active ingredients to protect the planting material from fungi infection.

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value choice[15]. The weighting factor in Eco-Indicator 99 is based on opinion from 82 members of the Swiss platform on LCA (questionnaire survey) who assigned 40% importance to human health, 40% importance to ecosystem quality and 20% importance to resources[3].The weighting results for the production of one polybag of TWYBP are shown in *Table 4*.

Fossil fuels impact recorded the highest impact, followed by respiratory inorganics, carcinogens and climate change for the weighting results as shown in *Table 4*. Fossil fuels impact represents 63.2% from the total value of 11 weighting impact categories (*Table 4*). Another seven impact categories *i.e.* acidification/eutrophication, land use, ecotoxicity, minerals, radiation, respiratory organics and ozone layer contribute less than 1% from the total value of the 11 weighting impact categories. Ozone layer impact recorded the lowest value at 8.67E-07 point representing 0.01% from the total 11 impact categories.

The two major process contributors in the weighting stage are diesel production and HDPE resin E production as shown in *Figure 3*. Diesel production contributes 41.3% from the total value of the 11 weighting impact categories while HDPE resin E production contributes 29.7% from the total value of the 11 weighting impact categories (*Figure 3*).

DISCUSSIONS

Based on the LCIA results for characterisation and weighting, production of diesel and HDPE resin E play a major role towards environmental impact in the production of TWYBP. These environmental impacts can be reduced through the reduction of diesel consumption and the usage of polybags by the rubber nursery operators. One possible option for the rubber nursery

TABLE 4. WEIGHTED VALUES FOR THE PRODUCTION OF ONE POLYBAG OF TWYBP

Impact Category	Unit	Value	Percentage from Total Impact Categories Value (%)
Carcinogens	Pt	0.00161	8.76
Respiratory organics	Pt	7.02063E-06	0.04
Respiratory inorganics	Pt	0.00371	20.09
Climate Change	Pt	0.00010	5.47
Radiation	Pt	8.47127E-06	0.05
Ozone layer	Pt	8.66925E-07	0.01
Ecotoxicity	Pt	0.000122	0.66
Acidification/Eutrophication	Pt	0.00016	0.86
Land use	Pt	0.00014	0.77
Minerals	Pt	1.89845E-05	0.10
Fossil fuels	Pt	0.01166	63.20

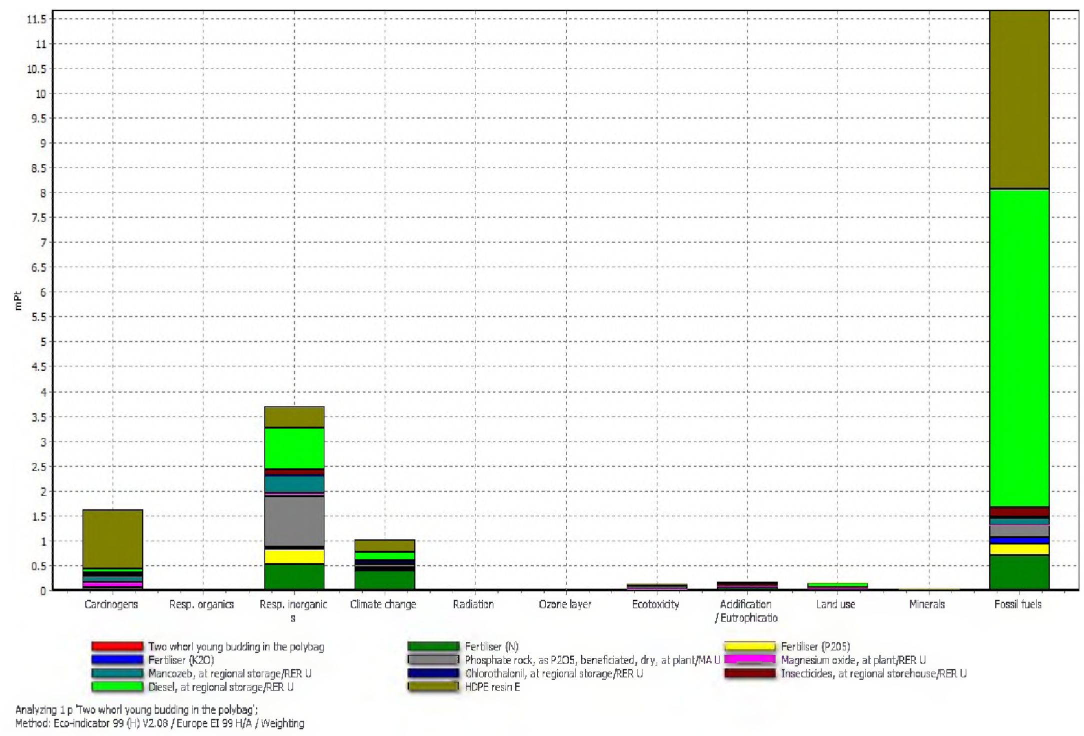

Figure 3. Weighting results for the production of one polybag of TWYBP.

operators to reduce the amount of diesel used in the production of TWYBP is through employing very experienced and skilled grafters. By employing very experienced and skilled grafters, the bud grafting success rate can be increased up to 92.3%[17]. The selection of good quality seedlings from recommended clones to produce young rootstocks and good quality bud patches to be grafted to young rootstocks will also definitely enhance the bud grafting success rate. The increase in the bud grafting success rate will reduce the number of discarded young rootstocks in the polybags that failed the bud grafting process and this will lead to overall reduction in the amount of diesel used and number of polybags needed to produce TWYBP.

Based on the survey data, 40.6% of rubber nursery operators in this study recorded the bud grafting success rate of below 80% due to difficulty in getting very experienced and skilled grafters. A possible way to overcome the problem of getting skilled grafters is by requesting the rubber related agencies such as MRB to organise a training session specifically for grafters as these agencies normally have expertise in this area.

Another way to reduce the diesel consumption in the production of TWYBP is through the reduction of the growth period of these planting materials. The TWYBP which can be produced in six months will definitely use less diesel in the watering process as compared to 12 months needed to produce TWYBP. Based on the survey data, the range to produce TWYBP from individual rubber nursery operator varied between 6 to 12 months. From the total number of rubber nursery operators in this study, 31.3% recorded more than nine months to produce TWYBP.

Certain agronomic practices that can lead to shorter period in producing the TWYBP need to be identified in order to reduce the impact of it to the environment. The identification of these agronomic practices however, was not carried out due to time limitation and being outside the scope of this study.

Sensitivity Analysis

Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the results of the LCIA[15].

Sensitivity Analysis Based on Type of Polybag

A sensitivity analysis was carried out to assess the assumption used in this study that all the polybags used are based on high density polyethylene (HDPE). During the survey verification study visit, it was observed that only a few rubber nursery operators use low density polyethylene (LDPE) polybags in their operations while the majority of them are using the HDPE polybags due to its durability. Results from this LCIA study was compared with that from the usage of LDPE resin E as polybag raw material for the production of TWYBP. The weighted result for this sensitivity analysis is shown in *Figure 4* and *Table 5*.

Based on *Figure 4*, the environmental impact from the production of one polybag of two whorl young budding using the HDPE polybag in this study is relatively comparable with the production of one polybag of two whorl young budding using LDPE polybag with both scenarios were observed following

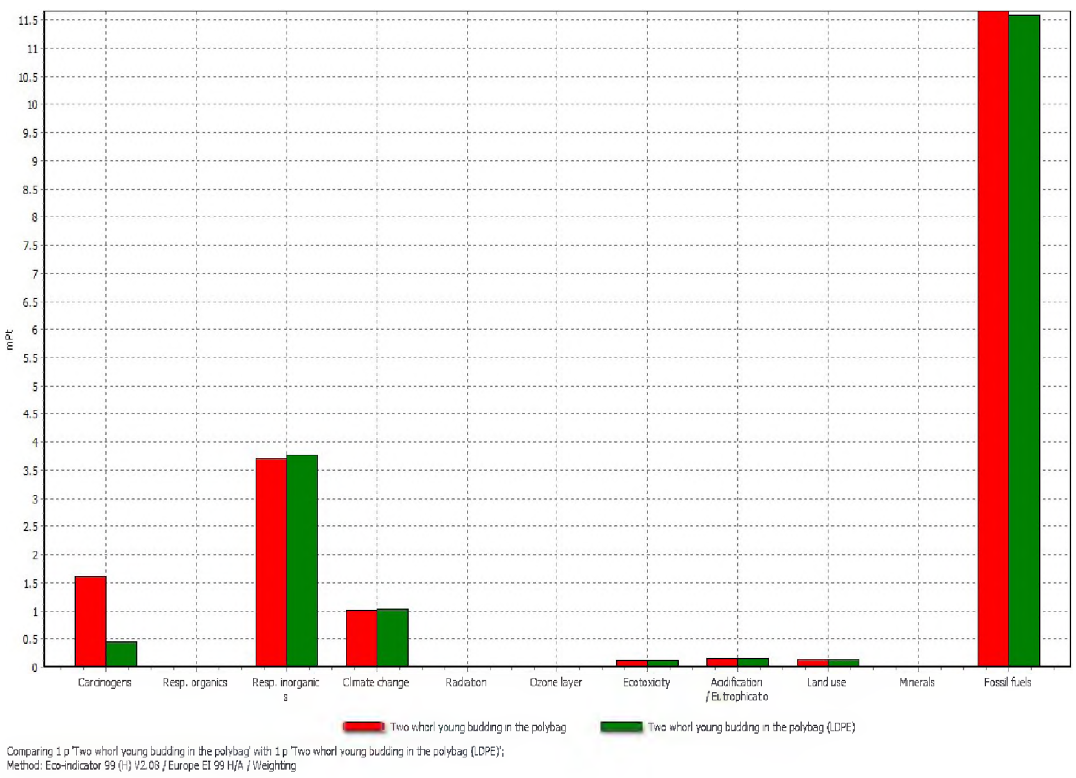

Figure 4. Weighting results in LCIA based on different types of polybags for sensitivity analysis.

the same trends with fossil fuels impact category recorded the highest contribution and followed by respiratory inorganics.

For weighting carcinogen impact category, the usage of HDPE polybag is relatively higher at 0.00016 Pt as compared to 0.00044 Pt for the usage of LDPE polybag (*Table 5*). The total environmental impact weighting value for the production of one polybag of TWYBP using HDPE polybag in this study is 6.7% higher than using LDPE polybag (*Table 5*). This sensitivity analysis confirms that the environmental impact from the usage of HDPE polybags is comparable with the usage of LDPE polybags.

Sensitivity Analysis based on Bud Grafting Success Rate

A sensitivity analysis was carried out to assess the assumption used in this study that the young rootstock that failed the bud grafting process will be left together with the YBP and will only be discarded when the whole batch is transported from the rubber nursery. The result from this LCIA study based on 77.5% bud grafting success rate is compared with the result based on theoretical value of 100% bud grafting success rate. The weighted result for this sensitivity analysis is shown in *Figure 5* and *Table 6*.

TABLE 5. WEIGHTED VALUE BASED ON IMPACT CATEGORIES FOR DIFFERENT TYPES OF POLYBAGS FOR SENSITIVITY ANALYSIS

		Production of two whorl young budding in polybag	
Impact category	Unit	Survey polybag (HDPE)	LDPE polybag
Total	Pt	0.01845236	0.017299
Carcinogens	Pt	0.001616528	0.000441
Resp. organics	Pt	7.02063E-06	7.27E-06
Resp. inorganics	Pt	0.003706871	0.003778
Climate change	Pt	0.00100948	0.001028
Radiation	Pt	8.47127E-06	8.47E-06
Ozone layer	Pt	8.66925E-07	8.67E-07
Ecotoxicity	Pt	0.000122369	0.000122
Acidification/ Eutrophication	Pt	0.0001595	0.000163
Land use	Pt	0.000141827	0.000142
Minerals	Pt	1.89845E-05	1.94E-05
Fossil fuels	Pt	0.011660442	0.011587

Based on *Figure 5*, the environmental impact from the production of one TWYBP with 77.5% bud grafting success rate is relatively higher than the production of one TWYBP with 100% bud grafting success rate where both scenarios were observed following the same trends with fossil fuel impact category recorded the highest contribution followed by respiratory inorganics and carcinogens. The total environmental impact value for the production of one TWYBP based on 77.5% bud grafting success rate is 30.1% higher than the value for the production of one TWYBP based on 100% bud grafting success rate (*Table 6*). This sensitivity analysis showed that the impact to the environment is relatively higher with 77.5% bud grafting success rate as compared to the theoretical value of 100% bud grafting success rate. This is due to wastage of resources in the form of fertilizer, chemicals, water and diesel that were used by the young rootstocks that failed the bud grafting process which was normally carried out when the young rootstocks were between 3 to 6 months.

CONCLUSION

The LCIA results showed that production of diesel and HDPE resin E were the two processes that contribute greatly towards the total environmental impact in the production of TWYBP. The two possible approaches which can reduce the environmental impact from the production of TWYBP are by increasing the bud grafting success rate among the rubber nursery operators and the reduction of the growth period of these planting materials. The bud grafting success rate can be increased through the assistance from the rubber related

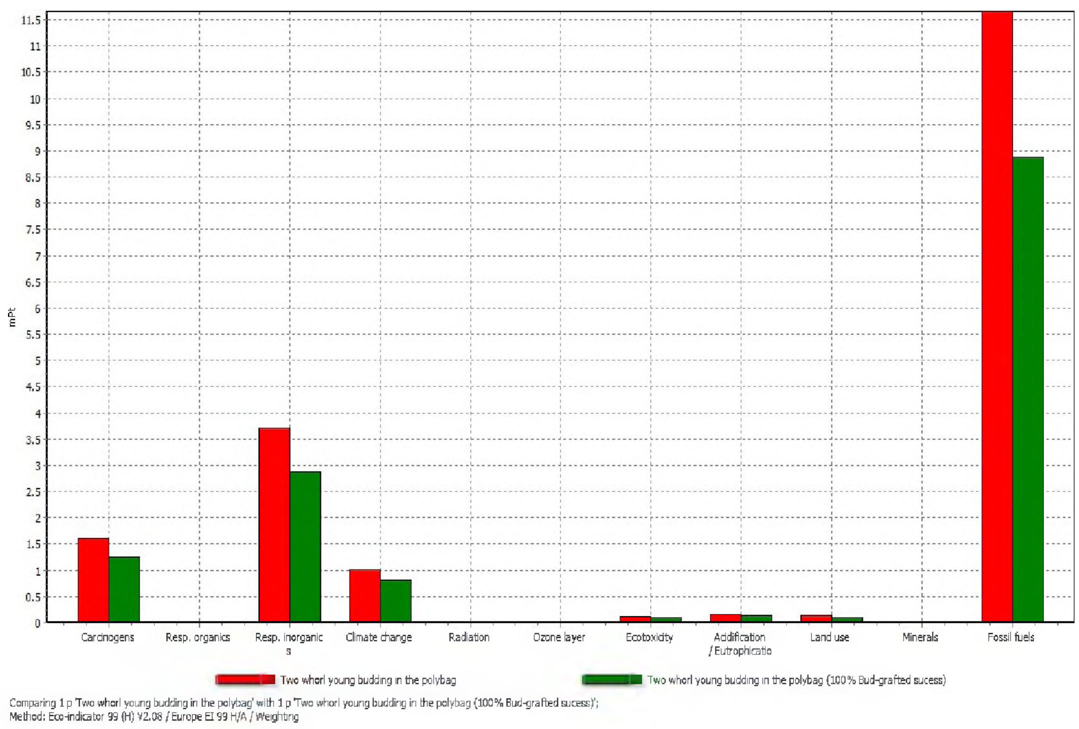

Figure 5. Weighting results in LCIA for different bud grafting success rate for sensitivity analysis.

TABLE 6. WEIGHTED VALUE BASED ON IMPACT CATEGORIES FOR DIFFERENT BUD GRAFTING SUCCESS RATE FOR SENSITIVITY ANALYSIS

		Production of two whorl young budding in polybags	
Impact category	Unit	Survey bud grafting (77.5%) success rate	100% bud grafting success rate
Total	Pt	0.01845236	0.01418404
Carcinogens	Pt	0.001616528	0.001246964
Resp. organics	Pt	7.02063E-06	5.3472E-06
Resp. inorganics	Pt	0.003706871	0.002879084
Climate change	Pt	0.00100948	0.000818339
Radiation	Pt	8.47127E-06	6.29002E-06
Ozone layer	Pt	8.66925E-07	6.43241E-07
Ecotoxicity	Pt	0.000122369	9.25775E-05
Acidification/ Eutrophication	Pt	0.0001595	0.000129893
Land use	Pt	0.000141827	0.000104531
Minerals	Pt	1.89845E-05	1.42731E-05
Fossil fuels	Pt	0.011660442	0.008886099

agencies in Malaysia in the form of training on the correct bud grafting technique for rubber nursery workers. Proper selection of good quality seedlings from recommended clones to produce young rootstocks and the selection of good quality bud patches from recommended clone to be grafted to young rootstocks are also very important. Research to identify certain agronomic practices that can shorten the period of producing the TWYBP should be prioritised and promoted to the rubber nursery industry in the form of standard operation procedure. This will help in reducing the environmental impact from the production of TWYBP, as lesser growth period means less consumption of resources especially diesel in running the water sprinkler system.

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