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Comparative Analysis of Environmental Evaluation of LAS and MES in Detergent-A Malaysian Case Study

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Abstract: As the awareness among the consumers is increasing, the detergent industries need to meet challenges and cope with consumers demand for eco-friendly products. Today, the manufacturers are competing to produce detergents with more environmental-friendly properties to remain competitive in the industry. Study was conducted to assess and compare the environmental impacts from the production of surfactant used in detergent, alkylbenzenesulfonates (LAS) and methyl ethyl sulfonates (MES). The difference in term of environmental impacts from LAS manufactured in Malaysia and LAS data available in Ecoinvent database was also assessed. Data and information on the inputs used throughout the production processes was compiled and calculated using Life Cycle Assessment (LCA) procedures, where environmental impacts and hotspots were identified. The functional unit was defined as one kilogram of surfactant. From this study, among the significant environmental impacts for the production of one kilogram surfactant is depletion of fossil fuels, land use change and respiratory inorganics. LAS is the main contributor to the depletion of fossil fuels while the production of MES cause land use change and respiratory inorganics. From the results of this study it can be concluded that MES is a more environmental-friendly surfactant compared to LAS.

Key words: Linear Alkylbenzene Sulfonates (LAS) · Methylethyl Sulfonates (MES) · Life Cycle Assessment (LCA) · Detergent

INTRODUCTION

Increasing human population and economic activity exceed the capacity of ecosystem. As a consequence, problems such as global warming, eutrophication, acid rain as well as depletion of ozone layer are occurring. Those days process industries had to consider only customer demands: qualities, prices and variations of their products. Now they have to consider the demands from society: reduction of environmental impact and energy consumption.

The detergent industries need to meet challenges and cope with consumers demand for eco-friendly products to remain competitive in the industry. For the past few decades industry has been taking initiative to substitute ingredients in the laundry detergent with more environmental friendly ingredients especially surfactants. Currently the straight-chain, linear alkyl benzene sulfonates (LAS) has completely replaced ABS (branched-chain dodecyl benzene sulfonates (ABS or DDBS) as LAS were found to be readily biodegradable compared to ABS [1].

There are four types of surfactants: anionic, non-ionic, cationic and amphoteric. Linear alkyl benzene sulfonates (LAS) are almost extensively utilized synthetic anionic surfactants. In 2003, the global usage of LAS has reached over 18.2 million tonnes [2] compared to other surfactants which only accounts for 2.4 million tonnes. As LAS is a petrochemical based surfactant, it will not last in the long run as it has been predicted that oil will only last for another twenty years to cater the needs in Malaysia [3].

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LAS is used as ingredient in many household and industrial detergents which can pollute the environment after disposal of the wastewater to the sewage or directly to the river [4]. There are many studies done related to the environmental profiles of LAS and Linear Alkyl Benzene (LAB), which is one of the raw materials for production of LAS [2, 5, 6]. Twenty years ago, Ludwig and Sekaran (1988) have concluded that LAS could create environmental problems as the usage of LAS will increases in the future due to expanding population in Malaysia. LAB derived from linear paraffin and benzene and mainly used for derivatization to LAS.

Other than LAS there is another new surfactant used in Malaysia, methyl ethyl sulfonates (MES), a palm based surfactant. Both Malaysia and Thailand are recognised as main producers of palm oil about 80% of the global production in 2007 [7]. MES is new to the surfactant industry and is normally used together with LAS as surfactants in the laundry detergent in Malaysia. Because of utilization of Palm oil and Palm kernel in the Oleo chemical industries an well as in the surfactants industries, their demand has been raising recently within last few years. The surfactants are commonly used as raw materials in various types of consumer products like laundry detergents and cleansers, shampoos, soaps; also in lots of other household related, industrial (both general purpose and special purpose), institutional as well as personal cleaning products [8]. According to Malaysian Palm Oil Board (MPOB), MES possesses required potential so that the biodegradation is expedited and the production costing is lower than that of LAS due to their higher cost of Linear Alkyl Benzene (LAB) [9]. As MES has already taken place in the industry, it is essential to assess the impacts on environment of both LAS and MES from in the laundry detergent. To assess various impacts of newly produced or processed products on the environment, an evaluation tool of entire product lifecycle is necessary. Such tools are called LCA tools and can be done using Life Cycle Assessment (LCA) approach.

MATERIALS AND METHODS

Life Cycle Assessment: Environental impacts identified using Life cycle assessment (LCA) approach based on ISO 14040:2006 and ISO 14044:2006 [10, 11]. LCA is an internationally accepted technique that has been employed to deal the product's environmental aspects as well as their impacts on the environment all the way through a product's life cycle or lifespan. Based on ISO 14040, there are four steps in LCA: (1) Defining the goals and the scopes, (2) Analysis of the inventory (3) assessment or appraisal of impact\ (4) interpretation. LCA analysis was done to identify the hotspots in the lifecycle of a product and used to compare with alternative products or processes available. The analysis of inventory involves aggregation of data on raw material as well as energy consumption, emissions to air, water and soil of MES and LAS. The conversion of these emissions into impact categories is called life cycle impact assessment (LCIA). The evaluation of impact aims to assess the environmental impacts of MES and LAS based on the inventory collected. All collected data was computed using SimaPro 7.2.3, which uses Eco-indicator 99 method and the LCI database from the Ecoinvent.

LCA Goal and Scope of the Study: The goal of the LCA is to compare the environmental impact of the production of LAS and MES from cradle to gate. The LCA results determine whether the bio-based surfactant (MES) are more environmental-friendly compared to the petroleum based surfactant (LAS). The study also aims to compare LAS manufactured in Malaysia with LAS data available in the Ecoinvent databases.

Functional Unit (FU): Providing a reference unit for which the inventory data are normalized is the objective of the functional unit. It is important for products to posses similar service or function to have fairness and relevance in conducting LCA [12, 13]. This study focuses on LAS and MES used as a surfactant in the laundry detergent. Surfactants are the main components in the laundry detergent. The FU of this LCA study is defined as the mass of the surfactant, i.e. one kg of surfactant. We assume the same amount of either LAS or MES is used to fulfill the function in the production of laundry detergent.

Cut-Off Criteria: No specific cut-off criteria based on environmental load have been adopted. Whenever a data is not reported, this does not implicate a cut-off because of limitation of available data. The number of cut-off input or output parameters is small and is not expected to contribute significantly to the results of the study.

Allocation Principles: Allocation principles as described under ISO 14041 are adequately applied to co-products, allocating the internal energy, services as in transportation and waste treatment as well as open or closed-loop recycling. Allocation by weight is used to partition the impacts with the main and co-products of the mills and methyl ester plants.

System Boundaries and Assumptions: The system boundaries for MES is from cradle-to-gate which includes oil palm seedling (nursery), production of Fresh Fruit Bunch (FFB) (plantation), production of Crude Palm Oil (CPO) (mill), production of Refined Bleached Deodorized Palm Oil (RBD), production of methyl ester (biodiesel), production of both MES and its flake.

The oil palm grows to a height of 10 m and replanted approximately after 25 years. The plantations of Oil Palm yield for 25-30 years continuously and the palm trees can be reaped after 3 years of planting. The reaping from palm trees can be performed year around. The palm oil is extracted from the fruitlets as well as palm kernel oil is extracted from the kernels. The oil palm fruits are clung to bunch. Currently the major palm oil products refer to the crude palm oil (CPO) that are obtained from the fibrous mesocarp of the fruitlets of the FFBs (FFB- fresh fruit bunches), the palm kernel (PK) that yields the palm kernel oil (PKO) from which oleochemicals are produced and the residue palm kernel cake (PKE), which are used as animal feed. The FFB contains around 20% oil, 25% nuts (5% kernels, 13% fibre and 7% shell) and 23% empty fruit bunches. The kernels contain around 55% oil and 8% protein [14].

The oil palm is planted in poly bags in the nurseries. The seedlings in the polybags are kept under a cover protecting them from direct sunlight. After a year the seedling is ready to be planted in the plantation. The values that have been used to develop the material flow and material balance for the production of CPO, Refined Bleached Deodorised (RBD) oil from the refineries and palm methyl esters are shown in Table 1.

LAS used in Malaysia is either imported from China or manufactured locally in Malaysia. However, linear alkyl benzene (LAB) used as raw material in the production of LAS is imported from China. The system boundary for LAS covers the whole production of LAS in Malaysia including transportation of LAB from China. Both Figure 1 and Figure 2 are the system boundary of LAS and MES production respectively.

Environmental impacts: Impact categories which are included in this analysis are based upon the potential of global warming over the eon of about 100 years (GWP, on certain occasions it is also pertained to carbon footprint), the eutrophication potential (EP), the acidification potential (AP), the photochemical ozone creation potential (POCP) and primary energy use. The methodological characterisation employed in the analysis was Ecoindicator 99 which was available in the SimaPro software [15].

Table 1: Data sources and component involved in the production of MES

Component	Data description	Data source
Oil palm seedling (nursery)	Inputs and energy involved for the production of a single seedling	Data from MPOB database (Halimah *et al*., 2010)
Palm fruit bunches	Cultivation of oil palms in Malaysia including use of diesel, machines, fertilizers and pesticides	SimaPro database/ Ecoinvent unit process
Palm oil mill	The production of crude palm oil in Malaysia. The process includes the extraction of palm oil, palm kernel oil from palm fruit bunches. Energy supply from extracted solids (fibres, shells, digester solids and EFB) and treatment of specific wastewater effluents are taken into account	SimaPro database/ Ecoinvent unit process
Palm methyl ester (biodiesel)	The esterification process of palm oil to methyl ester in Malaysia. Process includes the esterification, intermediate storage of the oil and products and the treatment of specific wastewater effluents	SimaPro database/ Ecoinvent unit process
Methyl ethyl sulphonates (MES)	Sulphonation process of methyl ester	MES manufacturer in Malaysia

Table 2: Data sources and component involved in the production of LAS

Component	Data description	Data source
Linear alkyl benzene sulfonates (LAS) manufactured in Malaysia	Raw materials and emissions from the production of LAS in Malaysia. Includes LAB, sulphur, sodium hydroxide, oxygen, natural gas, diesel, wastewater and others	LAS manufacturers in Malaysia
Alkyl benzene sulfonate, linear (Europe)	Inputs and energy involved in the production of one kg LAS	SimaPro database/ Ecoinvent unit process

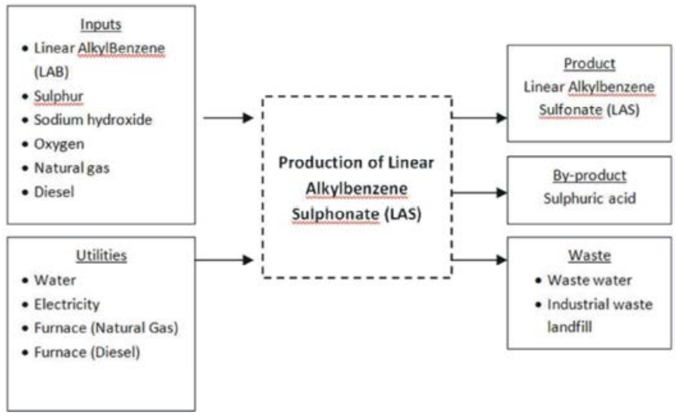

Fig. 1: System boundary of the production of linear alkyl benzene sulfonates (LAS)

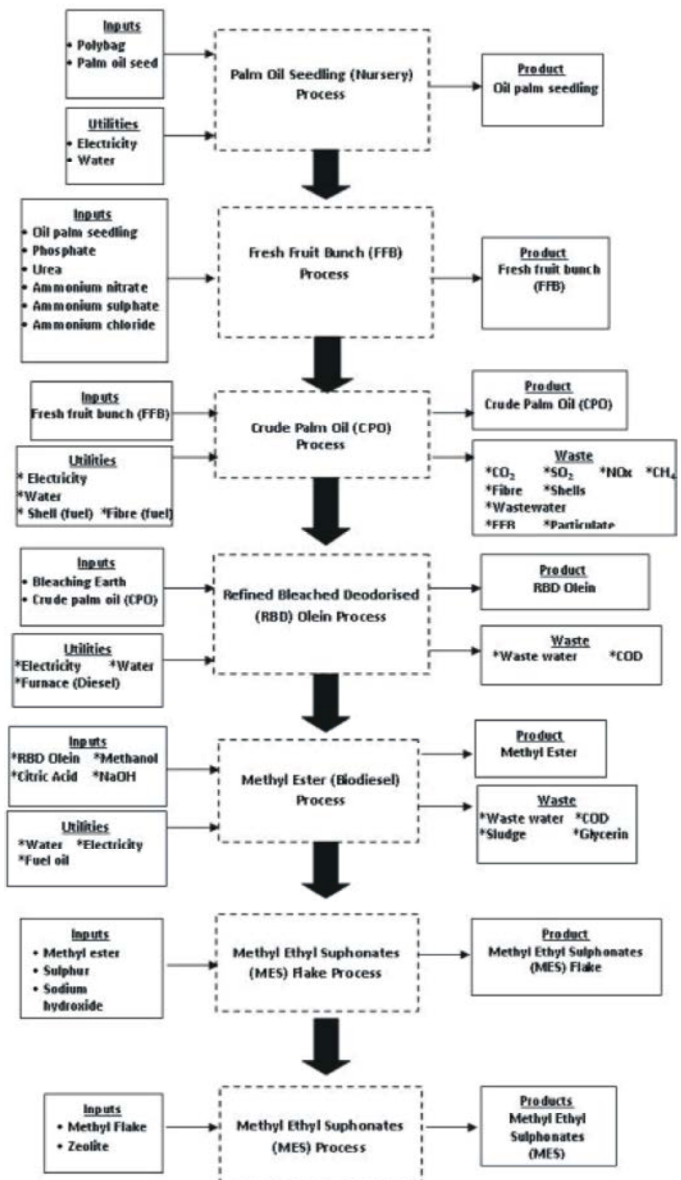

Fig. 2: System boundary of the production of linear methyl ethyl sulphonates (MES)

Impacts related to land use is also relevant for production of MES system, although it was impossible to evaluate those impacts owing to the lack of data availability, thus, not included in this study.

Data and Sources: Data for the production of MES was taken from the National LCA databases which were developed by SIRIM Berhad under the 9th Malaysia Plan. Data gaps were filled by background data, sourced from existing databases included in SimaPro, particularly Ecoinvent databases. Ecoinvent database is considered the most comprehensive LCA database developed by LCA experts [16].

Meanwhile, the inventory for the production of LAS was compiled from the foreground data obtained from LAS manufacturer in Malaysia. However, the initial data was completed using the Ecoinvent database, i.e; the production of LAB, sulphur, sodium hydroxide, oxygen, natural gas and diesel. Table 1 and Table 2 shows the data sources and component involved in the production of MES and LAS.

RESULTS

Life Cycle Impact Assessment (LCIA): Life cycle impact assessment (LCIA) was conducted using Eco-indicator 99 methodology equipped in SimaPro software version 7.2.3. LCIA was conducted based on two scenarios. The first scenario compares between the LAS manufactured in Malaysia and the LAS data available in the Ecoinvent database. The second scenario compares LAS and MES manufactured in Malaysia.

Impact Assessment from LAS production: Both Figure 3 and Figure 4 shows the comparison of LAS produced in Malaysia and LAS data from Ecoinvent database (available as Alkylbenzene sulfonate, linear, petrochemical, at plant/RER).

Here, Figure 3 illustrates the damage assessment of LAS produced in Malaysia compared with the Ecoinvent database which is also referred as damage assessment. Based on the figure, the production of LAS in Malaysia has a greater impact on resources than LAS from Ecoinvent database. However, LAS manufactured in Malaysia has lower impacts on the human health and ecosystem quality compared to the LAS from the Ecoinvent database.

On the other hand, Figure 4 shows the weighting results for the comparison between LAS produced in Malaysia and LAS in Ecoinvent database. Based on the information presented in the figure (Fig. 4), the impacts categories for LAS produced in Malaysia is similar as LAS data obtained from the Ecoinvent. Both LAS produced in Malaysia and LAS from Ecoinvent database have the highest impact on the depletion of fossil fuels compared to the other impacts with 0.263 Pt and 0.257 Pt, respectively. (The unit used is Pt, an Eco-indicator 99 point where 1 Pt is equivalent to the impacts from one-thousandth person per year). From the assessment, the major contributor to the fossil fuel is from the raw material, Linear Alkyl Benzene (LAB). From the graph, other significant impacts are on the respiratory inorganics, carcinogens and climate change.

MES Hotspots: Both Figure 5 and Figure 6 illustrate the LCIA on processes involved in the production of MES. Based on Figure 5, generally, the stage of MES production has the highest impact on the land use change, respiratory inorganics, depletion of fossil fuels, climate change and eutrophication. Meanwhile, the production of crude palm oil has the highest impact on respiratory organics and inorganics, eutrophication and land use change. Previous studies by Sumiani and Hansen concluded that respiratory inorganics and fossil fuel depletion were the most significant impacts with global warming and acidification/eutrophication [17]. The stage of palm oil seedling has the lowest impact on the environment followed by fresh fruit bunches production stage.

Figure 6 shows the weighted values of environmental impacts from the production of MES. The most significant environmental impacts for the production of MES are land use change followed by depletion of fossil fuels and respiratory inorganics. The highest contributor to the land use change is from the production of crude palm oil in the mill, followed by the production of palm methyl ester (biodiesel) at the esterification plant, the production of MES flake, the production of MES and the production of palm fruit bunches in the plantation. The production of MES has the highest impact on the depletion of fossil fuels while the production of crude palm oil is the highest contributor to the respiratory inorganics. Overall, the production of oil palm seedling has the lowest impact on the environment, only on depletion of fossil fuels from the polybag consumption.

Comparison of LAS and MES: Assessment was done to compare the environmental impacts between the production of MES and the production of LAS. Figure 7 shows the characterized results of LCIA. The results indicated that MES has more significant impacts in the following categories; respiratory organics and inorganics,

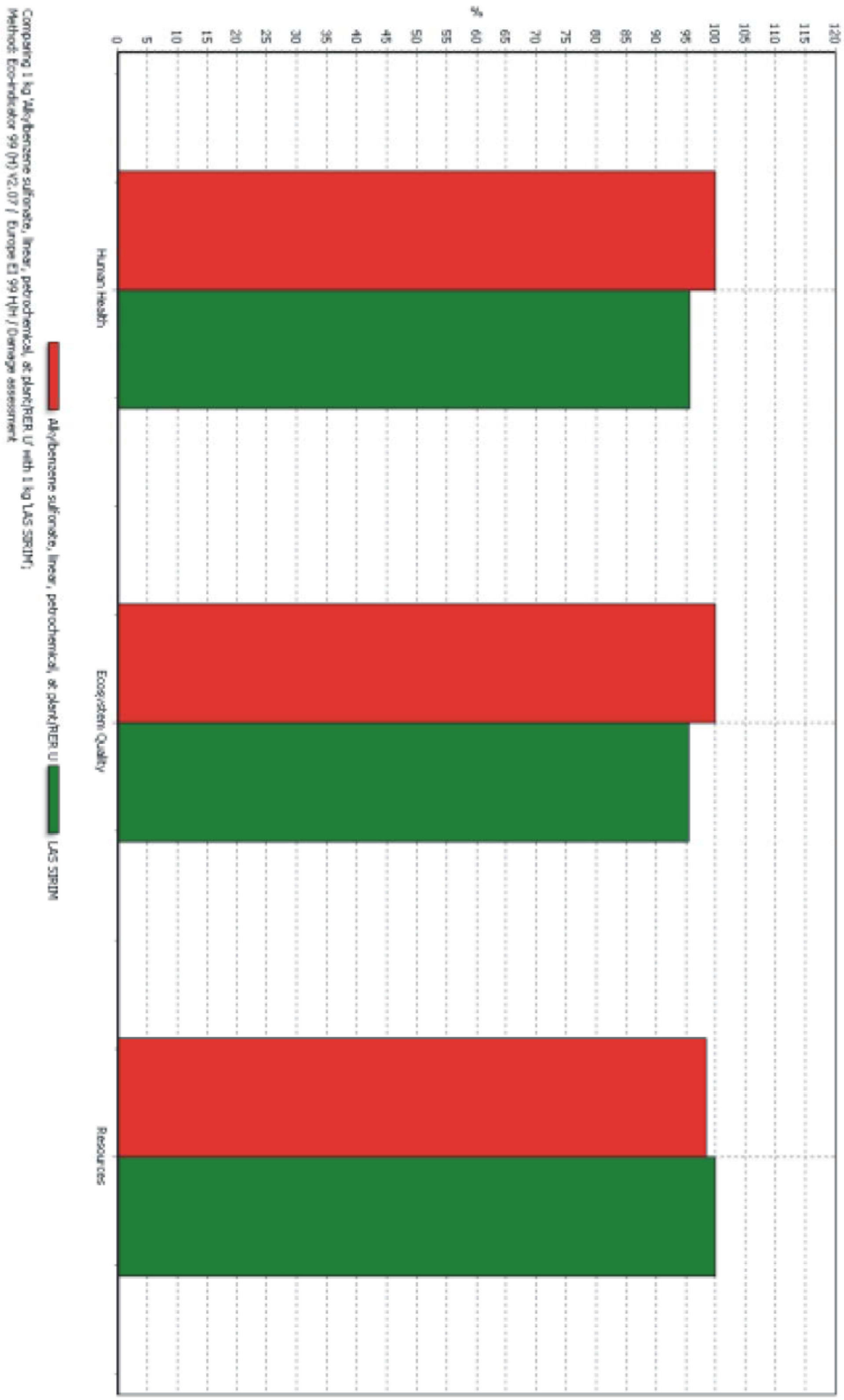

Fig. 3: Comparison of LCIA between 1 kg LAS manufactured in Malaysia and LAS in Ecoinvent database (damage assessment)

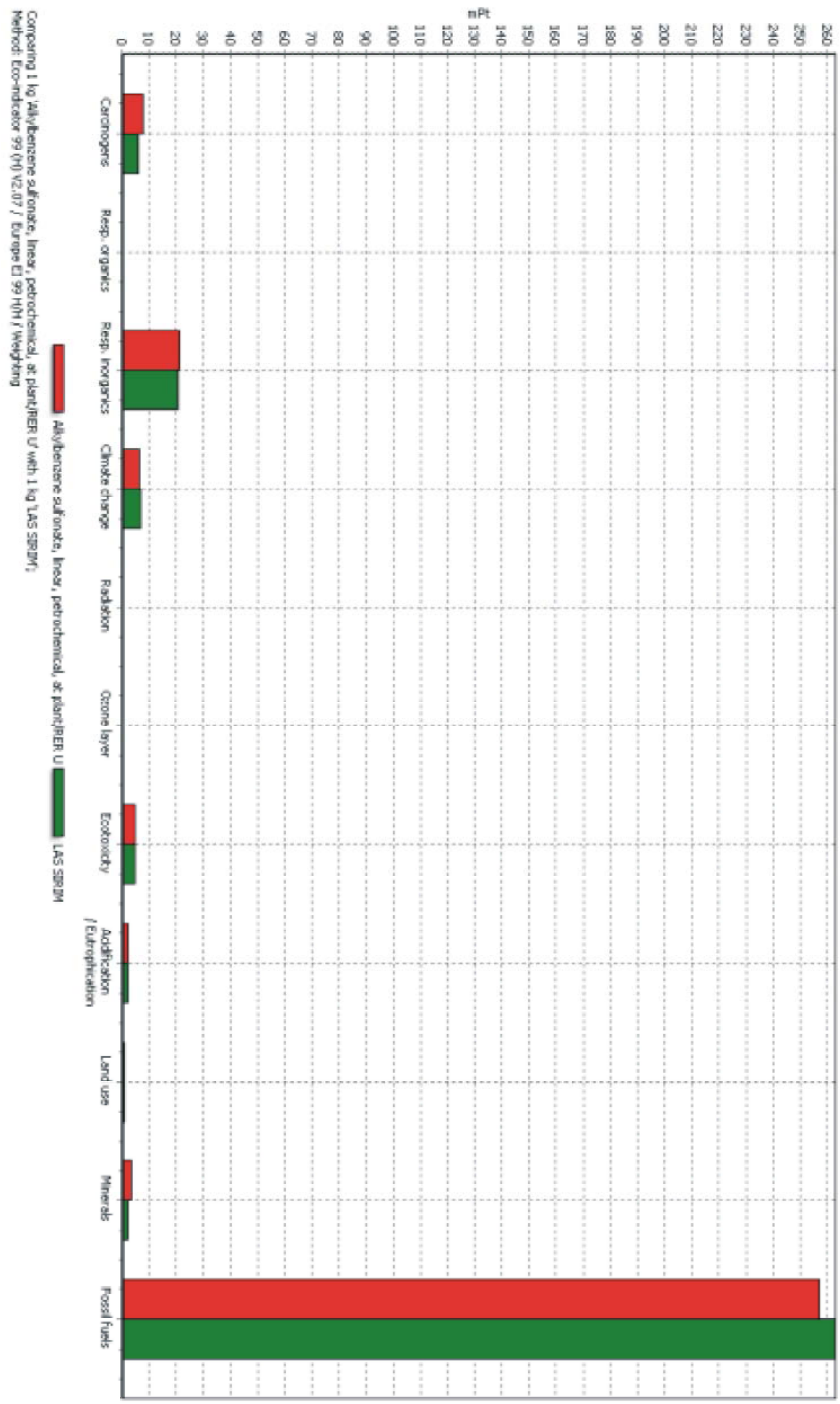

Fig. 4: Comparison of LCIA between 1 kg LAS manufactured in Malaysia and LAS in Ecoinvent database (weighted values)

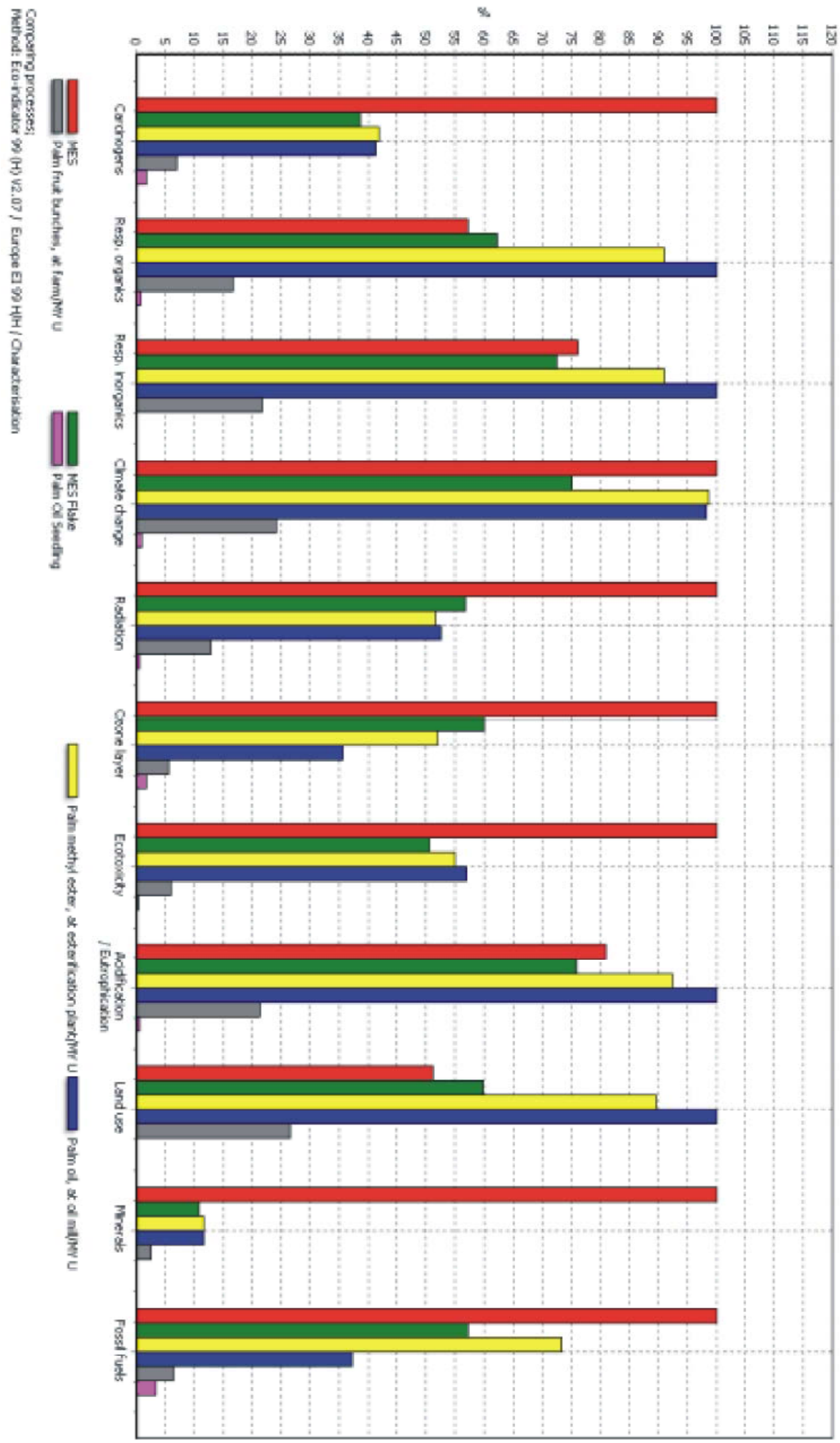

Fig. 5: LCIA (characterization) on the processes involved in the production of MES

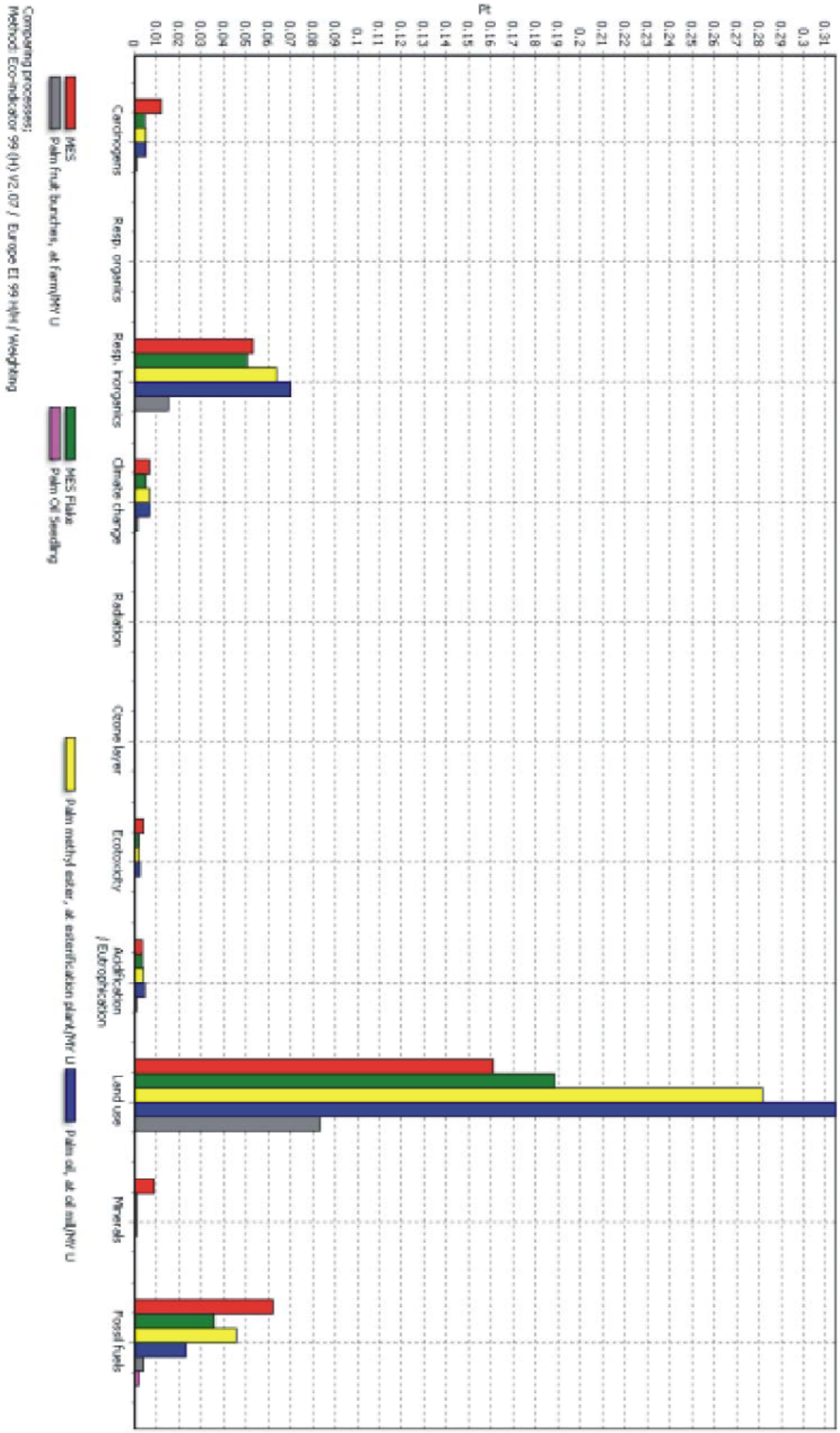

Fig. 6: LCIA (weighted values) on the processes involved in the production of MES

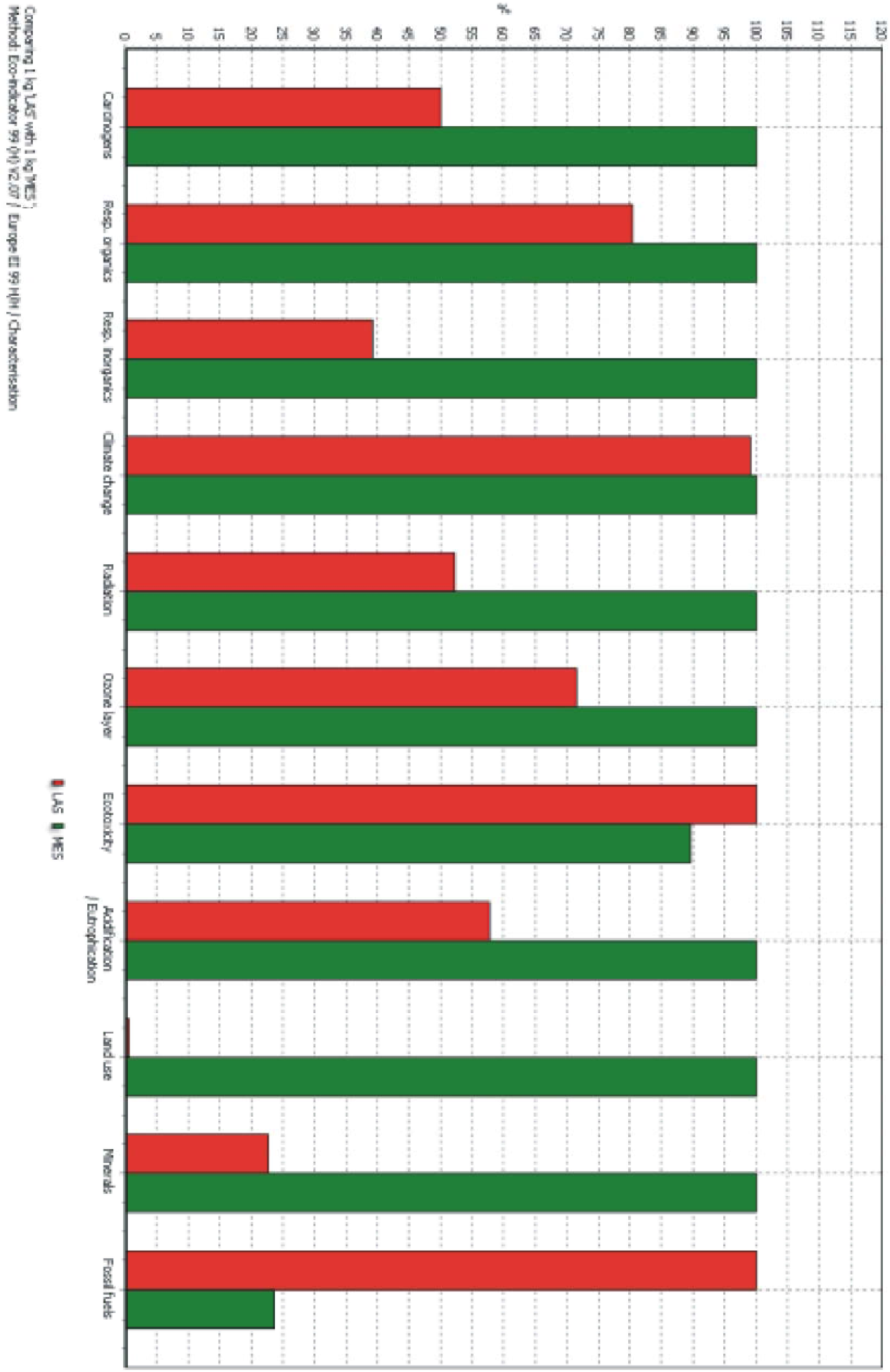

Fig. 7: Comparison of LCIA (characterization) between the production of MES and LAS

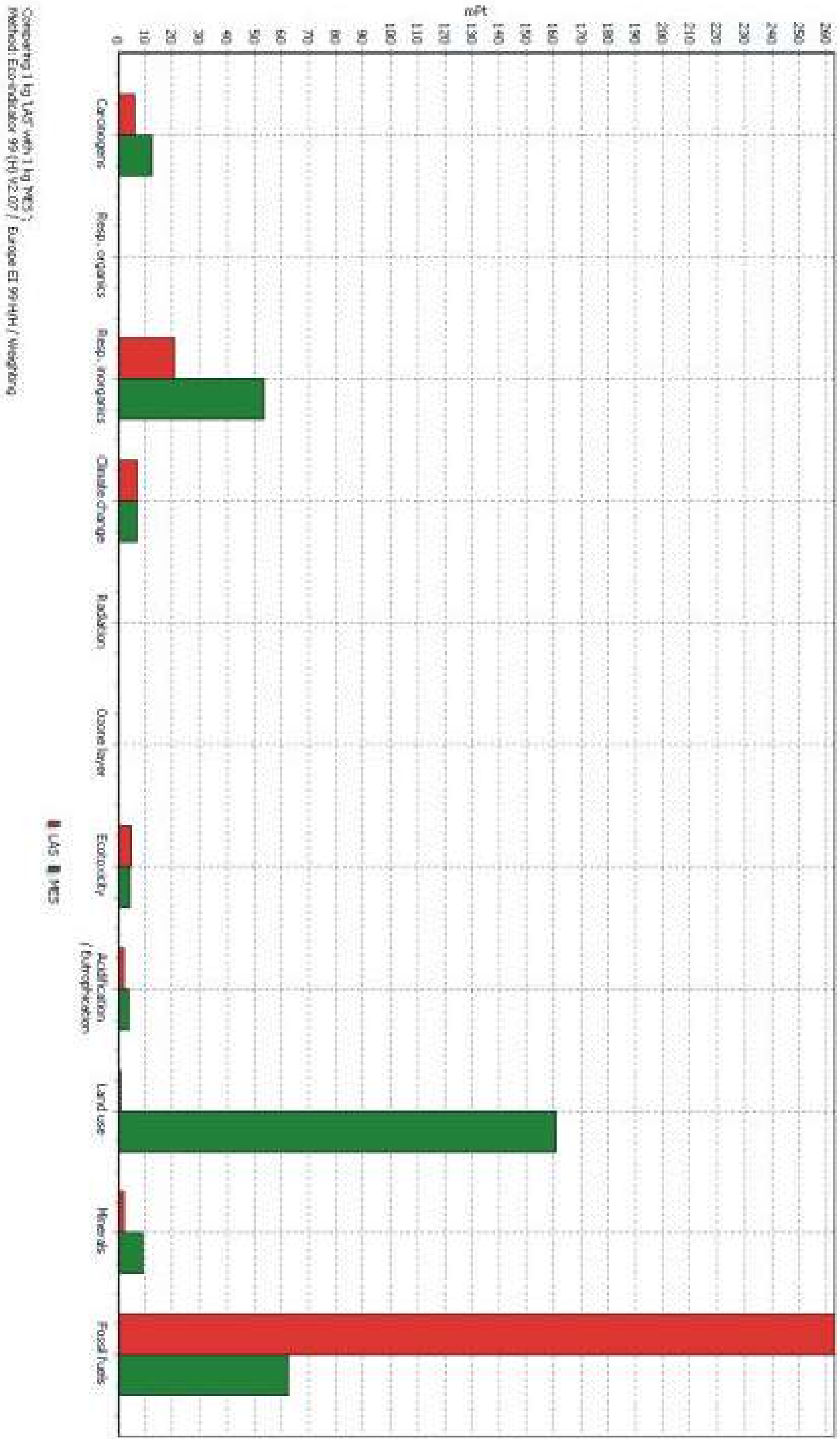

Fig. 8: Weighted results of LAS and MES

carcinogens, climate change, radiation, depletion of ozone layers, acidification/eutrophication, land use change and depletion of minerals. Meanwhile, the most significant impact of LAS is ecotoxity and depletion of fossil fuel.

The weighted result is shown in Figure 8. The figure demonstrates that the following impacts are significant in the production of MES and LAS: depletion of fossil fuel, alteration of land using, respiratory inorganics, depletion of minerals and climate change. From the LCIA results, it was found that LAS is the main contributor to the depletion of fossil fuels, while the production of MES cause land use change and respiratory inorganics. Eutrophication impact is higher in MES compared to LAS. According to Heinz Stichnothe *et al*. [18], phosphate leaching is regarded as the most significant process out of plantation as well as the waste stages for the eutrophication. Moreover, the organic nitrogen as well as the phosphate POME bears a substantial amount of vegetable oil which is adequately biodegradable and is a major cause of eutrophication [18].

The production of LAS depletes the fossil fuels as LAS is a petrochemical based surfactant. LAS is produced from three main substances; linear alkyl benzene (LAB), benzene and n-paraffins (J.L. Berna *et al*., 1995), which are produced from crude petroleum. The high production of LAS decreases the availability of fossil fuels. Whereas, MES is a made from renewable raw materials and has the potential to biodegrade faster than LAS [9].

From Figure 8, MES is the main contributor to the change of impacts due to land using alterations. As MES is a palm oil-based methyl ester, MES is produced from the crude palm oil. Throughout the palm oil production, countless square miles of forest were replaced by oil palm plantation destroying flora and fauna of the tropical forest [19, 20]. Land conversion caused greenhouse gases emission and affect climate change.

Based on Figure 8, respiratory inorganics are mainly caused through MES production while emission is taking place from the application of fertilizers during oil palm cultivation [21]. The production and consumption of fertilizer has the highest potential in harming the environment, resources and affecting human health. It is evident that the impacts from the plantation are mainly contributed by the production and consumption of fertilizer such as ammonium sulphate, ammonium nitrate, urea and input of N [22]. Nitrogenous fertilizers (N-fertilisers) are known to release nitrous oxide (N^2O) when applied to the fields. The Global Warming Potential (GWP) of N^2O is 298 times higher than CO^2.

CONCLUSIONS AND RECOMMENDATIONS

The utilization of LCA has enabled the quantification of environmental impacts for both MES and LAS are associated with agricultural and industrial practices.

Biogas from anaerobic digestion of POME should be trapped to use as fuel, thereby preventing emission of methane that is 25 times the GWP of carbon dioxide (CO^2). Installation of digesters that can trap the biogas to be used as fuel for boilers or electricity generation are technically viable solutions that will overtake the current industrial practices of open pond system as a matter of time.

Firstly, the payback period for investment needed for building anaerobic treatment plants, new boilers that can use the biogas and electricity generation facilities is not attractive to the industry players. The incentives provided in the form of Clean Development Mechanism (CDM) projects have yet to gain sufficient clout to motivate the companies other than those who want to portray their environmental sustainability.

The mills have been operating with excess energy supplied through the shells and fibres as fuel and are therefore not hard-pressed to explore for new energy sources. Aside from continual research that can reduce the capital cost of the treatment and conversion plants, tax incentives and better pricing for sale of electricity generated from the mills may spur the propagation of the closed-digester treatment plants.

Good Agriculture Practice (GAP) can reduce the environmental impacts of MES. The major contributor to the environmental impacts of MES in oil palm cultivation is from the application of agrochemicals that include N-fertilisers and P-fertilisers. The bigger portion of the contribution in this unit process comes from the production stage of fertilisers which is out of the direct control of the plantation management. However, it is within the portfolio of the plantation management to implement good agriculture practice that include optimise application of synthetic fertilisers that will contribute to the overall reduction of the environmental impacts.

As a conclusion, with equal washing performance, MES is a more environmental-friendly surfactant than LAS as MES has the potential to biodegrade faster than LAS, made from renewable raw material and the production cost of MES is lower.

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