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3 **The impact of palm oil feedstock within the LCA of a bio-sourced cosmetic** 4 **cream**

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13 Keywords: Life cycle assessment, Cosmetic, Palm oil, Peat soil, Deforestation, Land Use

14 Abstract

15 We performed a cradle-to-grave life cycle assessment (LCA) of a bio-based cosmetic cream
 16 containing Refined Palm Kernel Oil (RPKO). The objective was to investigate the importance of the
 17 RPKO production within the environmental impact of the cosmetic cream. We assumed a baseline
 18 scenario with best oil palm agricultural practices in Malaysia, and then tested different parameters,
 19 i.e. deforestation, peat soil drainage and improved effluent treatment, in order to check their
 20 influences.

21 In the baseline scenario, transport of the cosmetic cream was the main contributing process (largest
 22 contribution for 11 out of 15 impact indicators). Contribution of the packaging of the cosmetic cream
 23 was also significant (largest for 2 out of 15). RPKO had a low impact contribution in the baseline
 24 scenario, albeit a much more critical one in the alternative scenarios. Deforestation and peat soil
 25 drainage (i.e. transformation and occupation) influenced two environmental indicators: Climate
 26 Change and Land Use. On Climate change indicator, deforestation caused an increase of about 9% of

the cosmetic cream impacts and peat soil occupation an increase of 16%. On Land Use indicator, deforestation caused an increase of 3%, peat soil transformation and occupation caused increases of 938% and 41%, respectively. Methane capture from palm oil mill effluent treatment and conversion to electricity represented a low decrease of environmental impact of cosmetic cream (from – 0.1% to – 2.8%). This paper showed that the palm oil agricultural phase could have a non-negligible impact over the life-cycle of a cosmetic cream in case of deforestation and peat cultivation, despite its small contribution in both mass and economic terms.

1 Introduction

Assessing environmental impacts has become mainstream when designing new or improved production systems. It is particularly crucial when promoting new bio-based products that are meant to displace their fossil equivalents in order to reduce the overall environmental impact. Arguments put forward are the renewable aspect and the independence from oil or mineral, implicitly promising low environmental impacts. However, several studies have shown that net environmental benefits from bio-sourced products are not automatic and depend on the studied commodity chain and the way it is assessed (Fargione et al., 2008; Farrel et al., 2006; Gibbs et al., 2008; Gnansounou et al., 2009).

Life Cycle Assessment (LCA) has been widely applied to assess the impact of bio-sourced product (ADEME and BIO Intelligence Service, 2010; JRC et al., 2008; Secchi et al., 2016). LCA holistic approach allows for comparing commodity chains while avoiding hidden problem shifting between stages or environmental impacts. It can integrate the whole life cycle of the product (from cradle to grave), i.e. starting with extraction of raw materials until the end of life of the used product, and assesses a wide range of potential environmental impacts.

The aim of this study is to assess the environmental impacts of a bio-sourced moisturizing cream applying LCA. This cream contains an alkyl polyglucoside (APG) surfactant based on palm oil. Palm oil is nowadays the most used vegetable oil worldwide, accounting in 2015 for 28.3% of the global oils and fats production (European Palm Oil Alliance, 2015). About 19% of total palm oil production is used as oleo-chemicals, especially palm kernel oil (Rival and Levang, 2014). Various LCA on palm oil and palm oil-based products have shown that the feedstock production at the farm stage is a major contributor to most of potential environmental impacts (Boonrod et al., 2016; Chavalparit et al., 2006; Choo et al., 2011; Chuchuooy et al., 2009; Nilsson et al., 2010; Schmidt, 2007; Yusoff and Hansen, 2007). This large contribution of the farm stage, due to combined high input levels in the field and low input levels at the mill and refinery stages, remains a key issue when including further

processing stages to convert palm oil into biodiesel (Achten et al., 2010; Angarita et al., 2009; Arvidsson et al., 2011; Choo et al., 2011; Harsono et al., 2012; Papong et al., 2010; Pleanjai et al., 2009). Focusing on global warming impact, main contributors are GHG emissions during the farm stage and methane emissions from palm oil mill effluent treatment (POME). Whereas the impact from POME can be drastically reduced if the biogas is captured (Choo et al., 2011; Chuchuooy et al., 2009) and further used at the mill stage (Chavalparit et al., 2006), the impact from the farm stage becomes overwhelming when forests or peat soil areas are converted to palm plantations (Reijnders and Huijbregts, 2008; Schmidt, 2007; Wicke et al., 2008; Zulkifli et al., 2009)

In this paper, we investigated the relative contributions of the various production phases of the moisturizing cream over its life cycle from cradle to grave, i.e. from the palm oil production up to the cream use. The first objective was to appraise the impact of the palm oil derivative within the whole supply chain of the moisturizing cream. Then, we focused on exploring how various palm oil production alternatives may critically influence the final LCA results of the bio-based used cream. We first described the implementation of the LCA following ISO norms and International Life Cycle Data (ILCD) guidelines. We then analysed and discussed the influence of the palm oil production scenarios in light of the overall environmental impacts of the studied moisturizing cream.

2 Material and methods

2.1 LCA goal and scope

We implemented LCA according to ISO norms 14040 series and following recommendations from the ILCD (EC-JRC, 2011). We used primary data, where available, and we used Simapro v.8 software with Ecoinvent v.3 database for background inventories. For palm oil feedstock, we used mixed primary and secondary data from the literature to model the plantation management and the industrial plant. Field emission models are detailed in sub-section 2.2.1.3. For the other biomass feedstock, we relied on Ecoinvent processes. Finally, for the industrial processing of the cosmetic cream, we used primary data from a site-specific industry (Guilbot et al., 2013) and secondary data for the background processes, e.g. electricity production and related emissions. ILCD guidelines define a set of 16 recommended impacts categories, which were applied in this study, except for Water Depletion due to some inconsistencies between the water impact assessment method and Ecoinvent v.3 database.

The studied functional unit was the preparation and use of one 30 g jar of cosmetic cream (Guilbot et al., 2013). The production system consisted of 8 main stages (Fig. 1). We first considered an average palm plantation located in Malaysia (stages 1-2), including all transports from the manufacture sites

to the field for field inputs and from the plantation gate to the mill for the fruits. Malaysia is the second world producer of palm oil and the most described system in life cycle inventory studies. The palm oil transformation into cetearyl alcohol (Transesterification & Hydrogenation) was assumed to take place in Germany (stage 3), including transport of palm kernel oil from Malaysia to Germany. The wheat production providing the D-glucose was assumed to be located in Northern France (stages 4-5), as well as the final processing step including the production of alkyl polyglucoside (APG) and the final cosmetic cream in accordance with primary data collected by the industry (stages 6-7). We added transport of D-glucose from the Northern (wheat production site) to the Southern part of France, where the final cream production occurred. We finally considered that the cosmetic cream was sold and use in Europe (stage 8), hence accounting for average European market conditions and adding transportation of cosmetic cream from manufacturer to retailer, from retailer to consumer, and of packaging residues from consumer to end of life treatment plant. All capital goods were included, except for the supermarket infrastructure.

To allocate co-product burdens, we reasoned with economic values in accordance with Ecoinvent v3 database guidelines, i.e. using 5 economic allocations:

- Kernel (18.7%) and Crude Palm Oil (81.3%) (Jungbluth et al., 2007)
- Crude Palm Kernel Oil (92.5%) and Palm Kernel Cake (7.5%) (Jungbluth et al., 2007) Palm oil prices may be quite volatile, however the ratios between palm oil and palm kernel oil or kernel meal are quite constant; hence price ratios from 2007 are still relevant for the study.
- Refined Palm Kernel Oil (99.22%) and Free Fatty Acid (0.78%) (Blonk Agri-footprint, 2014)
- Cetearyl Alcohol (27.9%), Methyl Ester (62.38%) and Glycerol (9.68%) (unpublished industrial data)
- The part of the cosmetic cream in transport during purchasing (the cosmetic cream price represents 4.66% of an average shopping basket)¹

2.2 Production sub-systems and life cycle inventories

2.2.1 Palm oil production scenarios

In the current work, the baseline scenario was defined according to main standard industrial practices and alternative scenarios were investigated to assess critical production parameters. These scenarios are further detailed in the following sub-sections.

¹ http://www.famillesrurales.org/franche_comte/Upload/LienCMS/dp_obsvprix_janv2015_2_ljv_CMS314.pdf, viewed 29/09/2016

2.2.1.1 Baseline scenario

We modeled the palm oil production system as a standard industrial production system in Malaysia based on published data. We included all processes and flows from nursery production up to the refined kernel palm oil (RKPO) including background processes. For the baseline scenario, we considered a settled plantation (i.e. without Land Use change) on a mineral soil and conventional industrial transformation processes up to palm oils, notably considering a conventional anaerobic treatment of palm oil mill effluents (POME) in open ponds.

Our inventory data for the nursery stage were based on two studies. Data for water consumption, electricity, diesel, plastic (production of polybags in Polyethylene, production of PVC irrigation pipes), fertilizers, pesticides and road transport (seeds, fertilizers and pesticides transport between Malaysian port and nursery) were taken from (Choo et al., 2011; Muhammad et al., 2010). Data for sea transport of field inputs from manufacture site to Malaysian port were taken from Schmidt (2007) (see Table S1, S2 and S3 in supplementary materials).

After the nursery, palm seedlings are transplanted in the oil palm plantation and cultivated for 25 years. The palms are planted at a density of 142 palms/ha (considering a 5% loss at replanting). Palm Fresh Fruit Bunches (FFB) are harvested the whole year long starting after the third plantation year. The composition of harvested FFB is: 20% oil, 25% nuts (5% kernels, 13% fibre and 7% shell) and 23% of empty fruit bunches (EFB) that are brought back to the field as organic fertilizers. We considered a standard management, including mineral and organic fertilizers, herbicides and field mechanization (Table 1), and an average yearly yield over the whole cycle of 19.16 tFFB/ha.year as detailed in the relevant background publications (Choo et al., 2011; Schmidt, 2007).

The collected FFB are directly sent to the palm oil mill and rapidly sterilized (within 24 hours) in order to limit the formation of Free Fatty Acid (FFA) (Guilbot et al., 2013). Pulp from mesocarp and kernel are then separated. Pulp is pressed with a screw press in order to obtain Crude Palm Oil (CPO). Pressed mesocarp fibers and crushed kernel shells are burnt in the boiler to provide heat and power leading to very limited amount of external energy input to the mill (Choo et al., 2011; Schmidt, 2007). Pressing of kernel allows for the extraction of Crude Kernel Palm Oil (CPKO). Inventory data were taken from various Malaysian studies (Choo et al., 2010; Vijaya et al., 2010). In the baseline scenario, POME, which are composed of sterilization condensates and clarification waters (Parveen et al., 2010), were conventionally treated in open anaerobic ponds that emit biogenic methane to the air (Wicke et al., 2008).

After the mill stage, CPKO is chemically refined, implying degumming with acid then cleansing with bleaching earth (Yew et al., 2010). Undesirable components such as FFA are stripped under vacuum in the de-acidification and deodorization steps to finally produce refined palm kernel oil (RPKO) (Guilbot et al., 2013). Energy for CPKO refining process is met by electricity from the grid (Malaysian grid) and fossil-fuel fed boilers. Liquid wastes from the refinery include wastewater and free fatty acid distillate (Table 1).

2.2.1.2 Alternative scenarios

Alternative scenarios were investigated from the farm stage up to the RPKO output, exploring (with or without) 3 critical parameters: deforestation, peat soil oxidation, and methane capture and electricity recovery from POME. Details on the calculation steps for the modified inventories are provided in the following sub-sections.

Within LCA, the impact of deforestation can be included at both inventory and impact assessment levels (the appraisal of the Land Use impact category is described in section 2.3.). In the inventory, deforestation is translated into carbon losses from above and below-ground biomass emitted as CO₂. We applied IPCC guidelines Tier1 (2006) to calculate these emissions, considering as previous Land Use a primary forest in Asia (insular) with 350 x (1+0.37) t biomass/ha using a 37% ratio of below to above-ground biomass. A palm plantation contains 136 x (1+0.28) t biomass/ha using a 28% ratio of below to above-ground biomass (IPCC, 2006). Emissions from land use change were implemented in both scenarios with deforestation on mineral and peat soils.

On top of deforestation, converting peat soil to cropland area requires a dense drainage that notably leads to the oxidation of soil organic carbon and finally CO₂ emissions. In the inventory, we accounted for annual CO₂ emissions due to the peat oxidation, which we further related to an occupation impact (see section 2.3). We relied on the constant emission factor of 40 tCO₂/ha.year (EPA, 2014). We did not account for a potential peak of emissions during the first 5-6 years right after the peat drainage started due to a lack of available emission factor and data. We also accounted for N₂O emissions from peat soil based on the IPCC emission factor (2013). According to IPCC (2013), we did not account for any CH₄ emissions specific to changes in peat soil aeration status. No matter whether the palm plantation on peat was established after forest or after replanting, the annual emissions from peat oxidation were considered constant. We did not consider any fluctuations depending on the initial thickness of the peat layer or the drainage depth. These assumptions were further discussed (section 4).

Finally, POME can be treated in different ways. The conventional treatment implies to store POME in open ponds, in which fermentation allows for the degradation of organic compounds in order to reach legal critical levels of Chemical and Biological Oxygen Demands before releasing or spreading of treated effluents. The anaerobic transformation of organic compounds leads to methane emissions, which contribute to global warming. Growing awareness on GHG issues has prompted the industries to seek for new solutions. The development of EFB composting allows for the recycling of raw POME. Moreover, a growing numbers of mills are combined with bioreactors that capture and flare methane from POME treatment with or without energy recovery (EPA, 2012). In our baseline scenario, we considered the conventional treatment and included pond methane emissions (Schmidt, 2007), as well as field emissions after treated POME field application based on IPCC emission factors for organic fertilizers (De Klein et al., 2006). In the alternative scenario, we considered the most interesting treatment alternative up to electricity recovery and substitution of grid electricity.

2.2.1.3 Field emission models

We took into account the emissions related to the use of fertilizers and pesticides. We followed IPCC guidelines (De Klein et al., 2006) in order to calculate the fractions of mineral and organic N-fertilizers emitted to the water (NO_3^-) and the air (NH_3 , direct and indirect N_2O). NO_x emissions were determined according to EMEP/EEA guidelines (EMEP and EEA, 2013). At the nursery stage, it was considered that no leaching could occur through the polybags. We also calculated P-fertilizer losses to the environment based on SALCA-P model (Prasuhn, 2006). For pesticides, we considered that the full rates of pesticides applied ended up in the soil. Fertilizers also contain heavy metals that we considered as stored in the soil (Brockmann et al., 2014).

2.2.2 Palm-based surfactant production

2.2.2.1 Production of the palm-based cetearyl alcohol

The processing of RPKO into a palm-based surfactant takes place in Europe. RPKO is transported from Malaysia to France (Marseille) by transoceanic freight ship, then to Germany by train (Guilbot et al., 2013). We considered a transesterification of RPKO with methanol in the presence of sodium hydroxide given the low cost, good yield and easiness to process (Zah and Hischer, 2007). The recovered methanol is recycled in the process. The C-8/14 methyl ester is slit from the C-16/18 methyl ester by distillation separation. The last step is a continuous catalysed hydrogenation of the C-16/18 methyl ester under high temperature (250–300 °C) and high hydrogen pressure (25–35 MPa)

in a fixed bed trickle flow process. The targeted C-16/18 alcohol is finally distilled to reach a purity of more than 95% (Giraldo et al., 2010) (see Table S4 in supplementary material).

2.2.2.2 Production of the complementary wheat-based crystallized D-glucose

Crystallized D-glucose is needed to produce the palm-based surfactant (128 g per kilogram of APG). The used crystallized D-glucose is derived from wheat starch (Guilbot et al., 2013). For our study, we used an Ecoinvent wheat inventory ("wheat grain {FR}, wheat production, alloc def") to represent a proxy for the culture of wheat in France. After harvesting, the wheat grains are washed and ground into flour and mixed up with water. The starch and gluten are then separated, and the resulting starch milk is totally hydrolyzed. The final processing steps involve demineralization, discoloration, concentration by evaporation and crystallization to obtain anhydrous D-glucose (Gerngross, 1999). An amount of 5.6 g of cultivated wheat provides 3.7 g of D-glucose, with a transformation energy cost of 1.6×10^{-2} MJ of energy (heat). The output crystallized D-glucose undergoes a Fischer Glucosylation, with sodium hydroxide as neutralization agent. Un-reacted glucose is removed by decantation and centrifugation (Guilbot et al., 2013).

2.2.2.3 Final production of the palm-based surfactant

The last step is the shaping of alkyl polyglucoside (APG) by pearlizing, which was assumed in this study to take place in France (Castres city). We assumed a standard batch of 10.9 t of APG (Guilbot et al., 2013), using 10.5 t of cetearyl alcohol and 1.4 t of crystallized D-glucose (Fig. 1). The supplying of these raw materials is done by lorry (~1200 km for the cetearyl alcohol coming from Germany to Castres and ~900 km for the glucose coming from the North of France to Castres). APG is stored in plastic bags, themselves stored in packaging board of 25 kg. We considered the following packaging: 5.44×10^{-2} g packaging board and 6.68×10^{-3} g of plastic film for 1.50 g of APG. This packaging was recovered in the cosmetic cream plant. We considered a recycling rate of 89% for packaging board and 20% for plastic film, the remaining being incinerated (Badey and Lahitte, 2013).

As the APG is solid at room temperature (melting point ~65 °C), the entire process is carried out by heating with steam produced by a gas boiler (104 kg of steam per t of APG) (Guilbot et al., 2013). Water input in the whole pearlizing process amounts 1.4 m³ per t of APG including the used cooling water use that is recycled in a closed circuit system. The final input is dinitrogen, 2.2 m³ per t of APG, which is used during the entire process in order to prevent coloration with oxygen from the air. Apart from APG, final co-products are: i) glucose muds from the decantation and centrifugation steps (~76 kg per t of APG), which are incinerated in a specific treatment plant (at ~160 km from the production site); and ii) liquid aqueous effluents (~14 l per t of APG containing 3000 mg per l of

245 COD), which are transferred to a wastewater treatment plant (see Table S5 in supplementary
246 materials).

247 2.2.3 Moisturizing cream production and use

248 2.2.3.1 Production of the cosmetic cream

249 The studied cosmetic cream contains 75% of water, 20% of an Argan oil phase (not available and
250 hence replaced by “global market for vegetable oil, refined ”from ecoinvent”), and 5% of APG
251 (Guilbot et al., 2013). The emulsification process consists in mixing the three components for about
252 2 h at 70°C under vigorous agitation, which requires 85 kg steam and 6 kWh electricity per tonne of
253 cream. Waste are mud (70 kg per t of cream) and liquid wastewater (10 l per t of cream with
254 3,000 mg COD per l). The final cream is bottled in a 30 g jar made of 7 g of HDPE and a tight fitting lid
255 made of 1.79 g of HDPE. Each jar is packaged in a small cardboard box (5 × 5 × 5 cm) wrapped in a
256 very thin HDPE film (100 µm). Our functional unit is the study of 1 jar (Table 2).

257 2.2.3.2 Use and end of life stage

258 The final use of the cream is its application on the skin of a consumer. The penetration (dose
259 absorbed through the skin) depends on skin permeability and properties of the cream as saturation
260 solubility. Some authors (Kroes et al., 2007; Williams et al., 2016) defined maximum flux ($J_{\max}$) to deal
261 with aspect and classified the dose absorbed during 24h according to it. A cosmetic cream with
262 surfactants, which was the case the present work, enhances skin penetration and promotes dermal
263 absorption of cosmetic ingredients (Williams et al., 2016). Jolliet (Jolliet et al., 2015) considered that
264 after 12h, 96% of the cream was absorbed. Consequently, in the present work, we assumed that the
265 cream was absorbed for the most part and the quantity of the cream streamed to the wastewater
266 treatment was negligible. This is in accordance with the Sustainability consortium (2013) guidelines
267 where wastewater treatment after the use of a cosmetic product is excluded of the system.

268 In our study, we did not consider any direct leakage after skin application (Guilbot et al., 2013).
269 However, we considered other potential impacts before and after the cream use, notably the
270 transport steps between production plant and storage (1,000 km by lorry), storage and retailer store
271 (100 km by lorry), from the store up to the consumer house. We also considered the recovery of
272 the jar.

We considered four types of transport in order to buy the cosmetic cream according to the European average: personal car (57%), walk (24%), public transport (11%), and bicycle (8%) (De La Fuente Layos, 2005).

The “public transport” category could be separated into 2 sub categories with the following percentages (European Commission, 2014):

- Subway: 18% (i.e. 2% from the 11% public transport)
- Bus: 82% (i.e. 9% from the 11% public transport)

The assumed average roundtrip distance between the customer house and the store was 10 km (De La Fuente Layos, 2005). We carried out an economic allocation in order to calculate the ratio of the cosmetic cream over the total shopped basket during the purchasing transport.

Wastes were collected to be treated. The cosmetic cream jar with associated packaging consists of 8.79 g of HDPE, 3.75 g of cardboard and 1.41 g of plastic film. If recycling rate for HDPE is very high like for bottles at consumer level, small dirty HDPE containers are commonly not separately collected and can be assimilated to undifferentiated small packaging with a recycled rate of 3% (BIO Intelligence Service, 2013). In the European context, 65%² of cardboard and 10% of plastic film are recycled (BIO Intelligence Service, 2013). The non-recycled parts (97%, 35% and 90% respectively), are incinerated and landfilled according European waste management practices³, (49% and 51 % respectively). These assumptions are further discussed (section 4).

2.3 Impact characterisation and selected indicators

We applied ILCD (2011 V1.06) (European Commission, 2012) recommendations regarding the selection of impact characterisation methods. We hence assessed 12 potential midpoint impacts (see Table S6 in supplementary material).

Concerning the Land Use impact, following ILCD, we applied the “Land Use” indicator (Brandão and Milà i Canals, 2013; Koellner et al., 2013; Milà i Canals et al., 2007). This indicator measures the change in the amount of organic matter in soil (30 cm deep) as a proxy to quantify how the use of a land area may impact the soil properties and functions. This indicator is expressed in kg C deficit. It integrates the impact due to land transformation and land occupation relatively to a reference state

² <http://ec.europa.eu/eurostat/web/waste/key-waste-streams/packaging> viewed 29/09/2016

³ <http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tsdpc240&language=en> viewed 29/09/2016

(without considering any irreversible process). The occupation indicator theoretically includes two compounds. The first one refers to the impact of delaying the restoration of the potential SOC due to land occupation, the second refers to a further actual degradation or improvement in the SOC due to the land occupation. The latter, further referred to as “occupational change”, is not yet implemented in ILCD (EC-JRC, 2011). We further refer to “occupational delay” for the currently implemented occupation impact in Land Use indicator. Characterisation factors are calculated based on SOC database from IPCC (2006).

For transformation, the gain or loss of SOC is calculated according to the following formula (Brandão and Milà i Canals, 2013; Milà i Canals et al., 2007):

Eq.1

$$\Delta SOC \left(\frac{kg_C}{m^2} \right) = \frac{\frac{1}{2} (t_{relax} - t_{ini}) * (SOC_{ini} - SOC_{end})}{(t_{end} - t_{ini})}$$

Where:

SOC_{ini} = Soil Organic Carbon at the initial state

SOC_{end} = Soil Organic Carbon at the final state

t_{ini} = Initial time

t_{end} = Final time

t_{relax} = Relaxation time (at t_{relax} SOC has reverted to the level in the reference state)

In the baseline scenario, there is no transformation ($SOC_{ini} = SOC_{end}$ = palm plantation). In the alternative scenarios, we first calculated the Land Use transformation impact linked to deforestation (i.e. SOC_{ini} = primary forest on mineral soil; SOC_{end} = palm plantation on mineral soil). We then also calculated the Land Use impact linked to peat soil cultivation with Land Use change (i.e. SOC_{ini} = primary forest on peat soil; SOC_{fin} = palm plantation on peat soil).

For peat soil in Asia, there was no characterisation factor in the Land Use indicator of ILCD methodology. We hence needed to create this soil category in order to take into account the original high carbon stocks in peat soils and potential subsequent effects from the draining and oxidation of peat soil. According to Page et al. (2011), the soil carbon content of a peat soil in Southeast Asia is 55.3 kg C/m² (considering the stock over the first 30 cm depth with a homogeneous distribution over

the first 150 cm). We considered this stock to be the potential initial carbon stock (SOC_{ini}) and used the soil carbon content of 8.6 kg C/m² as a final stock (SOC_{end}). The latter is the one given for tropical wetland under natural vegetation. We chose this stock as the final one considering that it was too low to refer to a natural undisturbed peat soil under forest.

In our study, we considered a regeneration or relaxation time, t_{relax} , for a used peat soil to recover its initial soil carbon stock, of 1,000 years. This time period corresponded to the highest relaxation time available (i.e. the one considered for sealed land)(Milà I Canals et al., 2007), considering that all potential changes are reversible. According to Milà I Canals (2007), we assumed an initial instantaneous transformation over one year, i.e. $t_{end} - t_{ini} = 1$.

The calculated characterisation factor for peat soil transformation was finally: $\Delta SOC = 23,350 \text{ kg C/m}^2$

For occupation, the impact on soil is calculated according to the following formula:

$$\Delta SOC \left(\frac{kgC}{m^2} \right) = \frac{(SOC_{pot} - SOC_{ini}) * (t_{relax} - t_{ini})}{(t_{end} - t_{ini})}$$

Where:

SOC_{ini} = Soil Organic Carbon at the initial state

SOC_{pot} = Soil Organic Carbon potential (at the native state)

t_{ini} = Initial time

t_{end} = Final time

t_{relax} = Relaxation time (at t_{relax} SOC has reverted to the level in the reference state)

In this formula, according to Milà I Canals (2007), we considered that $t_{relax} = t_{end}$

The occupational delay impact is a constant annual carbon deficit due to the lack in carbon stock compared to potential natural state. Result is valid for each year without specification on the soil type. For occupation of peat soil in Asia, we took $SOC_{pot} = 55.3 \text{ kgC/m}^2$, and $SOC_{ini} = 8.6 \text{ kgC/m}^2$, i.e. $\Delta SOC = 46.7 \text{ kg C/m}^2 \cdot \text{year}$. For occupation of mineral soil, we use the ILCD default characterisation factor for “permanent crop Land Use occupation”, without specification on the soil type, i.e. $\Delta SOC = 4 \text{ kg C/m}^2 \cdot \text{year}$.

In addition to this occupational delay impact factor, we also added an actual annual degradation, i.e. occupational change, in soil carbon content due to the draining and oxidation of peat soil. The oxidation of peat soil causes high CO₂ emissions, which we have included in the life cycle inventory in terms of greenhouse gas emissions contributing to the Climate Change impact (see section 2.2.1.2). In order to be consistent and to take into account this soil organic carbon loss for the Land Use, we converted this CO₂ inventory flow into an annual carbon stock change for Land Use impact category (was converted into 1.1 kg C/m².year) (section 2.2.1.2).

3 Results

3.1. Baseline scenario: continuous palm plantation on mineral soil

We performed a contribution analysis of the various production stages including the refined palm kernel oil (RKPO), the rest of the cosmetic cream compound production and processing, the production of the packaging, the transport to retailer and consumer, and the consumer waste management (Fig.2). We notably wanted to assess the relative contributions of agricultural stage (with a focus on palm oil production) and other industrial and logistical stages.

The contribution of each stage group to the total impacts varied with the impact category. Most impacting stages were transport to retailer and consumer, packaging and cosmetic cream. Transport to retailer and consumer was the main contributing process (largest for 11 out of 15 impacts indicators, min = 12% for Ionising Radiation Human Health, max = 82% for Mineral, Fossil and Renewable Resources Depletion). The high impact in terms of Mineral, Fossil and Renewable Resource Depletion was due to fossil fuel use in engines. Packaging production was also a significant contributing process (largest for 2 out of 15 impacts indicators, min = 4% for Mineral, Fossil and Renewable Resource Depletion, max = 82% for Ionising Radiation Human Health). The high impacts were notably related to the energy input, especially the electricity use from the French mix that relies greatly on nuclear electricity leading to a high contribution on Ionising Radiation Human Health. The total contribution of the production of the cosmetic cream itself, i.e. the production of refined palm kernel oil and other compounds and further transformations and assemblages up to the cream without its packaging, represented a high impact (min = 6% for Ionising Radiation Human Health, max = 58% for Land Use) of the impacts. Main contributing stages in the cosmetic cream production were the industrial transformation processes and the production of other vegetable oil, followed by RPKO and the wheat derivative. Cosmetic cream production, RPKO apart, had a non-negligible impact (min = 6% for Ionising Radiation Human Health, max = 54% for Land Use). The high

impact for Land Use was related to the use other vegetable oil besides RPKO. The RPKO production in the baseline scenario, which represented a non-negligible agricultural input on a feedstock mass basis (1.9 g RPKO for 0.3 g wheat and 6 g of other oils, i.e. 20% of the 30 g cream), only had limited impacts (min = 0.3% for Ionising Radiation Human Health, max = 12% for Marine Eutrophication). The consumer waste management had a non-negligible impact in terms of avoided impact due to material recycling notably regarding Ionizing Radiation Ecosystems, where it led to a 32% reduction of the global impact.

We further investigated the process contributions within the RPKO production stage (Fig. 3). In the baseline scenario, the impacts of RPKO production were driven by the fresh fruit bunch (FFB) production in the field and the palm oil processing. The palm oil mill effluent (POME) treatment essentially contributed to the Climate Change impact (53%) due to the release of methane during anaerobic treatment in open ponds. FFB production had the largest impact overall (min = 34% for Climate Change, max = 96% for Marine Eutrophication). This high impact was notably due to the use of synthetic mineral fertilizers greatly contributing to Climate Change, Photochemical Ozone Formation, Acidification and Eutrophication impact categories. Crude palm oil (CPO) extraction, i.e. fruit production apart, also had a high impact (min = 1% for Land Use, max = 60% for Climate Change). CPO has a high impact for Particulate Matter mostly came from power central (boiler) and to a lesser extent from the plant construction. Further contributions from other energy and chemical uses (refinery step), as well as input and fruit transport to the mill, had low impacts.

3.2. Influences of deforestation, peat soil oxidation, and POME treatment

We investigated deeper the influence on the overall cosmetic cream impacts of the palm plantation establishment and the palm oil mill effluent treatment. The parameters tested in the alternative scenarios (see section 2.2.1.2) were the following:

- The previous Land Use: primary forest, i.e. deforestation, or palm cultivation, i.e. continuous agricultural land use
- Soil type: mineral or peat soils
- The treatment of POME: conventional treatment or methane capture and electricity recovery.

Deforestation and peat soil transformation and occupation were translated i) in the life cycle inventory as GHG emissions, and ii) in soil organic carbon changes embedded in the Land Use impact. Hence, these two parameters only influenced two impact categories, i.e. Climate Change and Land

Use (Fig. 4). On Climate Change indicator, deforestation caused an increase of about 9% in the cosmetic cream final impact (i.e. +282% in the RPKO impact), peat soil occupational change (i.e. annual degradation of carbon stock and related CO₂ emissions) caused an even greater increase of 16% over the whole cosmetic cream life cycle (i.e. +46% for the RPKO). On Land Use indicator, deforestation caused an increase of 3%, peat soil occupational delay (i.e. both the annual degradation and the annual cost for delaying the relaxation to natural stock) and transformation caused impact increases of 41% and 938%, respectively. The influence of peat soil transformation and occupational delay was tremendous and in particular even much higher than that of deforestation. These high increases corresponded to a variation of +917% for peat soil occupational delay and +20,904% for peat soil transformation when focusing on the RPKO impacts.

Methane capture and conversion to electricity represented a low decrease in environmental impact (min = -0.1% for Ionizing Radiation Human Health, max = -3% for Marine Eutrophication). The gain provided by the improved treatment of POME was very low but consistent across all impact categories. Focusing on RPKO production stage, POME improved treatment allowed a low decrease. So, at the agricultural scale, POME improved treatment in order to produce electricity remained interesting. At the cream final product scale, the gain provided remained negligible. However, compared to deforestation and peat soil transformation and occupation, improved POME treatment had a general, albeit small, positive influence on all impact categories.

4 Discussion

In the baseline scenario, which corresponded to a standard industrial palm production system in Malaysia with no land use change, we could observe an impact of the palm kernel oil production and refinery on the overall life cycle impact of the cosmetic cream. In this context, the contribution of refined palm kernel oil was not critical with regard to the other process stages along the whole life-cycle of the cosmetic cream. Moreover, palm kernel oil extraction and refinery processes were less energy intensive (particularly in terms of fossil energy use) than most of the other up- and downstream processes.

In comparison with the baseline economic allocation approach, using mass allocation ratios (except at purchase stage due to lack of data for mass of shopping basket), environmental impacts would have been lower (min=-0.4% for Ionizing Radiation; max=-15% for Marine Eutrophication). Mass allocation ratios lowered RPKO impacts given the higher price per mass unit compared to refined palm oil. The contribution of RPKO production to the final cream impact was very low. Besides

reduction in RPKO impacts with mass allocation ratio, the contributions of other cream life cycle stages were not influenced by the change in allocation ratios.

Within the whole life-cycle of the cosmetic cream, the more impacting stages were packaging and transport. The primary data from the industrial partner allowed for a refined site-specific modelling of the industrial phase. However, some assumptions were still needed as well as the use of some secondary data from Ecoinvent v.3 database for some upstream background processes. We also modelled average current practices in term of transportation means and distances. More specific transport strategies might be explored to reduce the overall impacts but would need to be assessed on a case-by-case basis. Transport apart, the main remaining problem is the packaging which influenced significantly the final cream impacts, we looked at alternative scenarios for the end of life of the packaging (see Fig S1 in supplementary materials). When the HDPE packaging was entirely recycled, the total cream impacts were reduced (min=0% for Ozone Depletion; max=-25% for Ionizing Radiation), with a packaging impact (production + end of life management) contribution slightly decreased. Further complementary investigations might also be needed to check whether the assumption of the cream absorption with negligible washing out (Guilbot et al., 2013) may have an influence on the final results.

In the alternative scenarios, the RPKO contribution became much more critical for two impact categories, i.e. Climate Change and Land Use. The annual CO₂ emissions and the cumulated soil organic carbon depletion due to the draining and oxidation of the peat soil were the most influential parameters over all. Impact of peat soil drainage and oxidation would be even higher considering the former IPCC coefficient for wetland N₂O emissions (2006), i.e. +10% in the RPKO Climate Change impact, or lower with another reference for CO₂ emissions (Hooijer et al., 2010), i.e. -18% in the RPKO Climate Change impact. This emphasises the need for further research work and consensus finding on guidelines and coefficients to assess the environmental impact of peat soil conversion. We adapted some coefficients and stocks found in the literature and proposed to include some part of the occupation impact, which is usually considered as negligible. However, more needs to be done. Concerning peat soil conversion, several factors in particular would need to be further addressed, e.g. the flush emissions right after opening and drainage start, the irreversible impact due to acute subsidence, the methane emissions from the drains or the indirect impacts at the watershed level, etc. From an environmental point of view, though, these estimate on Climate Change and Land Use impacts, albeit incomplete and perfectible, already highlight the prohibitive impact of peat soil conversion to agricultural uses where dense drainage is mandatory.

Our study aimed at providing a comprehensive LCA of a bio-sourced product, while focusing on the relative importance of the agricultural stage and production conditions over the whole supply chain. Further investigations would be necessary in order to better model potential discrepancies in agroecological performances between oil palm productions on mineral or peat soils, e.g. potential variations in crop cycle length, yields, disease pressure, and pesticide or fertilizer managements.

5 Conclusion

This study dealt with environmental impacts of a cosmetic cream, which contained palm kernel oil-based as surfactant, from feedstock production to end of life management. It gave a precise picture of main impact contributors over the whole life-cycle of a bio-based cosmetic cream. It turned out that the transport from the retailer to the customer had the highest impact (highest for 11 out of 15 impacts indicators, min = 12% for Ionising Radiation Human Health, max = 82% for Mineral, Fossil and Renewable Resource Depletion). It was mainly caused by the use of petrol. The packaging had also a high impact (2 out of 15, min = 4% for Mineral, Fossil and Renewable Resource Depletion, max = 82% for Ionising Radiation Human Health). Agricultural phase in order to obtain RPKO had a small impact contribution (min = 0.3% for Ionising Radiation Human Health, max = 12% for Marine Eutrophication). The rests of the impacts were due to chemical step (min = 6% for Ionising Radiation Human Health, max = 54% for Land Use) and end of life management (min = -32%, max = 11%).

Many parameters could influence the palm oil production (i.e. RPKO impact contribution) and we investigated three of them: the previous land use, soil type and POME management. Mainly two impacts indicators were concerned in the alternative scenarios: Climate Change and Land Use with an increase of 25% and 1,528%, respectively, compared to the baseline scenario. On Climate Change, 9% were caused by deforestation and 16% by peat soil transformation and use. On Land Use, 938% were caused by peat soil transformation, 41% by peat soil use and occupational delay, and 3% by deforestation. Within the complete cream life-cycle, peat soil transformation and cultivation had the highest impact, while POME management was negligible.

An eco-design of the cosmetic cream could reduce its environmental impact considering some improvements at several stages. One of the key aspects was the packaging, where lower mass could reduce production and transportation impacts. Ecodesign would also require the integration of good farming practices, mainly concerning the previous land use and the type of soil, avoiding peat soil use. Through the example of a palm oil based cosmetic cream, this study showed the interest of a whole approach to bring face-to-face agricultural productions, transformations and use of products.

References

- 508 Achten, W.M.J., Vandenbempt, P., Almeida, J., Mathijs, E., Muys, B., 2010. Life Cycle Assessment of a
509 Palm Oil System with Simultaneous Production of Biodiesel and Cooking Oil in Cameroon.
510 Environ. Sci. Technol. 44, 4809–4815. doi:10.1021/es100067p
- 511 ADEME, BIO Intelligence Service, 2010. Analyse de Cycle de Vie appliquées aux biocarburants de
512 première génération consommés en France.
- 513 Angarita, E.E.Y., Silva Lora, E.E., da Costa, R.E., Torres, E.A., 2009. The energy balance in the Palm Oil-
514 Derived Methyl Ester (PME) life cycle for the cases in Brazil and Colombia. Renew. Energy 34,
515 2905–2913. doi:10.1016/j.renene.2009.05.007
- 516 Arvidsson, R., Persson, S., Fröling, M., Svanström, M., 2011. Life cycle assessment of hydrotreated
517 vegetable oil from rape, oil palm and Jatropha. J. Clean. Prod. 19, 129–137.
518 doi:10.1016/j.jclepro.2010.02.008
- 519 Badey, L., Lahitte, N., 2013. Guide de méthodologie simplifiée pour la réalisation des ACV dans le
520 cadre de la mise à disposition de l'information environnementale des huiles végétales.
- 521 BIO Intelligence Service, 2013. Study on an increased mechanical recycling target for plastics, Final
522 report prepared for Plastics Recyclers Europe, BIO Intelligence Service for Plastics Recyclers
523 Europe.
- 524 Blonk Agri-footprint, 2014. Agri-footprint Methodology and Basic Principles.
- 525 Boonrod, B., Prapainainar, C., Narataruksa, P., Kantama, A., Saibautrong, W., Sudsakorn, K.,
526 Mungcharoen, T., Prapainainar, P., 2016. Evaluating the environmental impacts of bio-
527 hydrogenated diesel production from palm oil and fatty acid methyl ester through life cycle
528 assessment. J. Clean. Prod. 1–12. doi:10.1016/j.jclepro.2016.07.128
- 529 Brandão, M., Milà i Canals, L., 2013. Global characterisation factors to assess land use impacts on
530 biotic production. Int. J. Life Cycle Assess. 18, 1243–1252. doi:10.1007/s11367-012-0381-3
- 531 Brockmann, D., Hanhoun, M., Négri, O., Hélias, A., 2014. Environmental assessment of nutrient
532 recycling from biological pig slurry treatment--impact of fertilizer substitution and field
533 emissions. Bioresour. Technol. 163, 270–9. doi:10.1016/j.biortech.2014.04.032
- 534 Chavalparit, O., Rulkens, W.H., Mol, A.P.J., Khaodhair, S., 2006. OPTIONS FOR ENVIRONMENTAL
535 SUSTAINABILITY OF THE CRUDE PALM OIL INDUSTRY IN THAILAND THROUGH ENHANCEMENT
536 OF INDUSTRIAL ECOSYSTEMS. Environ. Dev. Sustain. 8, 271–287. doi:10.1007/s10668-005-9018-

- 537 z
- 538 Choo, Y.M., Muhamad, H., Hashim, Z., Subramaniam, V., Puah, C.W., Tan, Y., 2011. Determination of
539 GHG contributions by subsystems in the oil palm supply chain using the LCA approach. *Int. J.*
540 *Life Cycle Assess.* 16, 669–681. doi:10.1007/s11367-011-0303-9
- 541 Choo, Y.M., Puah, C.W., Yew, A.T., Vijaya, S., Zulkifli, H., Halimah, M., 2010. Part 3a: Life cycle
542 assessment of the production of crude palm kernel oil. *J. oil palm Res.* 22, 904–912.
- 543 Chuchuo, K., Paengjuntuek, W., Usubharatana, P., Phungrassami, H., 2009. Preliminary study of
544 Thailand carbon reduction label : a case study of crude palm oil production. *Eur. J. Sci. Res.* 34,
545 252–259.
- 546 De Klein, C., Novoa, R.S., Ogle, S., Smith, K.A., Rochette, P., Wirth, T.C., 2006. Chapter 11 N₂O
547 emissions from managed soils , and CO₂ emissions from lime and urea application 1–54.
- 548 De La Fuente Layos, L.A., 2005. Mobilité des passagers à courte distance en Europe.
- 549 Drösler, M., Verchot, L., Freibauer, A., Pan, G., 2013. Chapter 2 drained inland organic soils 1–79.
- 550 EC-JRC, 2011. International Reference Life Cycle Data System (ILCD) Handbook: Recommendations
551 for Life Cycle Impact Assessment in the European context EUR 24571 EN - 2011, First Edit. ed.
552 Publications Office of the European Union, Luxembourg. doi:10.278/33030
- 553 EMEP, EEA, 2013. Air pollutant emission inventory guidebook. doi:10.2800/92722
- 554 EPA, 2012. Final Directive on Palm Oil. RFS2. Federal Register / Vol. 77, No. 18.
- 555 European Commission, 2012. Characterisation factors of the ILCD Recommended Life Cycle Impact
556 Assessment methods. doi:10.2788/60825
- 557 European Commission, E., 2014. EU Transport in Figures. Statistical Pocketbook 2014.
558 doi:10.2832/63317
- 559 European Palm Oil Alliance, 2015. Palm Oil Consumption [WWW Document]. URL
560 <http://www.palmoilandfood.eu/en/palm-oil-consumption>
- 561 Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land Clearing and the Biofuel Carbon
562 Debt. *Science* (80-.). 319, 1235–1239.

- Farrel, A.E., Plevin, R.J., Turner, B.T., Jones, A.D., O'Hare, M., Kammen, D.M., 2006. Ethanol Can Contribute to Energy and Environmental Goals. *Science* (80-.). 311, 506–509.
- Gerngross, T.U., 1999. Can Biotechnology move us toward a sustainable society? *Nat. Biotechnol.* 17, 541–544.
- Gibbs, H.K., Johnston, M., Foley, J. a, Holloway, T., Monfreda, C., Ramankutty, N., Zaks, D., 2008. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. *Environ. Res. Lett.* 3, 34001. doi:10.1088/1748-9326/3/3/034001
- Giraldo, L., Camargo, G., Tirano, J., Moreno-Piraján, J.C., 2010. Synthesis of Fatty Alcohols from Oil Palm Using a Catalyst of Ni-Cu Supported onto Zeolite. *E-Journal Chem.* 7, 1138–1147. doi:10.1155/2010/439801
- Gnansounou, E., Dauriat, A., Villegas, J., Panichelli, L., 2009. Life cycle assessment of biofuels: Energy and greenhouse gas balances. *Bioresour. Technol.* 100, 4919–4930. doi:10.1016/j.biortech.2009.05.067
- Guilbot, J., Kerverdo, S., Milius, A., Escola, R., Pomrehn, F., 2013. Life cycle assessment of surfactants: the case of an alkyl polyglucoside used as a self emulsifier in cosmetics. *Green Chem.* 15, 3337. doi:10.1039/c3gc41338a
- Harsono, S.S., Prochnow, A., Grundmann, P., Hansen, A., Hallmann, C., 2012. Energy balances and greenhouse gas emissions of palm oil biodiesel in Indonesia. *GCB Bioenergy* 4, 213–228. doi:10.1111/j.1757-1707.2011.01118.x
- The sustainability consortium, 2013. Life Cycle Impact Study of Leave-on Skin Care Products. <https://www.sustainabilityconsortium.org/hpc/>
- Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H., Jauhiainen, J., 2010. Current and future CO₂ emissions from drained peatlands in Southeast Asia. *Biogeosciences* 7, 1505–1514. doi:10.5194/bg-7-1505-2010
- Hutchings, N., Webb, J., Amon, B., 2013. EMEP/EEA air pollutant emission inventory guidebook - 2013 - Crop production and agricultural soil.
- Intergovernmental Panel on Climate Change, 2006. Volume 4 Agriculture, Forestry and Other Land Use.

- 591 Jolliet, O., Ernstoff, A.S., Csiszar, S.A., Fantke, P., 2015. Defining Product Intake Fraction to Quantify
592 and Compare Exposure to Consumer Products. *Environ. Sci. Technol.* 49, 8924–8931.
593 doi:10.1021/acs.est.5b01083
- 594 JRC, EUCAR, CONCAWE, 2008. Well-to-Wheels study. Version 3, year 2008.
- 595 Jungbluth, N., Chudacoff, M., Dauriat, A., Dinkel, F., Doka, G., Emmenegger, M.F., Gnansounou, E.,
596 Kljun, N., Schleiss, K., Spielmann, M., Stettler, C., Sutter, J., 2007. Life Cycle Inventories of
597 Bioenergy. ecoinvent report No. 17, Ecoinvent. Dübendorf.
- 598 Koellner, T., de Baan, L., Beck, T., Brandão, M., Civit, B., Goedkoop, M., Margni, M., i Canals, L.M.,
599 Müller-Wenk, R., Weidema, B., Wittstock, B., 2013. Principles for life cycle inventories of land
600 use on a global scale. *Int. J. Life Cycle Assess.* 18, 1203–1215. doi:10.1007/s11367-012-0392-0
- 601 Kroes, R., Renwick, A.G., Feron, V., Galli, C.L., Gibney, M., Greim, H., Guy, R.H., Lhuguenot, J.C., van
602 de Sandt, J.J.M., 2007. Application of the threshold of toxicological concern (TTC) to the safety
603 evaluation of cosmetic ingredients. *Food Chem. Toxicol.* 45, 2533–2562.
604 doi:10.1016/j.fct.2007.06.021
- 605 Lodén, M., 2012. Effect of moisturizers on epidermal barrier function. *Clin. Dermatol.* 30, 286–296.
606 doi:10.1016/j.clindermatol.2011.08.015
- 607 Milà i Canals, L., Bauer, C., Depestele, J., Dubreuil, A., Freiermuth Knuchel, R., Gaillard, G., Michelsen,
608 O., Müller-Wenk, R., Rydgren, B., 2007. Key Elements in a Framework for Land Use Impact
609 Assessment Within LCA (11 pp). *Int. J. Life Cycle Assess.* 12, 5–15. doi:10.1065/lca2006.05.250
- 610 Milà I Canals, L., Muñoz, I., McLaren, S., Miguel, B., 2007. LCA Methodology and Modelling
611 Considerations for Vegetable production and Consumption. CES Working Papers 02/07. United
612 Kingdom, Cent. Environ. Strateg. Univ. Surrey 46.
- 613 Muhammad, H., Hashim, Z., Subramaniam, V., Tan, Y. a, Wei, P.C., Let, C.C., May, C.Y., 2010. Life
614 Cycle Assessment of Oil Palm Seedling Production (Part 1). *J. Oil Palm Res.* 22, 878–886.
- 615 Nemecek, T., Schnetzer, J., 2012. Methods of assessment of direct field emissions for LCIs of
616 agricultural production systems 0.
- 617 Nilsson, K., Flysjö, A., Davis, J., Sim, S., Unger, N., Bell, S., 2010. Comparative life cycle assessment of
618 margarine and butter consumed in the UK, Germany and France. *Int. J. Life Cycle Assess.* 15,
619 916–926. doi:10.1007/s11367-010-0220-3

- 620 Page, S.E., Rieley, J.O., Banks, C.J., 2011. Global and regional importance of the tropical peatland
621 carbon pool. *Glob. Chang. Biol.* 17, 798–818. doi:10.1111/j.1365-2486.2010.02279.x
- 622 Papong, S., Chom-In, T., Noksa-nga, S., Malakul, P., 2010. Life cycle energy efficiency and potentials
623 of biodiesel production from palm oil in Thailand. *Energy Policy* 38, 226–233.
624 doi:10.1016/j.enpol.2009.09.009
- 625 Parveen, F.R., Rajeev, P.S., Hakimi, I., Norizan, E., 2010. Review of current palm oil mill effluent
626 (POME) treatment methods: Vermicomposting as a sustainable practice. *World Appl. Sci.* ... 11,
627 70–81.
- 628 Pleanjai, S., Gheewala, S.H., Garivait, S., 2009. Greenhouse gas emissions from the production and
629 use of palm methyl ester in Thailand. *Int. J. Glob. Warm.* 1, 418. doi:10.1504/IJGW.2009.029213
- 630 Prasuhn, V., 2006. Erfassung der PO 4 -Austräge für die Ökobilanzierung. SALCA-Phosphor, in:
631 Agroscope FAL Reckenholz. Zürich.
- 632 Reijnders, L., Huijbregts, M.A.J., 2008. Palm oil and the emission of carbon-based greenhouse gases.
633 *J. Clean. Prod.* 16, 477–482. doi:10.1016/j.jclepro.2006.07.054
- 634 Rival, A., Levang, P., 2014. Palms of controversies Oil palm and development challenges.
- 635 Schmidt, J.H., 2007. Life cycle assessment of rapeseed oil and palm oil.
- 636 Secchi, M., Castellani, V., Collina, E., Mirabella, N., Sala, S., 2016. Assessing eco-innovations in green
637 chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient. *J.*
638 *Clean. Prod.* 129, 269–281. doi:10.1016/j.jclepro.2016.04.073
- 639 Vijaya, S., Choo, Y.M., Halimah, M., Zulkifli, H., Tan, Y.A., Puach, C.W., 2010. LIFE CYCLE ASSESSMENT
640 OF THE PRODUCTION OF CRUDE PALM OIL (Part 3) 22, 895–903.
- 641 Wicke, B., Dornburg, V., Junginger, M., Faaij, A., 2008. Different palm oil production systems for
642 energy purposes and their greenhouse gas implications. *Biomass and Bioenergy* 32, 1322–1337.
643 doi:10.1016/j.biombioe.2008.04.001
- 644 Williams, F.M., Rothe, H., Barrett, G., Chiodini, A., Whyte, J., Cronin, M.T.D., Monteiro-Riviere, N.A.,
645 Plautz, J., Roper, C., Westerhout, J., Yang, C., Guy, R.H., 2016. Assessing the safety of cosmetic
646 chemicals: Consideration of a flux decision tree to predict dermally delivered systemic dose for
647 comparison with oral TTC (Threshold of Toxicological Concern). *Regul. Toxicol. Pharmacol.* 76,

648 174–186. doi:10.1016/j.yrtph.2016.01.005

649 Yew, A.T., Halimah, M., Zulkifli, H., Vijaya, S., Puah, C.W., Chong, C.L., Maah, N., Choo, Y.M., 2010. Life
650 Cycle Assessment of refined palm oil production and fractionation (part 4) 22, 913–926.

651 Yusoff, S., Hansen, S.B., 2007. Feasibility Study of Performing an Life Cycle Assessment on Crude Palm
652 Oil Production in Malaysia. *Int. J. Life Cycle Assess.* 12, 50–58.

653 Zah, R., Hischer, R., 2007. Life cycle inventories of detergents, Report n°12, Ecoinvent. ed.

654 Zulkifli, H., Halimah, M., Mohd Basri, W., Choo, Y.M., 2009. Life cycle assessment for FFB production.
655 PIPOC 2009 Palm Oil - Balanc. Ecol. with Econ. 6.

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Table 1: Life Cycle Inventory for the production of 23.57kg of RPKO (from 1000kg of FFB)

	Unit	FFB	Kernels	CPKO	RPKO
Output products					
FFB	kg	1,000 ^b			
Kernels	kg		53.2 ^b		
CPKO	kg			23.88 ^b	
RPKO	kg				23.57 ^b
CPO	kg		199.8 ^b		
EFB	kg		225 ^b		
POME			672.5 ^b		
Palm kernel cake	kg			27.72 ^b	
Free Fatty Acid	kg				0.24 ^b
Input					
Soil transformation	m ²	20.9 ^h			
Soil occupation	m ² year	521.9 ^h			
Energy use					
Diesel : agriculture machinery	L	2.37 ^a	0.57 ^b		
Electricity from the grid	MJ		0.8 ^b	10.03 ^b	2.99 ^b
Electricity produced	MJ		31 ^b		
Heat (steam)	MJ				7.73 ^b
Material use					
Water	L		1,300 ^b	9.55 ^b	16.5 ^b
Oil palm seedling	Transplant	0.33 ^a			
Amonium sulfate	kg	8.05 ^a			
Urea	kg	0.41 ^a			
Ammonium nitrate	kg	0.76 ^a			
Ammonium chloride	kg	0.72 ^a			
Nitrogen fertiliser, as N	kg	3.49 ^a			
Potassium chloride, as K ₂ O	kg	11.60 ^a			
Potassium fertiliser, as K ₂ O	kg	4.50 ^a			
Phosphate rock, as P ₂ O ₅	kg	6.55 ^a			
Phosphate fertiliser, as P ₂ O ₅	kg	0.64 ^a			
Glyphosate	kg	0.34 ^a			
[Sufonyl]urea compounds	kg	0.15 ^a			
Bipyridylum compounds	kg	0.10 ^a			
Pyretroid compounds	kg	2.15x10 ^{-2a}			
Organophosphorus compounds	kg	6.40x10 ^{-2a}			
Dimethylamine	kg	3.10x10 ^{-2a}			
Pesticide unspecified	kg	2.13 ^a			
Phosphoric acid	kg				5.89x10 ^{-3b}

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NaOH	kg				6.83×10^{-2b}
Bleaching earth	kg				1.06×10^{-1b}
Transport					
FFB to mill, lorry	tkm	50			
Fertilizer from plant to port, ship	tkm	171.95^b			
Pesticides from plant to port, ship	tkm	14.14^b			
Fertilizer from port to plantation, lorry	tkm	5.10^a			
Pesticides from port to plantation, lorry	tkm	0.15^a			
Raw material and ancillaries, lorry	tkm		0.1^b		
Kernel, lorry	tkm			4.2^b	
Palm kernel cake, lorry	tkm			1.1^b	
Phosphoric acid	tkm				5.89×10^{-3b}
NaOH	tkm				6.84×10^{-2b}
Bleaching earth	tkm				1.06×10^{-1b}
Diesel	tkm				3.77×10^{-2b}
Fodder fat	tkm				4.71×10^{-2b}
Emissions to air					
CO ₂	kg	0			
CO ₂ land transformation	kg	0			
NH ₃	kg	4.50×10^{-1c}	4.24×10^{-2b}		
N ₂ O	kg	$7.57 \times 10^{-2b,c}$	6.81×10^{-3b}		
NO _x	kg	9.35×10^{-2e}	2.72×10^{-1b}		
CH ₄	Kg		8.74^b		
H ₂ S	kg		5.79×10^{-2b}		
SO ₂	kg		2.4×10^{-3b}		
CO	kg		6.71×10^{-1b}		
Particulates, < 2.5 um	kg		1.51×10^{-1b}		
Acetaldehyde	kg		1.2×10^{-4b}		
Arsenic	kg		1.9×10^{-6b}		
Benzene	kg		1.73×10^{-3b}		
Benzene, ethyl-	kg		5.72×10^{-5b}		
Benzene, hexachloro-	kg		1.37×10^{-11b}		
Benzo(a)pyrene	kg		9.52×10^{-7b}		
Cadmium	kg		1.33×10^{-6b}		
Chlorine	kg		3.42×10^{-4b}		
Chromium	kg		7.54×10^{-6b}		
Chromium VI	kg		7.62×10^{-8b}		
Copper	kg		4.20×10^{-5b}		
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg		5.90×10^{-11b}		
Formaldehyde	kg		2.48×10^{-4b}		
Hydrocarbons, aliphatic, alkanes, C10,	kg		1.73×10^{-3b}		

branched					
Hydrocarbons, aliphatic, unsaturated	kg		6×10^{-3b}		
Lead	kg		4.76×10^{-5b}		
m-Xylene	kg		2.28×10^{-4b}		
Manganese	kg		3.24×10^{-4b}		
Mercury	kg		5.72×10^{-7b}		
Nickel	kg		1.14×10^{-5b}		
NMVOC, non-methane volatile organic compounds	kg		1.71×10^{-3b}		
PAH, polycyclic aromatic hydrocarbons	kg		2.12×10^{-5b}		
Phenol, pentachloro-	kg		1.54×10^{-8b}		
Phosphorus	kg		5.72×10^{-4b}		
Toluene	kg		5.72×10^{-4b}		
Zinc	kg		5.72×10^{-4b}		
Emissions to water					
NO ³⁻	kg	4.78 ^c		7.16×10^{-5b}	
PO ₄ ³⁻	kg	3.94×10^{-2f}			
P	kg				1.88×10^{-3b}
Emissions to soil					
Lead	mg	51.9 ^{a,g}			
Cadmium	mg	140 ^{a,g}			
Chromium	mg	1,480 ^{a,g}			
Nickel	mg	265 ^{a,g}			
Copper	mg	292 ^{a,g}			
Zinc	mg	2,460 ^{a,g}			
Mercury	mg	0.682 ^{a,g}			
Arsenic	mg	73.8 ^{a,g}			
Thallium	mg	3.93 ^{a,g}			
Glyphosate	kg	0.338 ^{a,g}			
Metsulfuron-methyl	kg	0.148 ^{a,g}			
Paraquat	kg	0.104 ^{a,g}			
Cypermethrin	kg	$2.15 \times 10^{-2 a,g}$			
Glufosinate ammonium	kg	$3.20 \times 10^{-2 a,g}$			
Methamidophos	kg	$3.20 \times 10^{-2 a,g}$			
Carbofuran	kg	$3.50 \times 10^{-2 a,g}$			
Dimethylamine	kg	$3.10 \times 10^{-2 a,g}$			
Waste to treatment					
Waste water	kg				16.5 ^b
Bleaching earth to landfill	kg				1.51×10^{-1b}

^a (Choo et al., 2011)^b (Schmidt, 2007)^c (De Klein et al., 2006)^d (Drösler et al., 2013)^e (Hutchings et al., 2013)^f (Nemecek and Schnetzer, 2012)

^g (Brockmann et al., 2014)^h (faostat.fao.org/)

Table n°2: LCI of the production of 30 g of cosmetic cream (primary data from the industrial partner)

	Unit	Quantity
Inputs		
APG	g	1.5
Vegetable oil	g	6.0
Nitrogen	g	12.2
Tap water	g	24.7
Energy		
Electricity	kWh	2.1×10^{-2}
Steam	g	2.5×10^{-3}
Transport lorry	kgkm	6.3
Output		
Wastewater	ml	3.0×10^{-1}
Mud to incineration	g	2.1

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Fig 1: Overview of the global system for 1 jar of cosmetic cream.

Fig 2: LCA results of the continuous palm plantation on mineral soil (baseline scenario)

Fig 3: LCA results of RPKO in baseline scenario

Fig 4: Influence of deforestation, peat soil transformation, peat soil occupation, POME treatment

Highlights

- Transport and packaging contribute the most to all impacts over the cream life cycle
- Refined Palm Kernel Oil represents on average 20% of this total impact
- Deforestation increases Climate Change by 12% and Land Use impact by 6%
- Peat soil occupation increases Climate Change by 22% and Land Use impact by 84%
- Improving palm oil mill effluent treatment reduces impacts by 1.49% on average

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