Université Libre de Bruxelles

Institut de Gestion de l'Environnement et d'Aménagement du Territoire

Faculté de Sciences

Master en Sciences et Gestion de L'environnement

« Cradle-to-Gate Life Cycle Analysis (LCA) of Ylang-Ylang Complete Essential Oil Destined for Cosmetic Use from Central Region, Ghana Using the Software SimaPro »

Mémoire de Fin d'Etudes présenté par

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En vue de l'obtention du grade académique de Master

en Sciences et Gestion de l'Environnement,

Finalité Gestion de l'Environnement

M-ENVIG / ENVI4 /

Finalité Sciences de l'Environnement M-ENVIE

Année Académique : 2018-2019

Directeur : Professeur ACHTEN Wouter

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Abstract (English)

As consumer demands verge towards ecologically responsible products, the cosmetics industry must begin to accommodate life cycle assessment testing in order to identify the environmental impact of product ingredients. Ylang-ylang essential oil is marketed as a natural fragrance that is used in a broad range of cosmetic products. Given the high levels of cosmetic greenwashing present in cosmetic marketing however, it is important to assess ylang-ylang oil's production in order to determine if it merits its reputation. This dissertation attempts to identify the environmental impacts related to raw ylang-ylang oil production and hotspots within its production process. Data and assessment are performed by applying cradle-to-gate life cycle analysis on a Ghanaian ylang-ylang production system using the software SimaPro. Assessment results and comparison with available scientific literature show that ylang-ylang oil has a relatively similar environmental impact to other essential oils that have been studied. It does however have a significant impact in regard to water consumption, which is largely due to steam-distillation methods for its extraction. Other impact categories are mostly due to the use of chicken manure as fertilizer during cultivation stages, as well as the manufacturing of capital goods used throughout production. The results of this analysis represent an initial evaluation and categorization of the essential oil's environmental impacts for comparison or future study. It also attempts to increase available knowledge and product transparency of a widely used ingredient in the cosmetics industry.

Abstract (French)

Alors que la demande du consommateur se tourne vers des produits respectueux de l'écologie, l'industrie cosmétique se doit d'adopter des tests d'évaluation du cycle de vie afin de déterminer l'impact environnemental des ingrédients qui composent ses produits. L'huile essentielle d'Ylang-ylang est commercialisée comme un parfum naturel utilisé dans une vaste gamme de produits cosmétiques. Cependant, compte tenu du niveau élevé d'éco-blanchissement qui prévaut dans le marketing des produits cosmétiques, il est important d'évaluer la production de l'huile d'Ylang-ylang pour déterminer si elle est à la hauteur de sa réputation. Ce mémoire cherche à identifier les impacts environnementaux liés à la production d'huile vierge d'Ylang-ylang et les zones sensibles de son processus de fabrication. Les données et les évaluations proviennent d'une analyse de cycle de vie de la production de Ylang-ylang dans une ferme basée au Ghana, à l'aide du logiciel SimaPro. Les résultats obtenus et leur comparaison avec la littérature scientifique disponible montrent que l'huile d'Ylang-ylang a un impact environnemental relativement similaire à celui des autres huiles essentielles étudiées par des autres auteurs. Elle a toutefois un impact significatif sur la consommation d'eau, lié principalement à la méthode de production puisqu'elle est extraite par distillation à la vapeur. D'autres impacts intéressants proviennent largement de l'utilisation de fumier de volaille comme engrais au cours des phases de culture. Les résultats de cette analyse constituent une évaluation initiale et une catégorisation des impacts environnementaux de l'huile essentielle à l'usage de comparaison ou d'études futures. Ils cherchent aussi à faire mieux connaître et à donner davantage de transparence à un ingrédient largement utilisé dans l'industrie cosmétiques.

Introduction

Context

Given the recent shift in demand towards environmentally friendly products within the cosmetics industry, the exploration and study of ingredient manufacturing is essential in order to pin-point harmful and polluting procedures within the cosmetic production process. Ylang-ylang oil is hailed as a natural and ecological alternative to synthetic perfume ingredients in both the cosmetic and aromatherapy sectors. However, company "green washing" in order to profit from new ecological trends is of true concern, and thus, the "green" reputation of ylang-ylang oil – as well as that of other naturally derived cosmetic ingredients – must be studied for consumers and producers to make informed decisions regarding their purchase of cosmetic constituents.

Ylang-ylang is a pale-yellow oil with a powerful, elegant, flowery odor that has been considered a staple within the cosmetics industry for a number of years, notably in high-end perfumes. The oil is distilled from flowers of *Cananga Odorata*, a fast-growing tree cultivated in the tropics (Parotta, 2014). It is a featured ingredient in popular luxury perfumes such as *Chanel No.5*, and is also present in soaps and hair products, either for its beautifying properties or as a fragrance (Manner et al., 2006; Parotta, 2014; Saedi et al., 2006). A number of companies considered to be "natural" or "eco-friendly" feature the oil in their products.

Despite the importance of studying ingredient production processes and their effects on the environment, there is very little available scientific literature on the ecological impact of ylang-ylang oil production and other naturally derived cosmetics products in general. This may be explained by the relative novelty of this trend within the cosmetics industry, spurred notably by growing consumer demand for natural products in exchange of synthetic alternatives. Essential oils tend to have a positive reputation in the world of cosmetics for their natural scents and health benefits – the cosmetics industry is now the biggest consumer of essential oils in general (Bessah et al., 2015). It is however important for consumers to practice caution when faced with such sweeping claims – the production of these oils can potentially have a significant impact on the environment and contribute to climate change. Essential oils cultivated and produced for industrial use often hail from tropical locations and are established sources of revenue for the developing countries in which they are farmed (Salomon, 1979; ITC, 2015; Carrubba et al., 2009). High demand for these products spurs intensive agriculture that may cause harm to the immediate environment and to those around it. Processing of the oils for consumer use is also not free of impacts, and the social and economic aspects of producing essential oils in developing countries should also not be ignored. Natural does not always mean sustainable (Sahota, 2014). It is therefore important to explore these aspects in order to validate its praise and confirm ylang-ylang's place in the cosmetic industry as a natural ingredient to be favored and consumed.

Research Question and Hypotheses

The purpose of this dissertation is to define and evaluate the environmental releases associated with the production of ylang-ylang essential oil destined for cosmetic use. This includes determining significant environmental impacts associated with its manufacturing, as well as production factor hotspots throughout its processing. Defining the environmental influence for each step of production can also help in establishing key points to study further in the interest of rendering the process more environmentally friendly.

Life Cycle Analyses (LCA's) aid in assessing a product's potential environmental impact over its lifetime (Chevalier et al, 2011). They are an informative tool both for companies making efforts to green their production and ingredient lists as well as for consumers purchasing products. Increasing understanding of ingredient manufacturing can aid in informed decision-making and investment choices. A LCA of ylang-ylang production is fitting and appropriate in this current shift in cosmetic trends and manufacturing.

Based on personal observations, the study of existing literature, and knowledge acquired during this masters program, it is hypothesized that the most impactful steps in the ylang-ylang production process will be its distillation along with its transportation to finalized processing facilities. The high technological and natural resource demand for these two steps and their higher rates of processing are expected to have high resource requirements and infrastructure needed for distillation. The heat requirements and large quantities of water needed to extract the oil are expected to consume a larger number of resources and eject a larger number of negative outputs into the atmosphere. The transportation of ylang-ylang oil, often by airplane from producing countries to processing facilities in the North, is also expected to necessitate a great number of resources and have significant emissions compared to the other steps in the process.

Given the characteristics and preferences of the ylang-ylang tree, as well as the employment of steam-distillation techniques for extraction the production of ylang-ylang oil is predicted to have a relatively significant water footprint. This is also the reason for its potentially high impact on land occupation. Depending on the tools and infrastructure used during cultivation, the rearing of ylang-ylang plants may have high greenhouse gas emissions, although this varies from one production site to another. Groundwater and soil pollution pertaining to their cultivation is expected to largely depend on fertilizer use. Emissions are expected explode during the transportation process.

Research Context and Methodology

A literature review conducted prior to and during data collection determined that there were no existing life cycle analyses similar or pertaining to the production of ylang-ylang oil for cosmetic use. Assessment of databases available in the LCA software SimaPro also do not contain information on ylang-ylang oil production. While impact assessment studies on ylang-ylang oil may exist, they are not available on accessible platforms - It was therefore determined that conducting a life-cycle analysis on this product would be diving into new territory as far as information available to the public and for research is concerned.

Before beginning the analysis, it was important to set boundaries for the investigation - this will be discussed further in the methodology section. Given that raw and processed ylang-ylang oil is rarely used alone in a cosmetic context and tends to be considered as an ingredient in cosmetic manufacturing, it was determined that a cradle-to-gate life cycle analysis on its production would be most appropriate. The study limits were also set at the production of the oil to its semi-processed or raw form, meaning its state after distillation once it leaves the farm for transport to its processing facility in Europe – for this study, the United Kingdom.

The farm on which this study was conducted operates in terms of ylang-ylang oil production as contract farming, with regulations set by its client to which it must pertain to. The farm is considered to be an organic farm which holds both European and North American certifications, meaning that the ylang-ylang oil produced here is indeed organic as well. This study will therefore reflect the organic cultivation of ylang-ylang oil that is thus marketed as an organic product.

It should be noted that this study is based on a relatively small-scale production site located outside the oil's main producing countries. This means that production methods may be different to classic ylang-ylang production sources, and this should therefore be taken into account as well.

Dissertation Structure and Research Plan

This dissertation will begin with a general review of Cananga Odorata (The ylang-ylang tree) and ylang-ylang oil. This introductory overview is the product of both published literature sources as well as direct observations in the field. Plant characteristics and geological preferences as well as the oil extraction process will be visited, as well as the place of ylang-ylang oil in the cosmetics industry. This introductory portion will then be followed by a literature review, organized by theme relative to the cultivation process of ylang-ylang oil, its distillation and extraction, as well as its potential social and environmental impacts. The literature review will also focus on the subjects of the recent "natural" trend in the cosmetics industry as well as the phenomenon of greenwashing that is strongly present within this economic sector.

The literature review will then be followed with the methodology section, which describes the planification and steps taken during the field study and data collection to data processing with SimaPro. Methodology describing each step will be thoroughly explained. The research plan is summarized in the following steps below:

- Literature review
- Establishment of distinct production steps according to literature review
- Rough, temporary inventory list of inputs and outputs of ylang-ylang oil production and creation of a flowchart illustrating said inventory analysis
- Establishment of research boundaries and system limits
- Field study on farm in Swedru, Central Region, Ghana and data collection via observation and qualitative questions
- Establishment of collected data with any processes and adjustments as needed with information provided by farm owner and research
- Review and reworking of inventory analysis with collected data included
- Data processing using SimaPro software and databases
- Critical analysis of SimaPro results and findings

The results of the data processing will be resumed in the Results and Discussion sections. Here, the environmental impacts of ylang-ylang production will be listed and described, and the most impactful steps identified and deliberated. Observations and analysis regarding the production process will be followed by eventual remarks and suggestions. Final comments will be summarized in the conclusion.

The Flower of Flowers: A General Review of Cananga Odorata (Ylang-ylang)

Botanical nomenclature

Meaning the flower of flowers in the Malay and Tagalog languages, ilang-ilang - commonly written with its Spanish spelling ylang-ylang - is the common name for Cananga Odorata, a tropical tree with large yellow-green flowers from which ylang-ylang oil is extracted (Turner and Veldkamp, 2009).

The Cananga Odorata tree belongs to the *Annonaceae* family, from which two sub-species of *Cananga Odorata* are used to make ylang-ylang oil: the *Cananga odorata* Hook.f & Thompson forma *genuina*, and the *Cananga odorata* Hook.f & Thompson forma *macrophylla* (de Bontin, 2006). The two species were initially assumed to be identical, but further studies of each tree have concluded the plants to be distinct (Burdock et al., 2008). A description distinguishing the two species can be found in figure 1. This thesis will focus solely on *Cananga odorata* Hook.f & Thompson forma *genuina*, as only this species can produce true ylang-ylang oil (Benini et al., 2010).

Species / form	Common name (and of the oil)	Main origin of oil today
Cananga odorata Hook.f & Thompson forma *genuina*	Ylang-ylang	Madagascar and Comoros
Cananga odorata Hook.f & Thompson forma *macrophylla*	Cananga	Indonesia

Figure 1: Table distinguishing the two main sub-species of Annonaceae cultivated to create oils. Retrieved from de Bontin, 2006.

Distribution

The Ylang-ylang tree (*Cananga Odorata*) is native to South-East Asia and the Indo-Pacific region, notably Malaysia, the Philippines, and Indonesia (Parotta, 2014; Turner and Veldkamp, 2009; Manner et al., 2006; de Bontin 2006). Although its specific origin remains unclear, it is generally thought that the species first originated from the Molucca Islands in Indonesia or the Philippines (Benini et al., 2010; de Bontin, 2006). It has been introduced and distributed throughout the tropics and subtropics (Parotta, 2014, de Bontin 2006), notably in areas and islands around the Pacific and Indian oceans, where it has been naturalized (Manner et al., 2006). According to Parotta, the plant species has also been introduced to the Caribbean islands as well as Central and South America. The causes for distribution remain unclear, but Parotta (2014), de Bontin (2006), and Manner et al. (2006) site European contacts and foreign and local trade as likely factors.

Currently, all ylang-ylang oil is collected from cultivated trees (Burdock et al., 2008), often from large-scale plantations. Madagascar and the Comoros islands have been the dominant world suppliers of ylang-ylang oil for over a century (de Bontin, 2006).

Climate and Geological Preferences

The Ylang-ylang tree prefers equatorial to subtropical maritime tropic climates common to those around the Indian and Pacific Oceans. It can grow in areas with elevations up to 1200 meters, but notably prefers low-lands closer to sea-level. The tree demands a great amount of water during its initial growing stages, and thus grows best in areas receiving around 700 to 5000 mm of mean annual rainfall per year (Parotta, 2014; Manner et al., 2006; Cliff et al., 2014). Rainfall can be uniform or seasonal, and the tree can support dry periods that last up to two months. Ideal annual temperatures for the tree vary around 18° to 28°C, and it cannot tolerate temperatures lower than 5°C (Parotta, 2014; Cliff et al., 2014).

Cananga Odorata prefers fertile, light to medium texture, well-drained soils, but grows in a variety of different sorts and can support brief periods of waterlogging. It can also tolerate a wide range of soil Ph levels, from 4.5 to 8.0 (Parotta, 2014; Manner et al., 2006). The plant supports shade and grows well with other crops (Manner et al., 2006).

Morphology and Physical Characteristics

Cananga Odorata Tree, Roots, and Leaves

The Ylang-ylang tree is a fast-growing medium-sized evergreen tree with long, drooping branches that, when left in the wild, can grow to between 10 – 20 meters high (Manner et al., 2006; Salomon, 1979; Parotta, 2014). Levels of growth are highest during the tree’s early years, with rates reaching 2 meters a year during the initial stages of life. One should note that cultivated trees are normally topped off at 2-three meters in order to facilitate flower harvests (Salomon, 1979; Manner et al., 2006), and branches are pruned all year round to maintain this height. This allows not only to facilitate the harvesting of flowers, but also stimulates higher flower yields (Salomon, 1979). The trees branches tend to droop down naturally, although some productions tie their ends to pegs in order to accentuate this (Manner et al., 2006). The tree has a single main trunk with an uneven crown of branches fitted with twigs on which dark, waxy leaves grow in two rows on a single plane. This is the case for most species belonging to the family *Annonaceae* (Parotta, 2014).


Figure 2: 1. Cultivated Ylang-ylang tree in Central Region, Ghana. 2. A better look at the ylang-ylang tree's leaves that grow on its twigs in perpendicular rows.

Numerous sources state the ylang-ylang tree to be a rustic plant, meaning that it is capable of living in soils of lesser quality (Benini et al., 2010; Salomon, 1979). The trees do grow long taproots, however, and thus prefer deep soils (Parotta, 2014). These roots are extremely fragile and grow straight into the soil relatively quickly, which can cause problems in the nursery stage of cultivation once the plant is ready to be moved.

Flowers

The ylang-ylang tree has highly fragrant flowers with petals that droop similarly to the tree's branches and twigs. They grow in arbitrary clusters, normally on older twigs towards the base of the tree. Sources disagree between the number of flowers between each cluster, with numbers ranging from 4 – 20 (Parotta, 2014, Salomon, 1979). Each flower has two series of petals with three to four petals each, ranging between 4-6 cm in length (Parotta, 2014).

Figure 3: A cluster of ylang-ylang flowers featuring mature and immature flowers.

Thick, twisted, and pointy, the flower petals are initially green when young, then turn yellow over time. Mature flowers turn a yellowish brown and begin to droop. Once mature, the flowers form a reddish-maroon dot at the three inner petals' base. The presence of this dot means that the flower is ready for picking. These adult flowers are the most fragrant, and thus are the only ones to be picked during harvest.

Figure 4: Pictures showing the reddish dot that forms at the base of ylang-ylang flower petals when they are mature and ready to harvest.

Cultivated trees begin to sprout a low number of flowers around 2 – 3 years old once they reach two meters, then begin to form larger clusters of flowers at around 5 years old, reaching full production capacity between five and seven years. Wild ylang-ylang trees begin to produce flowers later, at around 10 to 12 meters. Flowering tends to accelerate during the wetter months. In regions where rain falls throughout the year, ylang-ylang trees produce flowers annually (Parotta, 2014). A fully mature cultivate Cananga Odorata tree can produce between 15 to 100 kg of flowers per year (Manner et al., 2006; Salomon, 1979), although these claims vary from one source to another.

Fruits

Figure 5: 1. Ylang-ylang fruits growing in clusters. 2. A ylang-ylang fruit cut open to reveal a yellow-green interior and a small, flat seed inside.

Ylang-ylang fruits grow in clusters of 6 to 12 fruits, and multiple fruits can spawn from the same flower. They contain flat, brown, 6 mm seeds that are embedded in a yellow-green pulp. The pods are similar to olives in size and appearance and range from a dark green color to black when ripe. In the tree's native lands, these are a source of subsistence for numerous small mammals such as squirrels, bats, birds, and even monkeys (Parotta, 2014). On the farm in Ghana, there is no official knowledge regarding the consumption of ylang-ylang fruits by native species – goats from nearby villages have however been observed enjoying the leaves.

Cultivation

While the ylang-ylang tree can be propagated from cuttings, the most common method of propagation is direct seeding from seeds found in mature black fruits (Parotta, 2014; Salomon, 1979). Seeds are separated from the fruit and may be propagated in a nursery or directly into the ground, depending on preference. If reared in a nursery, seedlings are tended to for around 4 months before being transferred to fields, or once they reach around 30 cm in height.

Ylang-ylang seedlings are very delicate during the first two years of the plant's life and thus must be cared for judiciously. Their long, tubular roots quickly grow deep into the soil and attach fastidiously (Parotta, 2014). They are also easily broken, making the plants extremely difficult to move once having rooted to the ground. Ylang-ylang cultivation that involves an initial nursery stage must thus be organized to minimize rooting as much as possible.

In commercial production settings, trees are spaced six by six meters apart, as closer spacing can lead to over-crowding and reduced production capacity (Manner et al., 2006; Parotta, 2014; Orwa et al., 2009). Tending techniques throughout the year vary from one production site to another. Some ylang-ylang farms choose to weed the undergrowth beneath ylang-ylang trees. This can be done up to 2- 3 times per year (DAAF, 2016). Weeding can be done either by hand with manual cutting tools such as machetes, or with specialized machinery. Again, cultivated Cananga Odorata trees are pruned throughout the year to keep them at a height that facilitates flower picking.

Cananga Odorata trees require consistent watering for the first few years of their lives. Water consumption then slows after two to three years as the plants become resilient enough to survive on annual precipitation. While ylang-ylang trees can support short periods of drought (up to two months) (Manner et al., 2006), this can affect their flower production. Depending on their location, watering mature ylang-ylang trees is necessary during long spells without rain during the dry season.

As stated above, ylang-ylang trees do not begin to make flowers until after 2 – 5 years, and only become fully productive after 5 – 7. The tree is considered mature once it reaches full production capacity (Salomon, 1979; Parotta, 2014). Cananga Odorata is known to have a lifespan that can reach up to 100 to 200 years and continues to produce flowers throughout its lifetime. A well-managed plantation can continue to be commercially productive for up to 50 years (Orwa et al., 2009).

Ylang-Ylang Oil

Harvest and Distillation

Ylang-ylang flowers are recommended to be picked in the early hours of the morning, when their scent is most fragrant. The flowers are harvested entirely by hand; Farm employees pick the flowers and place them in different reciprocals such as rice sacks or crates. After 30 minutes however, the flowers must either be distilled or lain on the ground and left to aerate properly. If picked flowers are stuffed together without aeration, they will begin to turn brown, altering their scent. In order to preserve the truest odor of ylang-ylang oil possible after distillation, it is important to distill as little brown flowers as possible. Flowers are often distilled immediately or within the first two hours after picking (Parotta, 2014; de Bontin, 2006). This is often the reason why distillation infrastructure is located directly on or in proximity to where ylang-ylang cultures are grown (Salomon, 1979).

Ylang-ylang oil is normally obtained by steaming or distilling the tree's flower petals to extract the oil from them. While other techniques do exist, steam and hydrodistillation are the most common methods and are sited the most in scientific literature (Salomon, 1979; de Bontin, 2006; Haluk, 2005; Mahfud et al., 2017; McGaw et al. 2016; Cortez, 2016; Saedi et al., 2006). Steam distillation may vary in dimension, materials, and techniques from one system to the other. These choices made during the extraction process can strongly affect the quality of the essential oil itself, which can then affect the way the human body reacts to its components - This is common for essential oils and is important to consider when making a product for commercial consumption (Lemesle, 2012).

The energy source for ylang-ylang distillation is created with either firewood or petrol - the type of combustion used depends on the distillation system and have notable differences:

Characteristics of Alembic Distillation Systems According to Fuel Source

	Firewood	*Petrol*
Type of alembic system (material)	Copper; Galvanized (Zinc Coated); Stainless Steel	Stainless Steel
Distillation time	24h	14h
Other	No temperature control; Smaller yield	Temperature control; Higher yield

Figure 6: Information found in Salomon, 1979. Iron is not recommended as a material as it reduces the oil's quality by coloring it (Salomon, 1979).

Firewood combustion systems are the most used by producers (Benini et al., 2010; Salomon, 1979; de Bontin, 2006), often due to lower costs. The alembic is heated over open flames (de Bontin, 2006), often with old-fashioned equipment that rears low yields (Salomon, 1979). The choice of material and system varies and is often a question of investment capacity and available technology. Depending on the alembic system and the fuel used for heat, the entire distillation process lasts between 12 to 24 hours (Salomon, 1979; de Bontin, 2006).

Ylang-Ylang Oil Grades

Essential oils are mixtures of lipophilic, volatile and liquid compounds that are stored in plant tissues and are extracted via physical methods including steam distillation, hydrodistillation, and cold pressing (Benini et al., 2010). In the case of ylang-ylang, the essential oil is extracted via distillation from its flowers, which must be processed within 24 hours after harvest, preferably as quickly as possible. The fresher the flowers, the stronger their perfume, and the higher their oil yield (Salomon, 1979).

Yields tend to gravitate around 1 to 2.5% of the flower's weight in kg depending on the source (DAAF, 2016; Parotta, 2014). This means that 100 kg of flowers are needed to produce 1 to 2 liters of oil. Variations depend on extraction techniques, fuel, flower quality, and handling throughout the harvest process (Parotta, 2014). Overall, essential oil distillation is a delicate process that demands experience and constant surveillance (Haluk, 2005).

Quality grades of ylang-ylang oil can be collected in fractions throughout the distillation process. On completion of distillation, oil fractions are classified and sold by their specific gravity (de Bontin, 2006; Burdock et al., 2008), although more recent sources state that they are classified by their chemical composition (Giang et al., 2016). This classification allows one to determine the average quality of the oil as well as its relative price. All grades are sold by density, apart from the third grade, which is sold by weight in kg (de Bontin, 2006). Most sources list four quality grades:

- Extra: Emerges within the first 6 hours of distillation, considered to be the highest quality grade.
- First (I): In-between quality
- Second (II): In-between quality
- Third (III), also known as complete: The result of an uninterrupted distillation of ylang-ylang oil, considered a "mix" of all grades (Arctander, 1960).

Grade	Aroma	Specific density (20/20ºC)			Refractive index (20ºC)		
			Madagascar	Comoros		Madagascar	Comoros
Extra	Strong floral, jasmine-like	Highest	0.950-9.965	0.956-0.976	Lowest	1.501-1.509	1.498-1.506
First	Floral and jasmine-like	↑	0.933-0.945	0.940-0.950	↓	1.500-1.510	1.500-1.509
Second	Duller	↑	0.923-0.929	0.926-0.936	↓	1.505-1.511	1.505-1.510
Third	Dull with sometimes burnt and harsh notes	Lowest	0.906-0.921	0.906-0.921	Highest	1.506-1.513	1.507-1.511

Figure 7: A table comparing aroma, density, and refractive index of the 4 ylang-ylang grades. Retrieved from de Bontin, 2006.

Some sources make a point of distinguishing ylang-ylang oil from the other derivatives of ylang-ylang sold on the market. Below is a brief description of these byproducts:

- Ylang-ylang super extra (ES): Collected within the first 2 hours, the crème de la crème of all ylang-ylang oils.
- Ylang-ylang concrète: A concentrated odorant, solid and almost wax-like that gets better with age. 1 ton of flowers is needed to produce 1 kg of concrète (Doyen, 2006).
- Ylang-ylang absolute: Pale yellow, oily, with a very diffusive, strong flowery scent. Obtained from the alcohol washing of ylang-ylang concrete (Doyen, 2006).

Given that the oil distillation process studied for this dissertation was uninterrupted, the LCA will focus on an evaluation of ylang-ylang III (complete). This study is therefore not intended to represent the relative production of other grades sold on the market or their impact.

While the cultivation and extraction of raw ylang-ylang oil and its grades are well documented, there is little information regarding further processing available to the public once the oil reaches factory gates. Factories often test and process the oil depending on company standards and certification requirements. The ISO norm ISO 3063:2004 details the international standard of Oil of ylang-ylang (*Cananga odorata (Lam.)* Hook. f. et Thomson *forma genuina*). This is often used to assess the quality of the essential oil from Madagascar, Mayotte, and the Comoros Islands (ISO, 2018). The contents of this norm are not freely available to the public.

Uses in the cosmetic industry

Ylang-ylang is rarely sold in the cosmetic industry on its own and is often an ingredient in other products. Due to its high concentration and powerful scent, the oil tends to be used sparingly, often as a fragrance. Using ylang-ylang oil in high amounts can be toxic or irritating (Manner et al., 2006), which also influences its limited use for topical products. It is found mainly in perfumes, but can also be found in soaps, massage oils, moisturizing creams and body lotions, and hair care products (Saedi et al., 2006; TCI, 2014; Orwa et al., 2009) This is often the case for concentrated essential oils (Lemesle, 2012). Ylang-ylang extra and super extra are used in perfume, whereas other grades including ylang-ylang complete (III) are used in lesser value items such as soaps (Parotta, 2014, Orwa et al., 2009).

The oil also possesses benefits beyond its scent - in aromatherapy, the oil is renowned to aid in relieving high blood pressure and symptoms of anxiety and depression (Saedi et al., 2006; Parotta, 2014), and some sources label is as an aphrodisiac (Parotta, 2014). In cosmetics, it is revered as a growth stimulant and for its strengthening properties for hair. It is also marketed to be soothing and softening for the skin (Saedi et al., 2006) and to have anti-inflammatory properties (source, the last favorite). Further research is needed to confirm these claims that, as of now, are not clinically proven. Burdock et al. (2008) do note its anti-fungal and antibacterial properties, which have been scientifically tested – these benefits are advertised as well.

Ylang-ylang is an established product ingredient in the cosmetic world. It is also a complex and multi-faceted product that requires heavy initial investment and delivers small yields. The importance of the oil to the cosmetic industry cannot be denied, however. In the following section, scientific literature pertaining to the oil will allow for a clearer picture of its the economic and environmental aspects implied for the obtention of this elegant perfume.

Literature Review

This section reviews existing literature on the production process of ylang-ylang and its use in the cosmetic industry. It also reviews literature pertaining to LCA's conducted in the agricultural domain, studies on the natural cosmetic industry, and greenwashing of cosmetic products. The topic of ylang-ylang production and its effects in the developing economies in which it is produced will also be considered, as well as research papers focused on economic and marketing elements. Special attention is given to what has already been said regarding the oil's environmental impact.

Currently, there is no available literature that has conducted life-cycle analyses on ylang-ylang oil or other essential oils in general. There is also little scientific literature available that focuses on ecological effects of ylang-ylang oil production or its contribution to climate change. Therefore, these aspects will be determined by studying publications that may mention them in passing, but in which they are not of prime concern. These will be explored alongside monographs of *Cananga Odorata* and country studies regarding the plant's production. These articles often discuss the production of ylang-ylang oil in countries where its production and distillation are relatively well developed - Indonesia, Madagascar, and the Comoros islands, as stated above. This should be considered while contemplating the research portion, as the research was conducted on a ylang-ylang farm in Ghana where the plant is not being cultivated as a major cash crop.

This literature review will not take publications regarding the production of oils destined for biofuels, nor medical articles discussing health benefits or allergic reactions involving ylang-ylang oil, as these do not make ylang-ylang oil or its production process their main focus.

LCA's for Agricultural Products

Life Cycle Thinking (LTC) and LCA's have become increasingly common in the domain of agriculture, largely in the attempt to determine sustainable food systems and global food challenges (Sala et al., 2016). This is driven largely by the race to assure the nutrition of 7 billion people despite food production's massive environmental footprint (Garnett, 2011; Notarnicola et al., 2016). It is also fueled by the race to replace conventional fossil fuels with agricultural alternatives to combat global warming (Rathore et al., 2013; Bryan et al., 2010). Farming puts enormous pressures on the earth's resources and ecosystems that, if not assessed and controlled, could push the sector's impact over planetary limits (Notarnicola et al., 2016). Worldwide demand for greener agricultural practices has pushed the agribusiness sector to turn towards LCA's as decision-making tools in regard to food production systems and technology (Ruviaro et al., 2011).

Existing LCA's on crops focus largely on agricultural products cultivated for food and for biofuels (Garnett, 2011; Rathore et al., 2013). LCA's in the food sector focus on larger contributors to climate change including staple crops and animal products (Garnett, 2011), while studies regarding biofuels are numerous and diverse, containing sourcing and extraction analyses and method comparisons from a large number of countries (Rathore et al., 2013).

LCA's in the Cosmetics Sector

Sustainability assessments and tracking metrics have become increasingly important for cosmetic companies as communication tools with both consumers and stakeholders as well as within businesses themselves (Sahota, 2014). The cosmetics industry has slowly begun to follow the food and fuel agriculture sectors in turning towards LCA's for its agriculturally derived products and ingredients – this can be observed for ingredient LCA's such as Glew et al.'s (2014) and Elias et al.'s (2013) assessments of shea butter, as well as for entire products such as Franke et al.'s (2013) LCA on a particular brand of bar soap and Secchi et al.'s (2016) analysis on a naturally derived cream. On a larger scale, Carvalho and Barbieri's 2012 case study describes a LCA that has been conducted on the supply chain of an entire cosmetics company, presenting the varying scales on which LCA's can be applied. While a small portion of literature does exist, the plethora of cosmetic products and ingredients on the market today in comparison marks a significant contrast between what has been and what still needs to be done. The adoption of LCT and its methodologies such as LCA's and other indicators is essential for agribusiness and farming practices (Notarnicola et al., 2016; Brentrup et al., 2004), both for food systems and for medical or cosmetic products.

Market Shifts Towards Sustainable Cosmetics

The lack of LCA's in cosmetic literature is surprising, given the heightened amount of scrutiny that the sector comes under in comparison to other industries (Sahota, 2014). Consumer awareness and shifting demands towards sustainable products has put enormous pressure on companies to incorporate these demands and deliver greener products (Aggarwaal et al., 2014; Maharaj et al., 2017; Duber-Smith, 2011; Dahl, 2010; Sahota, 2014). In their article on superfluid extraction of plant products, Maharaj et al. (2017) explain that growing consumer preference for more natural products has sparked the incorporation of new, natural alternatives in cosmetics and personal care. Animal testing, sustainable ingredient sourcing, excessive packaging, and the effects of finished products on the environment and human health have been key topics of customer scrutiny that have only gained in importance (Sahota, 2014).

In the book *Formulating, Packaging, and Marketing of Natural Cosmetic Products*, Duber-Smith (2011) writes on the influences of consumer demand on the growth of the natural product sector. This book is largely based on the American market, but serves as a useful resumé of the market shifts in cosmetics throughout the last few decades. The origins of the natural cosmetic industry, explains Duber-Smith, has roots in the healthy food and beverage movement launched in the beginning of the last century. The rising popularity of this sector can thus be considered as a spinoff of the organic and healthy food movement, which popularized natural products (Duber-Smith, 2011; Sahota, 2014).

Duber-Smith (2011) explains that natural cosmetics took a backseat after World War II, a time during which explosions in the technological spheres and preference for the effectiveness and preservative abilities of synthetic products reigned for a number of decades. However, rising consumer awareness fueled by the civil rights movement in the United States and books such as *Silent Spring* by Rachel Carson caused a shift in the current cosmetic dogma, and demand increased for products that were better for health and for the environment. While growth in the natural food and beverage sector took off during the 1970's and 1980's, the natural personal care sector has enjoyed a "sustained growth spurt" shortly afterwards that has continued up to present day (Duber-Smith, 2011). The effects and impact of environmentalism on cosmetic product marketing is documented in a 1992 article by Prothero et al. (1992), where it can be observed that marketing schemes were already taking environmental awareness into account nearly 30 years ago. While green cosmetic marketing is nothing new, the attempts of companies to brand themselves as greener can have perverse effects in terms of vapid claims and consumer deception. This phenomenon, known as greenwashing, is practiced by companies over a vast number of domains, but is particularly present in the cosmetic industry. This can be observed directly by the blatant lack of studies employing LCIA tools and methods to cosmetic products or other environmental analyses on the cosmetics industry directly available to the public. This limits transparency and leads to consumer confusion (Duber-Smith, 2011). There is a dire need to control and reduce the employment of greenwashing to avoid misleading consumers and to increase company transparency.

Cosmetic Greenwashing

Despite its benefits, the shift in market trends towards greener, more sustainable products has fueled the rise of company greenwashing, defined by Greenpeace as "the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service" (Aggarwaal et al., 2014). Given the urgency of environmental degradation, as well as the questionable ethics of misleading consumers, it is essential for greenwashing to be addressed in all sectors including the cosmetics industry.

A 2010 article from Dahl explains that companies have been reaping the benefits of promoting themselves as green since the 1980's, although Aggarwal et al. (2014) state that it has been practiced as far back as the 1960's. This marketing strategy's use has increased sharply in recent years as a result of growing consumer demand for greener products and services (Elias et al., 2013). The increased popularity of green products has fueled the development of official guidelines and codes regarding natural and organic production that is meant to aid consumers in navigating the plethora of products claiming to be "green" (Cervellon et al., 2011). These have been criticized however by numerous authors due to their multiplicity and puzzling nature, as no global regulation exists to control or synchronize current codes and labels (Duber-Smith, 2011; Aggarwal et al., 2014; Dahl, 2010). Aggarwal et al. (2014) state that the "green" advertising used in greenwashing is highly unregulated, calling for better guidelines. This is echoed by Duber-Smith (2011), who states that there is no regulation for the use of the word "natural" in marketing, leading to it being used liberally, along with other green terms. Dahl's article describes the misleading tactics used by companies, employing poorly defined claims and fake certification labels to trick consumers into buying a product.

While greenwashing may be a tactic to take advantage of consumer demands and increase sales, this article also notes that it may be a way of avoiding regulations. Increasing environmental rulings put pressure on companies to modify their products, who may in turn attempt to divert attention and appease regulators in order to keep their status quo (Dahl, 2010). While companies across the globe are guilty of this marketing scheme, differences in advertising laws and certifications can vary from country to country and thus may influence greenwashing's impact (Dahl, 2010; Duber-Smith, 2011).

Duber-Smith (2011) echoes the lack of government and international regulation on natural products, much less for "natural ingredients". The absence of official regulations has led to self-supervision of the industry by competitors, shareholders, non-governmental organizations (NGO's), customers, and the media, which favors vague, opinion-based definitions for terms and consumer confusion. Despite a growing number of third-party organizations creating certification and label requirements, the inconsistency between them and the multitude of labels does little to aid in consumer comprehension (Duber-Smith, 2011; Aggarwal et al., 2014).

Another concept related to greenwashing is corporate social responsibility (CSA). Aggarwal et al. (2014) define CSA as the accountability of organizations towards stakeholders including consumers, investors, the public, governments, and the environments as a whole. However, companies have been approaching green marketing as strategy to "gain an edge over competitors" (Aggarwal et al., 2014) and compete in the global market. The green exterior they portray, explain the authors, is superficial, and these companies invest more in the marketing of being green than actually changing their production norms. Tackling this issue by analyzing ingredient sourcing and production is therefore essential to confirm company claims and establish viable "natural" ingredients in cosmetics like ylang-ylang essential oil.

Ylang-ylang Oil Within the Cosmetics Industry and Market Exports

As stated above, commercial uses of ylang-ylang center around health and cosmetic purposes (Tan et al., 2015), mainly for use as a perfume ingredient. Ylang-ylang's place in the cosmetic industry is stable, given that its particular floral odor is impossible to replicate synthetically (ICT, 2014).

A 2015 report from the CBI center for the promotion of imports to developing countries' Ministry of Foreign Affairs states that Europe accounted for 43.5% of the world's essential oil demand in 2015, predicting a rise in the sector to reach 12.9 billion USD by 2023. France dominates as a major importer of particular high value oils that are used in cosmetics (ITC, 2014). According to the CBI report, France accounted for 23% of total European imports of essential oils in volume for 2017, and 32% of the imports in value. The CBI states that "The French market is particularly appealing for specialty oils used in the cosmetics sector and acts as a hub for the industry across Europe."

World demand for ylang-ylang oil was around 100 tons per year in 2014, a relatively fixed amount throughout the years, according to a 2014 product market study by the ITC. Doyen (2006) states France as the biggest importer of crude ylang-ylang oil in a 2006 market study of the product, which is confirmed by the more recent 2014 ITC market study. The oil is processed and finalized according to European and ISO norms in French factories, which then export the oil to a number of countries. It should be noted that while the United States are a large consumer of the oil as well, its supply is largely based on finalized processed oil imported from France (ITC, 2014). France is the largest exporter of transformed essential oil, according to Doyen (2006).

As stated above, the world production of ylang-ylang oil for export is dominated by Madagascar and the Comoros Islands (Doyen, 2006; ITC, 2014). Numerous sources state that ylang-ylang production is an essential part of the Comoros Islands' economic activity, despite the island nation's significant drop in ylang-ylang production in recent years. Most literature on the production and cultivation of ylang-ylang oil is based on these countries. New ventures in different developing countries have begun to emerge, however; Cliff et al. (2014) describe this in their article on ylang-ylang cultivation on the Imbo Plain in Burundi, a country that has similar geological conditions as those of high-producing countries. This is also the case on a much smaller scale in Ghana.

Once distilled, ylang-ylang oil destined for industrial production is sold and shipped out from production areas to factories in the global north as a semi-finished product (Salomon, 1979). While packaging may vary, Doyen states that the oil is often carried in 50L Polyethylene tanks and is generally transported by air. This of course, depends on production size and quantities. Given that transport costs are not excessively high, the essential oil market favors transnational trade (Lubbe et al., 2011).

While numerous product studies exist on ylang-ylang oil, most of the existing literature focuses on distillation processes or the ylang-ylang tree itself, only briefly mentioning the role of the product within the cosmetics industry, and often in the introduction. There is currently no available existing literature describing a LCA of ylang-ylang oil, or any LCA's that focus completely on essential oils for that matter despite their solidified place in the cosmetics market (CBI, 2015). By studying available literature on the oil and its distillation, one can begin to piece together a relative idea of its environmental impact. This will be resumed in the following sections.

Environmental impact

The production of essential oils, like other crops, falls under the 15th UN Sustainable Development Goal 'Life on Land' (FAO, 2017). As stated before however, little has been written on the environmental impact of ylang-ylang oil production or other essential oils in general. Despite this, one can begin to piece together the ecological impact of its production by studying plant monographies and other articles regarding the production process itself

The dependency of country economies on this export crop leads to increased production and in turn increased environmental impacts, the most notable of which includes deforestation for distillation. While ylang-ylang may contribute to environmental degradation and climate change, it also is threatened by them. The fact that the majority of ylang-ylang oil production is sourced from island nations increases its vulnerability. The Comoros Islands in particular are susceptible to numerous natural disasters such as earthquakes and flooding due to cyclones in the Indian Ocean that are expected to increase in frequency and magnitude due to climate change (IMF, 2015). Deforestation in vulnerable areas such as island nations also reduces their food security and greenhouse gas mitigation capacity (Cattaneo et al., 2016).

In this section, literature discussing Cananga Odorata's cultivation processes and specific preferences are explored to establish potential environmental impacts caused by the production of ylang-ylang oil.

Land use

Land use management is an environmental concern that comes into play during the cultivation stage of ylang-ylang trees. Parotta (2014), Manner et al. (2006), and Doyen (2006) state that Cananga Odorata must be planted in rows six by six meters apart in order to maximize production capacity. This means that ylang-ylang cultivation for commercial use requires large areas of land for optimal production and rentability. Increased vegetative density around the ylang-ylang tree causes rapid growth due to their competitive nature, which renders cultivation and harvesting difficult (Parotta, 2014; Manner et al., 2006). While the tree may coexist with other species, those cultivated for essential oil production cannot be grown in or under forest cover and require extensive land clearing for sun exposure and optimum production capacity (Parotta, 2014).

The question of deforestation due to land clearing and the popular method of wood burning during the distillation process is also a concern raised by Salomon (1979). Benini et al. (2010) discuss this as well, as they are one of the only existing publications that write of the ecological footprint of the oil's distillation. Given the long extraction time needed for firewood-fed systems (24h), large quantities of wood are needed to maintain heat (Benini et al., 2010). The authors describe that sourcing this wood can contribute to augmented deforestation and ecosystem disequilibrium. Forests are important carbon sinks that reduce the quantity of greenhouse gases in the atmosphere – the terrestrial biosphere absorbed up to 30% of emissions between 2005 and 2014, according to the Iversen (2016). The destruction of forests increases rates of namely CO_2 present in the atmosphere and contributes to the acceleration of climate change (Iversen, 2016; Loo, 2016). Land use change namely due to deforestation contributed to 9% of anthropogenic emissions between 2005 and 2014 (Iversen, 2016) – clearing of land for new ylang-ylang plantations in forest areas has thus contributed to these discharges.

The effects of ylang-ylang oil production on deforestation and its current extent have been cited in research notably on the Comoros Islands, where deforestation due to essential oil cultivation like ylang-ylang, cloves, and vanilla have put significant pressure on the island country's forest reserves (International Business Publications, 2007). Deforestation in the highlands of the volcanic nation has already contributed to soil erosion and vulnerability (USA International Business Publications, 2007).

While crop competition is of less concern in Ghana in regard to essential oil production, it is of notable importance in food deficient countries such as the Comoros. Kamal et al. (2019) explain that while Agriculture is the Comoros Islands' biggest sector (40% of GDP), rapid population growth and limited land for edible crops have rendered the country dependent on imported foodstuffs as local agriculture is incapable of feeding the country's population. While revenues from the country's biggest export crops including ylang-ylang are used to pay for these importations, the Comoros is one of the poorest countries in the world and has significant trouble in paying its food bills (Kamal et al., 2019). Land occupation of exploitable soils by ylang-ylang plantations only increases this dependency on outside food sources.

On the other hand, land use change can also have a positive role in the reduction and stabilization of greenhouse gasses (Iversen, 2016). In this case, the planting of aromatic trees and plants for cultivation could prove to be an essential tool for rehabilitating dry lands that have become unproductive due to desertification. Rajeswara Rao (1999) explains that essential oil cultivation could help in these cases for India. This however has not been explored for the case of ylang-ylang.

Water Consumption

Cananga Odorata trees are fragile during their first three years and necessitate consistent rainfall in the early stages of their lives. In drier areas, frequent watering is needed in order to maintain required moisture levels. This may increase the plant's water footprint during the cultivation stage. However, it seems to be that the high quantities of water needed for steam distillation during the extraction process may be responsible for the majority of the oil's water consumption. Benini et al. (2010) explain that this can pose problems as harvesting and extraction tend to occur during the dryer seasons due to increased floral bloom during this time.

Benitez Cortés et al. (2016) discuss the need to reduce the water consumption and waste due to ylang-ylang oil distillation, referring back to a pressing need to conserve the earth's water resources. Their article explains that often, used water after the distillation process is not recovered but rather dumped back into the surrounding environment. Elements found in the water after the distillation process can be harmful to the environment (Benitez Cortés et al., 2016). This could lead to numerous impacts such as water and soil toxicity along with water waste. While water recycling is possible during ylang-ylang distillation, many sources do not develop further on the subject. Further research into water consumption during the cultivation and distillation process is therefore needed in order to better understand ylang-ylang oil's water footprint.

Greenhouse gas emissions

In regard to CO2 and other greenhouse gases, a significant proportion of ylang-ylang oil production's carbon footprint could come from its distillation as well. The use of large quantities of wood or petrol to heat the water over long periods of distillation (12 to 24 hours) (Parotta, 2014; Salomon, 1979; Benini et al., 2010) contributes to greenhouse gas emissions and global warming – emission rates and compositions depend on the type of fuel used. While some literature differentiates the two forms of combustibles, the available works do not discuss their impact regarding gas emissions and global warming during the distillation process.

As discussed above, ylang-ylang oil production may also contribute to deforestation in certain areas of production. This leads to net carbon emission increases if significant portions of forest area are cleared for the oil's cultivation. This is in large part due to its need for space, which is described above, as well as fuel needs in classic firewood distillation systems. Again, forests play an essential role in the reduction of greenhouse gas particles present in the atmosphere (Iversen, 2016; Loo, 2016). The reduction of forest cover, namely in developing island nations such as the Comoros where ylang-ylang is grown, increases their climate change vulnerability (Cattaneo et al., 2016).

One should also note the high rates of emissions used to transport the oil from its cultivation grounds in the tropics to refineries and cosmetic labs in the global North. As mentioned earlier, the oil is transported by air (Doyen, 2006), which requires large quantities of jet fuel. Transportation of the oil is not limited to aircraft, however, and also includes domestic transportation in both producing and transforming countries. Total carbon emissions for the oil's journey from farm to factory could contribute significantly to its overall impact.

Fertilizers and Pesticides

Use of fertilizers and pesticides in ylang-ylang cultivation enterprises is not thoroughly documented and largely depends on the production source. The Ylang-ylang tree has several known parasites, including stem borers, flower-eating beetles, and other insects that attack both the flowers and the leaves (Orwa, 2009) and thus may necessitate protection. Currently, there are no standardized measures put in place to protect the plant from insects or illness (Benini et al., 2010). Nevertheless, the choice of using natural or synthetic fertilizers and pesticides has a significant effect on environmental impacts such as soil acidification, water and soil runoff, and eutrophication of nearby water bodies (Bengtsson et al., 2005; Hermary, 2007; Khanal, 2009; Kazafy, 2015). Most ylang-ylang oil however is reported to be grown organically without the use of these (Doyen, 2006).

In itself, components of ylang-ylang oil and its byproducts after distillation can be used both as fertilizer and as insect repellents. Salomon (1979) states that cooked ylang-ylang flowers are an excellent source of fertilizer but are rarely used in ylang-ylang cultivation. The use of fertilizer largely depends on the producer and the production requirements set by either industrial clients or the plantation itself. No scientific literature speaking of fertilizers used or fertilizing techniques was found for this section.

Thorough research has been done however on the effects of ylang-ylang oil as an insecticide or insect repellent (Zhang et al., 2013) for use as a greener alternative to traditional insecticides. However, given the specified outlook of these publications, they will not be discussed further in this literature review.

Biodiversity and Crop Management

Benini et al. (2010) focus on the conservation of genetic material in regard to preserving product quality and resource conservation, which is important in terms of biodiversity and crop resistance. The authors explain that caring for genetic resources has become a greater priority in agricultural sectors due to the pressure that crop management and selective breeding put on agrobiodiversity. This is echoed by Carrubba et al. (2014). Currently, there are no standardized management systems or practical guides put in place to protect Cananga Odorata's genetic diversity or any best practices for its cultivation in general. Knowledge of the plant is largely sourced from traditional and implicit wisdom of producers (Benini et al., 2010).

One should note that the act of introducing foreign plants into an area may also have an effect on the structure of native plant populations. This is the probable case of Cananga Odorata, which has been introduced into numerous countries foreign from its South Asian roots, all with their own cultural and vegetal characteristics (It should be noted that the plant is now considered to be naturalized in these once 'foreign' areas. (Parotta, 2014; Manner et al., 2006)). There is however no existing available literature that exclusively details this in the case of ylang-ylang oil.

As stated above, land clearing for crop cultivation contributes to anthropogenic emissions of greenhouse gases into the atmosphere (Imersen, 2016). Deforestation caused by ylang-ylang oil production can significantly impact levels of biodiversity in forest ecosystems. The preservation of genetic resources discussed by Benini et al. (2010) is just as important for those contained in forest ecosystems – the genetic resources of trees are essential for adaptation and mitigation response to climate change (Loo, 2016). Genetic diversity is lost when forest cover is significantly diminished (Loo, 2016), not only for vegetal species but for animals as well. This is an essential aspect to consider when touching on the effects of ylang-ylang production on the local environment in which it is grown.

Ethical Sourcing

Countries that depend on essential oils as cash crops that contribute to a significant proportion of their economy are particularly dependent on the production of oils such as ylang-ylang (ITC, 2014; USA International Business Publications, 2007). However, this economic dependence raises particular concerns.

The Comoros and other big producing countries are heavily dependent on the oil's production, as its sales constitute for a significant portion of their export revenue. This makes it extremely difficult for them to diversify their economies (IMF, 2015). Despite this, producers in these countries rarely benefit from the added value of the essential oil; Salomon explains that ylang-ylang oil is only distilled to its crude once it leaves its producing country and must follow further treatments before it becomes a product suitable for commercial and cosmetic use (Salomon, 1979). This processing is done in France and other developing nations with the required infrastructure (Salomon, 1979, ITC, 2014), meaning that the added value of the product after treatment goes to these said developed countries.

The question of ethical sourcing is also raised here, as it is particularly important to assess the respect and treatment of local communities in developing countries where ylang-ylang is sourced. Fair trade and ethical sourcing labels are already present for other cosmetics such as shea butter (Elias et al., 2013), but are not as present in dialogue on ylang-ylang production. As stated above however, it is important to proceed with caution when considering such labels. Given that ylang-ylang oil production is labor intensive however, the question of ethical treatment of laborers working in the sector requires more consideration.

Surprisingly, very little established literature speaks fully of economic and social implications regarding ylang-ylang production on local populations. While this is spoken of briefly by Salomon (1979), the age of this report may not reflect the current state of affairs. Given that ylang-ylang constitutes an important cash crop for both the Comoros and Madagascar, and is highly labor intensive (Parotta, 2014), further research focusing on local populations working within its cultivation is necessary to put a face on those responsible for its production and their reality working within the sector. It can thus be concluded that the production of ylang-ylang oil is a multi-faceted activity that entangles social and environmental issues at each step of its production.

Conclusion

While numerous scientific works focusing on ylang-ylang oil exist, there is a veritable lack of publications regarding its sustainability or environmental impact. Most available literature focuses on the biological and molecular characteristics of ylang-ylang oil or the Cananga Odorata tree. While some sources do write of potential environmental degradation caused by ylang-ylang extraction (Benini et al., 2010; Salomon, 1979), others tend to focus on the production in general without addressing exterior characteristics. Many of the publications addressing ylang-ylang oil also focus on other oils as well, meaning that the oil within itself is often grouped into categories with other cash crops and essential oil production in Madagascar and the Comoros Islands.

The majority of sources are based on research in Madagascar and the Comoros, which is understandable given their domination of ylang-ylang production. The production of ylang-ylang oil also implies complicated social implications in these countries that tangle the economic and social sectors together with environmental impacts and climate change vulnerability.

Despite a lack of concrete literature, analysis of the sources discussed above lead to the conclusion that ylang-ylang production can have significant effects on the local environment as well as on more global issues like climate change. Deforestation and rudimentary distillation practices seem to be significant sources of environmental impacts and are the most spoken of in literature speaking of the oil in an ecological context. Analysis concludes that the environmental impact of ylang-ylang oil production largely depends on the production practices used; land clearing, fertilizer and pesticide use, distillation methods, and transport all vary from one plantation to another, which may make a general overview of the oil's production difficult. A relative estimation of environmental impacts can be acquired by combining production studies on multiple production sites however, and the execution of such studies is necessary to determine the oil's ecological footprint and to reduce the impact of green washing in the cosmetic industry. The analysis of this relatively small-scale production in Ghana is hopefully a first step in this direction for the ylang-ylang market.

Methodology

Introduction

The systemized methodology for LCA's is described in the International Organization for Standardization norm ISO 14040-14044:2006 (ISO, 2016). Both this dissertation and the LCA software SimaPro used for data collection apply and follow these standards.

Goal and Scope

This dissertation will examine the production of the ylang-ylang oil grade known as ylang-ylang III, also known as complete, destined for cosmetic use. The goals of this LCA are to 1. Determine the environmental impact characteristics of ylang-ylang oil production, and 2. Isolate the steps within the production process that contribute the most to said impacts. Identifying the oil's main environmental effects and the hotspots within its production will not only allow for a better understanding of the oil's environmental footprint, but will also distinguish steps in its production that can or should be improved to increase its sustainability. The purpose of this study is to provide a primary analysis that will aid in the accumulation of knowledge on ylang-ylang oil production and increase the transparency of this cosmetic ingredient, as well as provide a basis for further detailed scientific assessments.

Information for this assessment is based on the foreground data collected from Lush Inc. Farms based in Swedru, Ghana. This agricultural production site produces a diverse plethora of different products both for export and local use, including patchouli, vanilla, and oranges. All products produced on its territories are the result of organic cultivation - the farm holds organic certifications from the North American National Organic Program and the European Ecocert Organic Standard. All ylang-ylang oil produced on this farm is sold to one client, who imposes production norms based on international guidelines and company ethics and policies. These norms include the strict prohibition of animal testing, although most testing is conducted by said company upon arrival of the oil to factory gates in accordance with product standards that are not publicly disclosed. The data and impacts collected during this assessment are thus based on the organic cultivation of ylang-ylang oil.

Functional Unit

The functional unit applied for this LCA is one liter (L) of raw ylang-ylang complete (III) oil. This was chosen as the production and sale of raw ylang-ylang oil during processing is described in liters both during the data collection process carried out in the field and within existing literature. 1 L has also been chosen as raw ylang-ylang oil is often bought in bulk by cosmetics companies to later be added to larger products. The oil is in fact only present in small amounts in finalized cosmetics. The International Fragrance Association (IFRA) limits the presence of ylang-ylang oil to consist of maximum 3% of total product mass. This ratio can vary however depending on product characteristics. Following these recommendations, one L of ylang-ylang oil can be used to create:

- 74 450 g bars of soap
- 66 500 ml bottles of shower gel

System Boundaries

Provided the relative nature of ylang-ylang oil's use as an ingredient rather than a product on its own in the cosmetics industry, this LCA will focus only on the raw production process of ylang-ylang complete (III). Given that the oil is exported from its production countries in its crude form and must travel a significant distance to processing facilities, transportation will also be included. Ylang-ylang oil production follows a multiple-step production process that varies depending on its processing and use during factory treatment – the intended use of the oil, the product in which it is destined to be added to, and rules and regulations regarding labels and the country in which it is finalized all have an impact on its production. In order to avoid complications regarding these specifications, only the processing steps leading to the raw oil to factory gate for finalized processing will be assessed. Therefore, only the steps leading to the production of this oil and its delivery to its intended factory are analyzed, and further processing within the factory will not be included. Use of the oil after production and waste scenarios will also not be assessed here. This system limit qualifies this LCA as a cradle-to-gate analysis. Therefore, the steps that will be included in this study are the following:

- Nursery
- Field Establishment
- Cultivation
- Extraction (Distillation)
- Transportation

This LCA will follow an analysis of the third order, meaning that all processes including those for capital goods are included (Goedkoop, 2016). All agricultural steps will be considered as part of the production system, also known as the Technosphere. Inputs such as land use, soil, and water consumption however are included as inputs from nature.

Given that the purpose of this study is to identify the environmental impacts of ylang-ylang oil production and impact hotspots during its processing, this LCA will follow the attributional model, also known as the allocation model. This is also referred to as the environmental footprint of a product (Goedkoop, 2016).

All byproducts produced in the foreground system for ylang-ylang oil re-enter the production system, classifying their use as closed-loop recycling. All capital goods used throughout the process excluding buckets, rice sacks, water pumps, and machetes are only expended for the production of ylang-ylang oil. Therefore, multi-product allocation will not be applied to this system's foreground data. Background data used has however been subject to allocation. Allocation at the point of substitution (APOS) calculations have thus been applied, as this system model attributes environmental burdens to processes proportionately (Ecoinvent.org, Accessed May 1**,** 2019). All treatments for by-products included in background data are added to final results.

Attributional modeling has been applied to foreground data according to frequency of use and lifespan of permanent capital goods. The impacts of both ylang-ylang trees and the distillation system used for extraction have been attributed based on their years of service, which has been set at a generational timeframe of 25 years for each. This logic therefore supposes that all initial material investments and inputs from nature for these goods can be divided by the number of years that they are in use. This same logic has been applied to other capital goods divided by the time frames attributed to each step. Distillation and extraction inputs outside the distillation alembic system such as water have been divided by the number of distillations conducted per year and frequency of replacement. Details for these calculations can be found in Appendix **7**.

Inventory

Primary foreground data was collected by interviewing farm management and employees following a predetermined production step flow chart constructed by studying scientific literature and initial conversations with farm management. The information obtained was divided by production category, and accounts for energy consumption, raw material consumption, and environmental releases. A detailed inventory list for each step is described below in the inventory table (Figure 8). Background data is sourced from the Ecoinvent databases available in SimaPro.

Ylang-ylang trees occupy roughly 28 hectares of the total farm property, with 250 trees planted per hectare, all spaced six by six meters apart. Nurseries, field establishment, cultivation, and harvesting steps are all done by hand using rudimentary tools such as watering cans and machetes for weeding and digging. Water is given to the tree saplings during the Nursery and Field Establishment phases when they are most delicate and demand frequent watering. Consistent watering stops after the trees reach three years old and is only conducted thereafter in the event of abnormally long dry spells during the dry season in Ghana. Trees are grouped together in areas depending on age and date of planting. The age of the oldest ylang-ylang trees is 11 years old. Fully mature trees produce 5 kg of flowers per year and are expected to continue to produce for 50 years, according to farm management. The farm conducts roughly 40 harvests per year. The quantity of flowers harvested depends on the time of year and the age of the ylang-ylang trees. Distillation is conducted within two hours of flower picking and is heated by wood burning: anywhere between 10 – 1000 kg of flowers are distilled, although larger quantities are preferred. This process lasts 20 hours and demands 3m³ of hardwood and 20L of water per hour, regardless of the quantity of flowers distilled.

Data collected was summarized into a product inventory that was determined by creating a flowchart that was cross-checked with farm management. The inputs and outputs were then inserted into the SimaPro Software for analysis. Available background data was sourced from the Ecoinvent database. Units for foreground data were converted as needed for SimaPro inputs based on online sources and conversion calculators. Input magnitudes were calculated based on an optimal oil production scenario determined by explanations given by farm management, which is comprised by the following points:

- All ylang-ylang trees produce at the farm average production capacity reported (5kg flowers/year) throughout the entire 25-year productivity generation lifespan (22 years at full production capacity).
- Optimum climatic conditions: no water is given to the ylang-ylang trees during the Cultivation stage after they have reached maturity.
- Land destined for use for the ylang-ylang tree cultivation was already farmland when the property was bought by the current owner, and therefore all effects caused by land use change by the previous owner is not attributed to ylang-ylang cultivation in this case.
- No sapling losses during Nursery and Field Establishment stages.
- All inputs (water, fertilizer, etc.) are applied equally to all trees.
- There are 40 harvests, and therefore 40 distillations carried out per year.
- Enough flowers are collected for each harvest to create 10 L of essential oil. The same rate of flowers is collected for all 40 harvests conducted each year.
- The oil yield ratio is set at 90kg flowers/1 L of oil.
- Each distillation (40 per year) is applied to the maximum quantity of flowers (900 kg) to produce 10L of ylang-ylang complete (III) essential oil.
- Losses of raw oil due to error or accident are not reported and therefore not included.

The following analysis therefore explores the impacts attributed to the ylang-ylang production system working at full capacity. Exterior influxes and elements determined by natural phenomenon such as drought are not taken into account. Yield variations per harvest are also not considered for this study.

Other Inventory Inclusion and Justification

Given the rustic nature of the capital goods used for this process, there was a significant amount of foreground data that had to be added in order to complete the inventory. Some capital goods were thus "constructed" within the database as new processes by adding material components in accordance to volume and weight. These processes are not completely accurate and are based on estimations concocted by studying relative weights of products online and applying unit conversions based on information provided during the data collection process. A table summarizing all inputs and outputs as well as their values can be found in Figure 8 and in the Appendices.

The frequency of use for capital goods used for the cultivation of other products grown on the farm such as a water pump used for sourcing well water is not included for this assessment. Initially, small capital goods such as machetes, rice sacks, and buckets were also to be included in step inventories. It was determined however after the attribution of lifespan and frequency of use to the mass of these products that their overall mass contribution was so minimal it was deemed insignificant. The multi-faceted use of these tools for other products grown on the farm further renders their contribution to ylang-ylang impacts obsolete. The decision was thus made to exclude these products from the impact assessment. Given that the harvesting stage for ylang-ylang is conducted exclusively with these small capital goods, the decision was also made to exclude this fourth step entirely. All production components that are included in the analysis are marked in an inventory flowchart (Figure 9).

This logic was also applied to the use of wood ashes and cooked flowers obtained after distillation as fertilizers for the ylang-ylang trees. The small quantities obtained after distillation were supposed to be distributed equally among all the trees grown on the farm. Like the small capital goods discussed prior, the mass contribution of these fertilizers was so small that they were determined to be obsolete. The use of these fertilizers is also not included in this impact inventory.

Inputs in the following inventory table that are underlined have been constructed for this analysis and contain multiple components that require further explanation. The components for these inputs and their inclusion in SimaPro can be found in Appendix 6.

Inventory for Crude Ylang-ylang Complete (III) Oil as Given by Farm Management			
Product Stages	**Inputs**	**Desired Output**	**Co-Products**
Nursery **(For 100 trees)**	- 100 Cananga Odorata seed, harvested from trees on site - 2x2 m plastic tarp – *0.038 kg Extrusion of plastic sheets and thermoforming, inline {GLO}| market for APOS, U* - 100 discarded plastic water sachets, collected from neighboring villages and dump sites – *475 g Extrusion of plastic sheets and thermoforming, inline {GLO}| market for | APOS, U* - 1 kg soil per sachet, sourced from site – *100 kg Soil, in ground* - 700 L water per tree, sourced from groundwater sources on site – *Water, well, in ground, agri, GLO* - 1 Watering can	- Ylang-ylang saplings	
Field Establishment **(250 trees, First 3 years of Lifespan)**	- 250 Ylang-ylang sapling - 1 ha Land with space 6x6 m per tree – 0*.0040 ha Transformation, from permanent crop, non-irrigated, extensive, GLO; 0.012 ha a Occupation, permanent crop, non-irrigated, UG* - 700 ml Water per tree x 40 days – *84 L Water, well, in ground, agri, GH* - 15kg/yr/tree poultry manure– *45 kg per tree, Poultry manure, fresh {GLO}| chicken production | APOS, U* - 1 Machete, used for weeding and digging holes for planting - 2 Watering cans, polypropylene 25 L	- 250 Planted Cananga Odorata tree	- Plastic waste buried with saplings
Cultivation **(1 ha, 250 trees)**	-Land occupation - *0,088 ha a Occupation, permanent crop, non-irrigated, extensive, GLO* - 15kg/yr/tree poultry manure – *330 kg Poultry manure, fresh {GLO}| chicken production | APOS, U* - 14,2 kg wood ash, taken from ashes after distillation, 40 distillations per year, spread over 28 ha. - 1285 kg Cooked flowers, 900 kg per distillation, 40 distillations a year, spread over 28 ha. - 1 Machete, used for weeding	- Healthy, mature Cananga Odorata tree - 5 kg flowers/yr/tree	- Cananga Odorata Seeds

Harvest **(per harvest, entire property exploited)**	-30 10L Plastic Buckets -30 Rice Sacks - Crates (no number)	- Harvested ylang-ylang flowers, ready for distillation	
Extraction (For 10 L of Crude Ylang-ylang oil)	- 900 kg ylang-ylang flowers - Steel Alembic distillation cucurbit - *Rustic Home-made Alembic - for distillation system* - Concrete Furnace oven - *Distillation System Furnace Oven - for distillation system* - 25m plastic piping, 1-inch diameter - *Extrusion, plastic pipes {GLO}| market for | APOS, U* - 1 10000 L capacity polytank, for cooling - *Distillation System Polytank (10000L Capacity) - for distillation system* - 2 400 L capacity polytanks, for water storage - *Distillation System Polytank (400L Capacity) - for distillation system* - 10400 L water, for distillation and cooling, recycled throughout - *Water, unspecified natural origin, agri, GLO; Water, well, in ground, GLO* - 1 Specialized recipient (Florentine vase), steel, used to separate oil from water - *Steel, chromium steel 18/8, hot rolled {GLO}| market for | APOS, U* - 3m^3 of firewood, hardwood variety (Orange), sourced from outside the farm - *Logs, hardwood, burned in furnace 30kW/CH U* - 2 2.5 L plastic bottles for rapid on-site oil collection - *Plastic 2,5 L bottle*	- 10 kg Crude ylang-ylang oil	-400 L Distilled Water - Cooked flowers (fertilizer) - Wood ash (fertilizer)
Transport (10L)	- 10 L capacity HDPE plastic transport casing - *HDPE bottles E* - 147 km by pickup truck, diesel from farm in Swedru to Accra, Ghana - *Transport, passenger car, large size, diesel, EURO 4 {GLO}| market for | APOS, U* - 5110 km by air, intercontinental, passenger airplane between Kotoka International Airport (GHA) and London Heathrow Airport (UK) - *Transport, aircraft, freight, intercontinental/RER U* - 160 km by delivery van, from London Heathrow to Poole via Southampton - *Transport, van <3.5t/RER U*	-Delivered ylang-ylang oil	

Figure 8: Table resuming total product inventory by step. Input representation in SimaPro for each process is listed after them in italics. Underlined processes are complex and are detailed in Appendix 6.

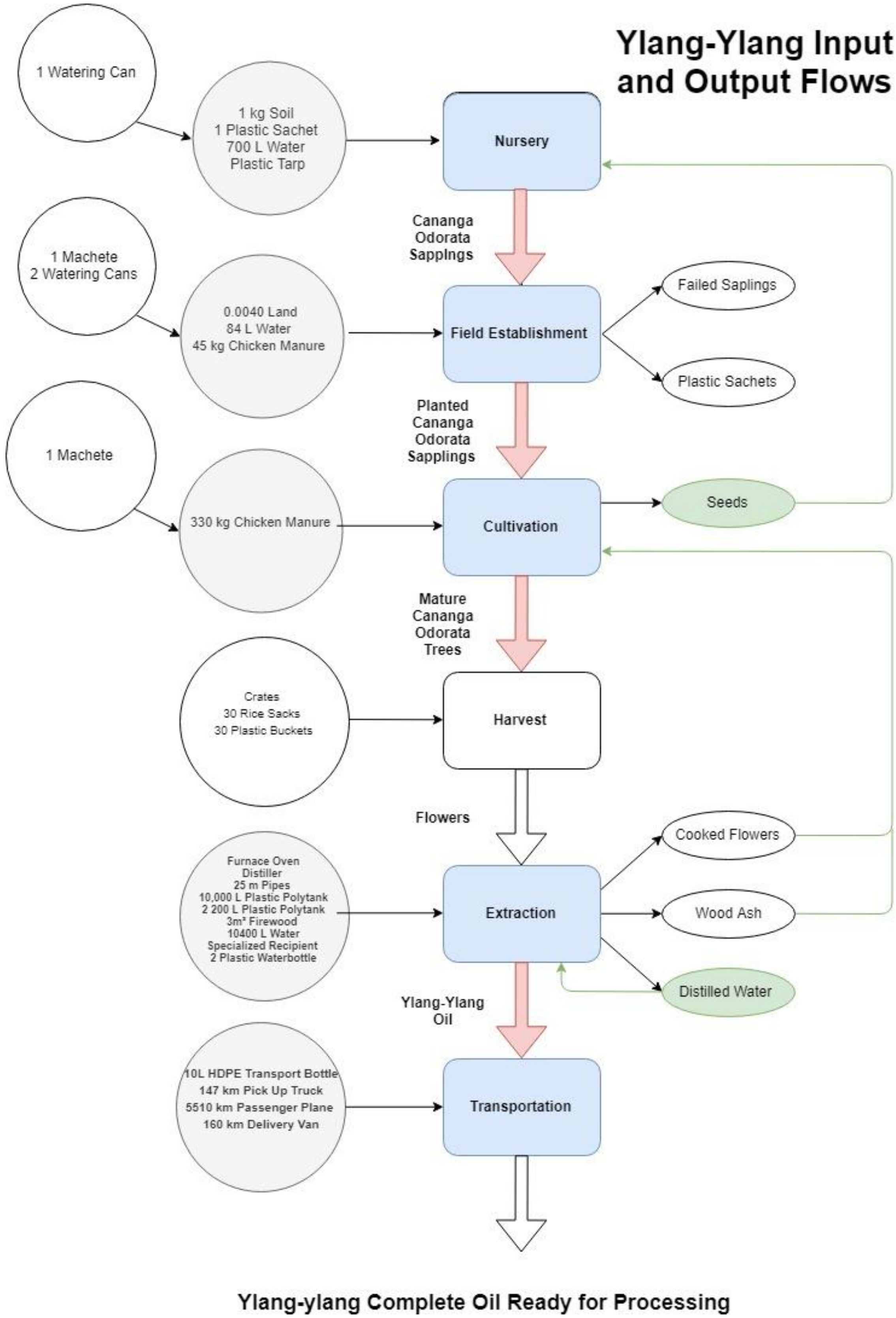

Figure 9: Flowchart illustrating the steps of ylang-ylang oil production studied for this LCA. All inputs are illustrated here, but only colored inputs have been included in the SimaPro inventory.

Impact Assessment

Impact assessments in SimaPro follow a basic structure: characterization, damage assessment, normalization, weighting, and addition. Only characterization is required by ISO norms; the rest are optional (Pré, 2019). This particular assessment suffers from the particularity of being a single product assessment, meaning that another oil has not been analyzed for comparison. The lack of consistent LCA analyses of essential oils in scientific literature further thwarts this issue. While the basis of this assessment is to pinpoint significant impact categories and hotspot steps within the ylang-ylang oil production process, normalizing and comparing its results to those of other similar products is essential in order to situate the oil's production on a greater scale. It was with this perspective that the impact assessments used for this study were chosen.

The global impact assessment method ReCiPe 2016 Midpoint (H) was chosen as the main evaluation and characterization method for the analysis of ylang-ylang oil production, as this is the only multi-category impact scheme that is not tailored specifically to Europe or North America. There are 3 different impact perspectives for Recipe 2016: Individualist (I), Hierarchist (H), and Egalitarian (E). The Hierarchist value choice is based on the most general policy principles in regard to time frame and uses choices that are both scientifically and politically accepted (Pré, 2019). It is thus the impact perspective chosen for this dissertation.

For this study, impact assessment was based on the foreground material components of the inventory that were collected during the field study in Swedru. Other data collection, such as direct soil toxicity measurements and heavy metal emissions were not acquired for this particular assessment. Midpoint impact categories were thus chosen according to available information, and categories such as marine toxicity for which the available data was deemed insufficient were not included. Of the 18 midpoint categories available in ReCiPe 2016, the following were chosen for assessment:

- Global warming
- Fine particulate matter formation
- Ozone formation, terrestrial ecosystem
- Terrestrial acidification
- Terrestrial ecotoxicity
- Freshwater ecotoxicity
- Freshwater eutrophication
- Land use
- Mineral resource scarcity
- Fossil resource scarcity
- Water consumption

It should be noted for the impacts of ecotoxicity that these results are based only on the contribution of fertilizers and wood burning. Heavy metal emissions have not been calculated and therefore are not considered for these two impact categories.

While ISO standards do not require normalization, this function allows for the comparison of data results obtained during analysis to reference information (ISO, 2006). It was discovered during evaluations in SimaPro however that normalization was not available for ReCiPe 2016 at the time of this dissertation. Evaluation of other multi-level assessments proved to be unusable due to incoherencies for the data being studied. Therefore, in order to visualize and better understand the data collected from ReCiPe 2016 assessment, other impact assessments were included to relativize ylang-ylang oil's results.

The impact assessment method IMPACT 2002+ was applied to make up for the lack of normalization functions in ReCiPe 2016. IMPACT 2002+ is a European assessment method based on European data that cannot be applied to African production systems. Its results for this dissertation must thus be considered with caution, as they do not reflect the characteristics exclusive to Ghanaian production systems and impact effects. Given that the results for impacts taken into account by both ReCiPe 2016 and IMPACT 2002+ are similar however, the normalization values expressed by IMPACT are presented here to aid as an illustrative tool regarding ylang-ylang oil's environmental effects.

This reasoning also prompted the use of the single-impact assessment method Greenhouse Gas Protocol, as it was presumed during sensitivity analyses that there would be significant differences between CO2 emission types for wood fuel in comparison to oil fuel. Greenhouse gas emissions are highlighted by scientific literature as a subject in need of attention in the agricultural sector (Beccali et al., 2010), and therefore have received particular attention in this assessment.

To further relativize ylang-ylang oil's impact values, the decision was also made to compare ReCiPe 2016 impact results with values available in a Beccali et al. (2010)'s LCA of citrus products, which also touches on the effects of orange and lemon essential oil on the environment. This is the only study touching on essential oils of any kind available on accessible research platforms. Given that ylang-ylang complete oil is often an ingredient added to creams and soap products, its impact has also been compared to the water and carbon footprint assessment of a bar soap conducted by Francke et al. (2013). This will aid in illustrating a general idea of the contribution of ylang-ylang oil to the environmental effects of an entire cosmetic product.

Sensitivity Analysis

As stated by Beccali et al. (2010), the results of LCA's are affected by uncertainty that arises from different factors including parameter and model uncertainty, uncertainty due to choices, spatial and temporal availability, and variability between sources and objects. Sensitivity analyses are systematic procedures that aid in estimating if collected data and impact results for a system are valid (ISO 14040, 2006; Beccali et al., 2010). The following sections that are implemented in the sensitivity analysis are applied to production inventory. They have been chosen according to differences in production techniques observed between the studied cultivation area and those cited in scientific literature, and are also based on the initial impact results acquired after application of the ReCiPe 2016 assessment method. With the studied farm being outside typical ylang-ylang production countries, the differences in fuel choice detailed in scientific literature, the impact of fertilizer choice, and reported differences in flower yield per tree have all contributed to the choice of the following variables for analysis:

- Choice of fertilizer
- Flower production capacity
- Generational timeframe
- Fuel used for extraction

Variables were inserted into the analysis independently from one another with all other factors and inventory component values remaining the same unless they were directly impacted by the variable change.

Results

Inventory was performed in line with the methodology and attribution calculations described above for each impact assessment.

ReCiPe 2016 Midpoint (H) Analysis

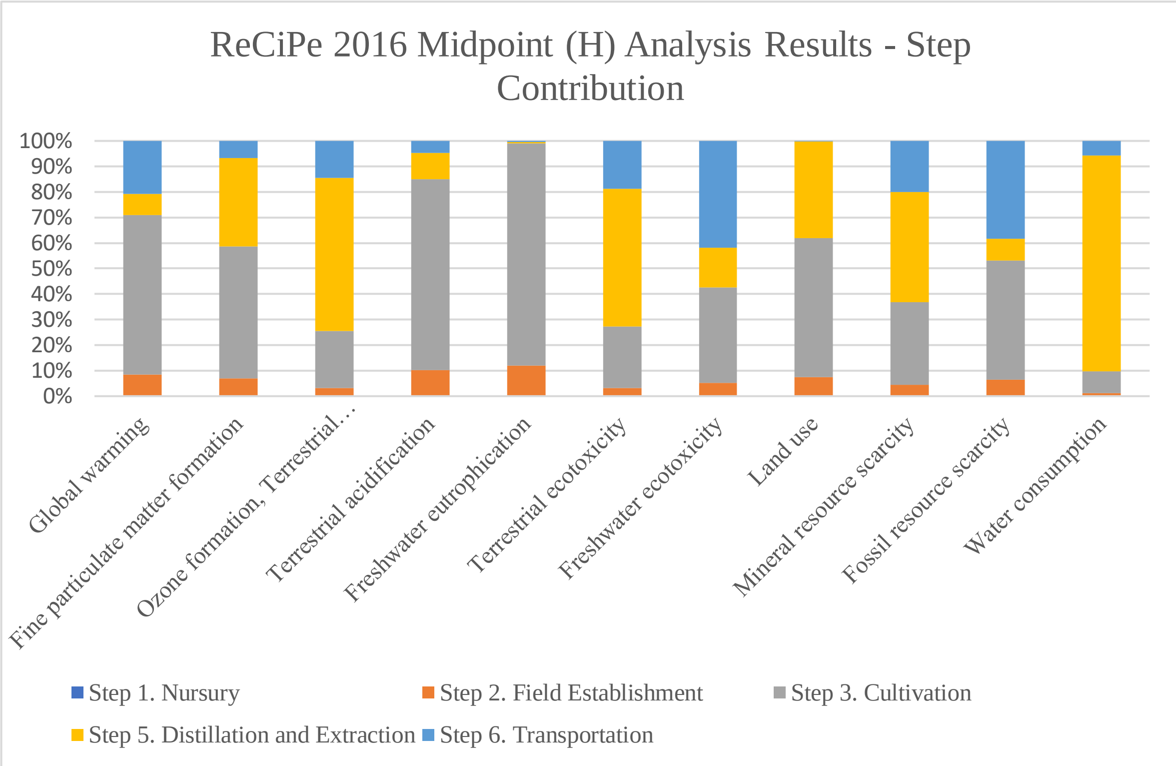

Figure 10: Graph presenting step contribution to total impacts for ReCiPe 2016.

Analysis for this impact assessment presented significant impact levels for global warming, terrestrial ecotoxicity, land use, and water consumption. Fossil resource scarcity and freshwater ecotoxicity also had notable impact levels to a lesser degree.

Global warming accounted to 56.1 kg CO2 eq, which was unexpectedly due notably to cultivation rather than distillation and transportation as initially expected. Terrestrial ecotoxicity totaled to 169.5 kg 1.4-DCB, and was largely due to distillation with 54.5% of total impact and cultivation which accounted for 23.9% of the total impact. Transportation was also a significant source for this impact, totaling to 18.7%. Cultivation and distillation contributed to 54.5% and 37.7% of the 63.5 m³ crop eq respectively. Water consumption rounds out to 44.7 m³ per L, an amount that is dominated by the distillation and extraction stage with 84.5% of total impact.

Fossil resource scarcity totaled to 9.6 kg oil eq, of which transport was a significant contributor, as expected. Cultivation also held a major proportion of this category however, representing 46.6% of total impact. Freshwater ecotoxicity represented a smaller 1.4 kg 1.4-DCB eq, which was overwhelmingly due to cultivation as well. All other impact levels totaled to values less of than 1 for their respective scales, but were typically caused by the cultivation stage. Tables detailing the entirety of ReCiPe 2016 Midpoint results can be found in Appendix 2.

IMPACT 2002+ V2.14

The results of the IMPACT 2002+ assessment method are based on European damage assessment data and calculations specific to this region. The findings found in this section must therefore not be taken as steadfast conclusions, but rather as an illustrative tool to aid in the understanding and significance of ylang-ylang oil's environmental effects. Given that normalization calculations are available for IMPACT 2002+, and given that the values expressed for this assessment method are relatively similar to those from ReCiPe 2016, the normalized scores from IMPACT 2002+ can be assessed to gain a relative idea of the impacts of ylang-ylang oil.

Normalization calculations in IMPACT 2002+ are based on dividing the impact per unit of emission by the total impact of all substances of the specific category for which characterization factors exist per person per year for Europe. Results for this section are calculated by person per year by the number of equivalent persons affected per year by unit of emissions (Pré, 2019).

IMPACT 2002+ Normalization Results

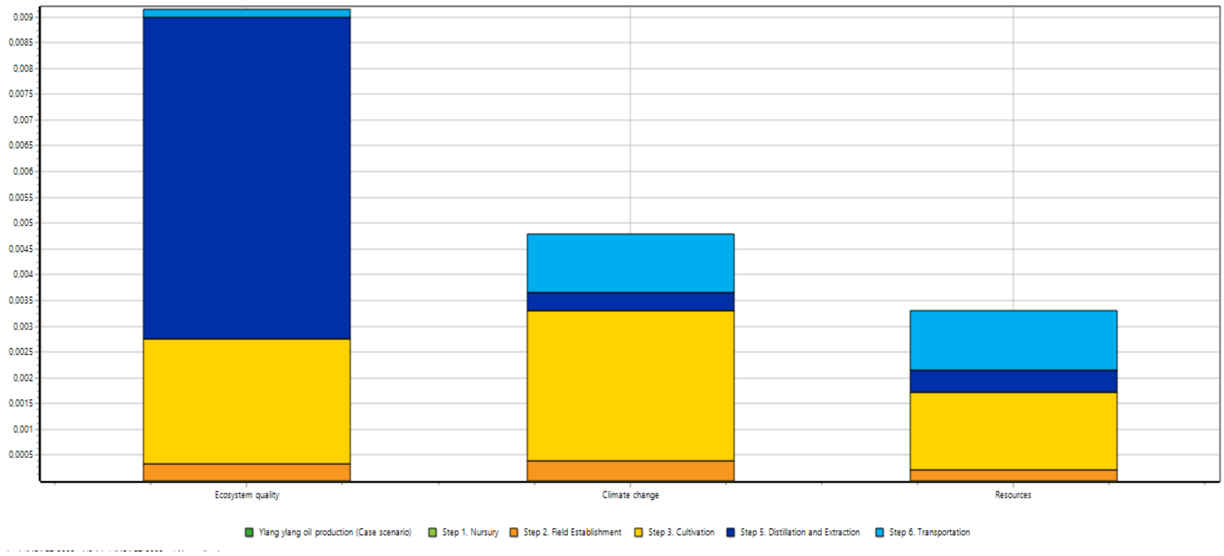

Figure 11 : Graph describing IMPACT 2002+ results for ylang-ylang oil production and step contribution based on the damage factors ecosystem quality, climate change, and resources. Nursery stage: green; Field Establishment phase: orange; Cultivation stage: yellow; Distillation and extraction phase: dark blue; Transportation phase: sky blue.

The normalization of impacts by IMPACT 2002+ allows one to confer on the relative impact categories caused by ylang-ylang production. One can observe that ylang-ylang production contributes far more to ecosystem quality than climate change or resources. Further analysis shows that this is largely due to the disposal of wood ash on farmland after wood burning during the distillation process. Cultivation contribution to this impact category is due to the use of chicken manure. Based on these results, the effects of ylang-ylang oil on ecosystem quality is of prime concern. Despite the differences between European and Ghanaian production realities, there are some similarities listed that could coincide with reality. Given that wood ash is indeed collected after distillation and used as fertilizer in the ylang-ylang fields, this impact contribution could very well reflect the reality of ylang-ylang production in this particular case to a degree. The results for the IMPACT 2002+ assessment can be found in Appendix 3.

Greenhouse Gas Protocol V1.02

The assessment of this single-flow impact assessment permits a deeper understanding of the effect of ylang-ylang oil production on the ReCiPe 2016 Midpoint (H) category Climate Change which is discussed above. CO2 eq emissions from fossil fuel, biogenic CO2, and CO2 emissions from land transformation are considered and compared for all process steps. CO2 uptake is also contemplated.

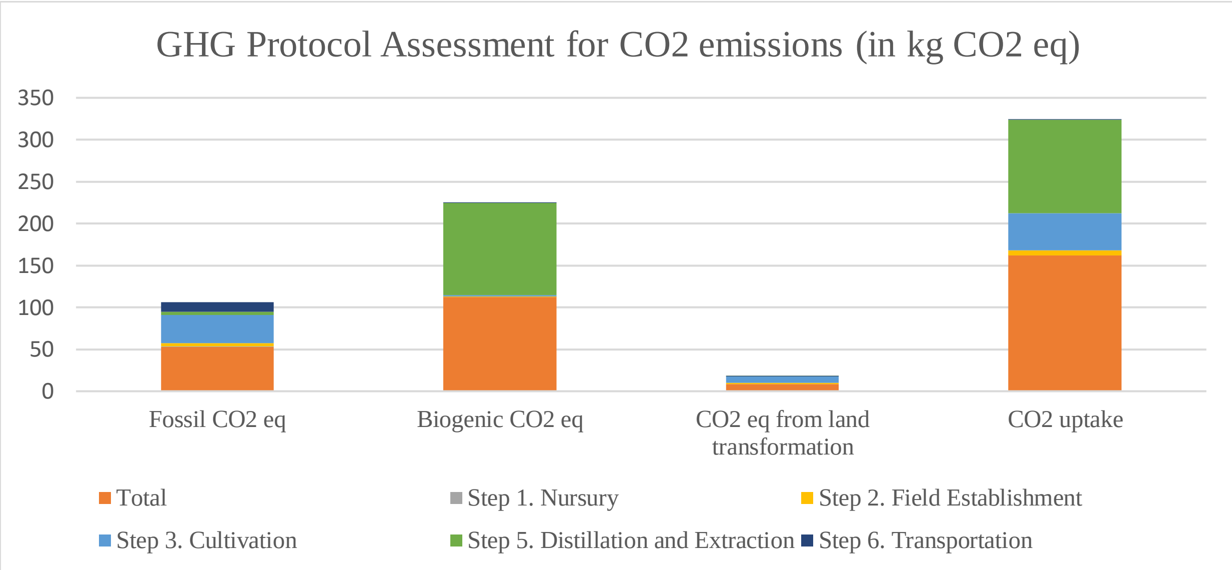

Figure 12 : GHG Protocol Impact Assessment Results in total kg CO2 eq, displaying process contribution for each category.

Further analysis attests that extraction's significant contribution to CO2 uptake is owed to the use of hardwood logs sourced from forests. It is important to note here however that the CO2 uptake from ylang-ylang trees is not considered for this analysis. This contribution could have a significant impact on total emissions. Results for the Greenhouse Gas Protocol Assessment can be found in Appendix 4.

Essential Oil Comparison

In order to situate the production impacts of ylang-ylang oil, it is important to compare it with products of similar nature. Information for orange and lemon essential oil impacts were taken from Beccali et al.'s 2010 LCA on Italian citrus-based products. The impacts featured in this report do not correlate with the impacts chosen for this dissertation, and comparison is therefore limited to coinciding impacts available for both studies. Nevertheless, evaluation of available data allows for a better understanding regarding ylang-ylang impact values. While results for both ReCiPe 2016 and IMPACT 2002+ are both shown, only the values from ReCiPe 2016 will be considered for comparison.

Essential Oil Comparison for Available Impact Categories

Impact	Orange Essential Oil	Lemon Essential Oil	Ylang-ylang Essential Oil (ReCiPe 2016)	Ylang-ylang Essential Oil (IMPACT 2002+)
Global Warming (kg CO2 eq)	72.5	43	56.1	47.4
Eutrophication (g PO_4^{3-} eq)	**187**	99	110	13.5
Acidification (kg SO_{2eq})	0.5	0.31	**0.7**	5.5
Water Consumption (m^3)	90.0	44.2	**659.4**	--

Figure 13: Table displaying impact values for impact categories discussed in Beccali et al. (2010)'s LCA on citrus products. The highest values are marked in bold font.

The value for water consumption compared here has been adjusted to include water as an input from nature in SimaPro. Calculations and reasoning for this are described in the Discussion section on water consumption.

Ylang-ylang oil situates itself between orange and lemon essential oil emissions for the global warming and eutrophication categories. It emits a relatively higher acidification rate in comparison to the other two products. Water shows the biggest contrast between the oils however, with ylang-ylang oil consuming 7 times more m^3 than orange oil production and 14 times more than lemon oil production.

Impacts in Comparison to Complete Cosmetic Products

Ylang-ylang essential oil is rarely used on its own within the cosmetic sphere, and often consists as a fragrance ingredient in larger products. It is therefore important to compare the environmental pressures caused by ylang-ylang complete with that of a cosmetic product in which it is typically used in. The possibilities for comparison are limited, given that there are very little production studies and LCA's for cosmetic products available on the market. Nevertheless, one can begin to situate the impact of the oil by comparing its carbon and water footprints to the results documented in Franke et al.'s 2013 study on a Brazilian soap bar. The following information and units are converted following the 3% maximum essential oil amount allowed for soap products defined by the IFRA.

Comparison of Carbon and Water Footprints for Ylang-ylang Oil and Soap Bar Production

	Ylang-ylang Oil (3% of total – 13.5 ml per bar)	Macadamia Bar Soap (450 g)
Carbon Footprint (kg CO2 eq)	0.758	625
Water Footprint (Blue) in m³	8.90	0.095

Figure 14: Graph comparing overlapping impact category results for ylang-ylang oil and Franke et al.'s 2013 assessment of production for a macadamia soap bar.

Calculations shown for ylang-ylang oil are based on ReCiPe 2016 Midpoint results. Total water footprint for ylang-ylang oil has been adjusted to include the water consumption added as an input from nature in SimaPro. The results expressed by Franke et al. (2013) have also been adjusted to only include impacts related to production.

According to this comparison, the carbon footprint of ylang-ylang oil is estimated to count for around 0.000012% of a bar of soap's total carbon footprint. It can be concluded that the carbon footprint of ylang-ylang oil counts only for an extremely small proportion of the cosmetic product's total impact for this category. One can attest however to ylang-ylang oil's significant impact regarding water use, as ylang-ylang consumes a surprising 9368 times more water that the soap bar studied. It can thus be concluded that the blue water footprint of ylang-ylang oil is disproportionately greater than the other ingredients and processes included in soap production and could very well count for a major part of a final product's total water consumption.

Sensitivity Analysis

As stated before, the categories chosen for sensitivity analysis are based on the variations of production found in available scientific literature, as well as the difference in location between the case studied for this dissertation based in Central Region, Ghana, and ylang-ylang oil's main producing countries, the Comoros Islands and Madagascar. The base scenario refers to the calculations and inventory contributions recorded for the Lush Inc. farm studied and described in the Methodology section above. The inclusion of other scenarios is based on scientific literature. Particularities are deliberated for each section. Complete results for each sensitivity analysis can be found in the Appendices.

Choice of Fertilizer

A significant proportion of ylang-ylang's impacts for global warming, terrestrial acidification, freshwater eutrophication, and fossil resource scarcity are due to fertilizer in the ReCiPe 2016 Midpoint Assessment. Individual analysis contributes 99,9% of cultivation's impacts to the use of chicken manure. It is reported by Parotta (2014), Benini et al. (2012), and Manner et al. (2006) that ylang-ylang trees are rustic plants that are able to survive and produce flowers in various soil conditions. However, well-balanced and fertilized soils are likely to increase their flower yield. While most industrial ylang-ylang trees are grown organically, there are no official guidelines available regarding the cultivation of the plant (Doyen, 2006), leading one to conclude that fertilizer use varies on a case-by-case basis. It is therefore interesting to compare the effects of fertilizer choice on the overall impact of ylang-ylang oil production in general. The following scenarios have been chosen for comparison:

- Base farm scenario: 15 kg chicken manure per tree
- Synthetic fertilizer scenario: Land occupied sprayed 3 times a year multiplied by years of productive lifetime (0.276 ha applied per tree)
- No fertilizer scenario: 0 kg of fertilizer applied per tree – excellent soil quality scenario

The synthetic fertilizer scenario consisted of manipulating the Ecoinvent database input "Fertilizing, by broadcaster CH/U" and deleting all inputs pertaining to machinery use as custom-made machines for spraying are not used on the farm. Therefore, only emissions included in the Ecoinvent database for this fertilizer are taken into account. Synthetic fertilizers are assimilated quickly and therefore must be applied multiple times throughout the year. An application estimation rate of 3 times a year was thus inputted multiplied by 25-generation years to the land occupied by 1 ylang-ylang tree. A no fertilizer scenario was also included, as the rustic nature of the ylang-ylang tree makes it possible for it to flower in a diverse range of soils without the need for fertilizer. Flower yield stays constant for all three scenarios, as do the other inputs not directly affected by fertilizer change.

Sensitivity Analysis for Fertilizer with ReCiPe 2016

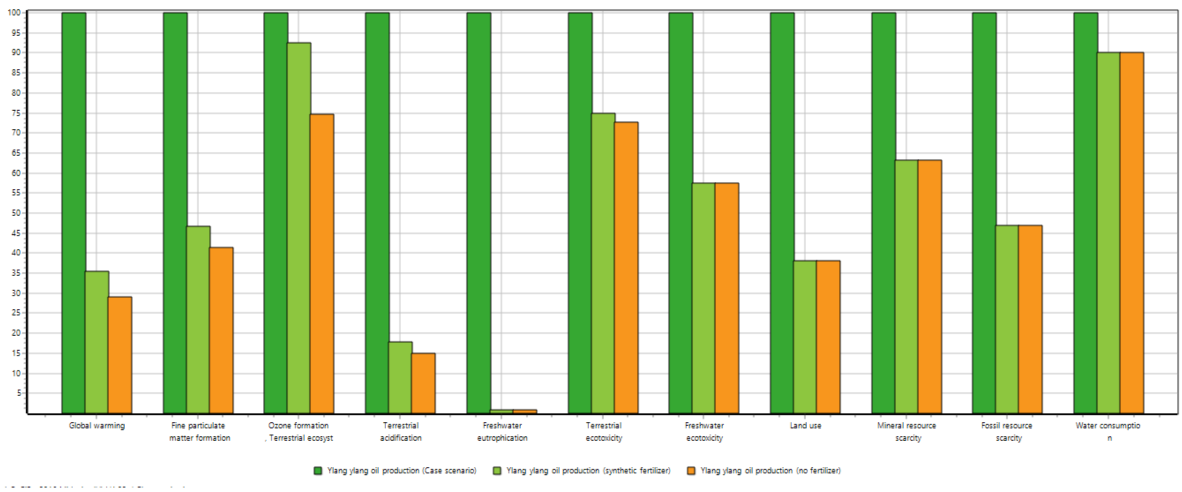

Figure 15 : Recipe 2016 Impact Comaprison for fertilizer. Case scenario: dark green; Synthetic fertilizer: light green; No fertilizer: orange. Categories follow the same order that they are presented in the Impact Assessment Methodology.

The use of chicken manure has a far greater impact compared to that of both synthetic and zero fertilizer scenarios for all impacts assessed. The synthetic fertilizer scenario had relatively similar results to the zero-fertilizer scenario. The three scenarios showed relatively similar rates of water consumption, but diverged heavily in terms of global warming, terrestrial acidification, and freshwater eutrophication.

Flower Production Capacity

Numerous sources diverge on the flower production capacity of Cananga Odorata Trees. Estimates ranging from 5 kg to 100 kg can be observed in works such as Salomon (1979), Manner et al. (2006), de Bontin (2006), Benini et al. (2012) and Parotta (2014). Given that impact analysis has contributed large proportions of ylang-ylang oil's impact to its cultivation stage, the overall flower yield of the ylang-ylang trees was assessed to determine if it has any effect on the cultivation step's impact contribution. Sensitivity analysis for this factor was conducted with ReCiPe 2016 Midpoint (H) and the Greenhouse Gas Protocol. The following scenarios have been extracted from statements in scientific literature.

- Base scenario: 5 kg flowers produced per tree per year over productive lifetime
- Benini et al. (2010) scenario: 5 kg throughout productive lifetime, but 6 kg between 10 and 15 years.
- Parotta (2014) base scenario: 5 kg after 4 years, and 11 kg after 10 years.
- Parotta (2014) extreme scenario: 5 kg after 4 years, 20 kg after 10 years.

Different scenario numbers were obtained by calculating mean productivity of different life stages, all on the same generational timeframe of 25 years applied to the base scenario. Input manipulation followed the same logic as that of the base scenario. Only step contributions for the nursery, field establishment, and cultivation stages were altered – all other inputs (fertilizer, water, etc.) within these steps are left unmodified.

Sensitivity Analysis for Yield with ReCiPe 2016

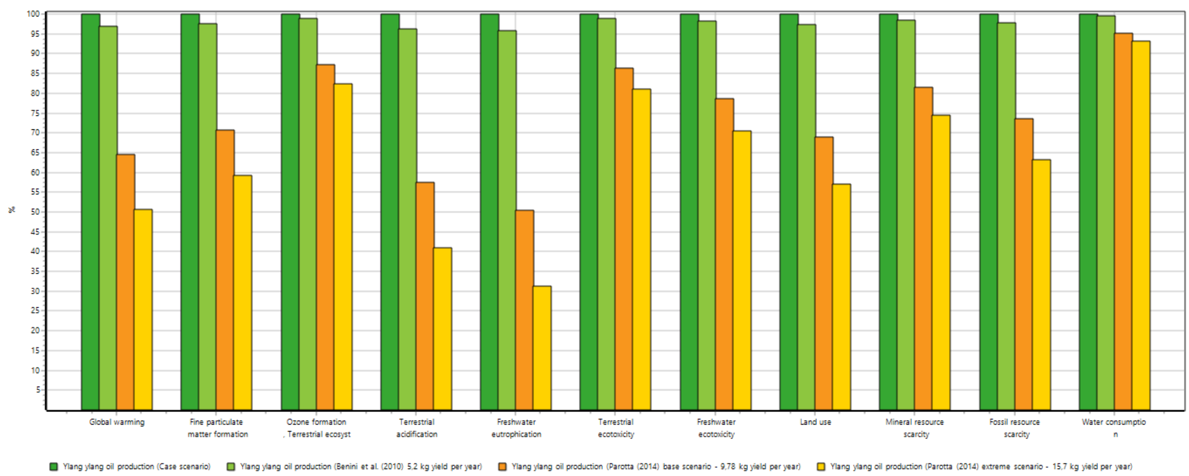

Figure 16 : ReCiPe 2016 Impact Comparison for yield. Case scenario: dark green; Benini et al. scenario: light green; Parotta base scenario: orange; Parotta extreme scenario: yellow. Categories follow the same order that they are presented in the Impact Assessment Methodology.

Analysis with ReCiPe 2016 Midpoint demonstrates significant differences between yields for the terrestrial acidification, freshwater ecotoxicity, global warming, and land use categories. Further exploration verifies that these divergences are due to the lower consumption of chicken manure per kg of flowers of the higher yields.

ReCiPe 2016 Midpoint reported significant divergences for the global warming impact category. Analysis with GHG Protocol upholds far more sober differences. While 5 kg flower yields do still have greater net CO2 eq emissions than those of higher yield levels, divergences between the two are far less obvious with this impact assessment method.

Tree Generation Lifespan

Orwa et al. (2009) report that ylang-ylang trees have a production lifetime of up to 50 years. This is echoed by farm management at Lush Inc. While this may be true, vulnerability factors and conditions are highly susceptible to change over long periods of time. It is therefore more reasonable to assess shorter productive timeframes in order to obtain fewer variable results. While 25 productive years were chosen for the base scenario of this assessment, 20 or 30 years are also considered generational lifetimes. While impacts can increase over time, attribution calculations can also lessen the overall ecological bearing of a product. Sensitivity analysis was thus conducted on productive years to determine if, all factors being equal, years cultivated had a significant impact on ylang-ylang ReCiPe 2016 Midpoint impact results.

- Base scenario: 25 productive years
- Long scenario: 30 productive years
- Orwa et al. (2009) scenario: 50 productive years

Different scenario numbers were obtained by applying different generational timeframes, still following the same application logic as the base scenario. Only step contributions for nursery, field establishment, and cultivation stages were altered. Fertilizer quantities were adjusted for added years, as were emissions to air and soil. Emissions to water and other emissions already included in background data for poultry manure were adjusted automatically. In the case of Orwa et al.'s 50 productive years scenario, it was decided to modify the inputs for the distillation system as well: Given that this system is hypothesized to have 25 years of use, the impact calculations were doubled for the 50 year scenario in order to mimic infrastructure replacement.

Sensitivity Analysis for Generational Timeframe with ReCiPe 2016

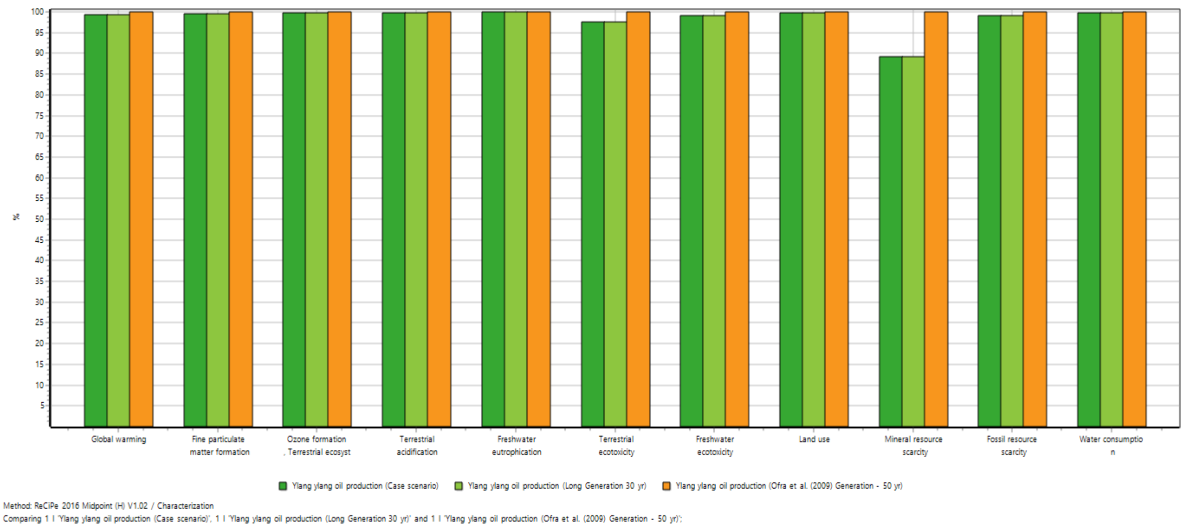

Figure 17 : ReCiPe 2016 Midpoint Impact Comparison for generation. Case scenario: dark green; 30 year scenario: light green; 50 year scenario: orange. Categories follow the same order that they are presented in the Impact Assessment Methodology.

Assessment of the three scenarios demonstrates that productive life span length has little effect on the overall impact of ylang-ylang oil. While there are slight divergences between the 50-year scenario and the 25- and 30-year scenarios in terms of terrestrial ecotoxicity and mineral resource scarcity, these are largely due to the replacement of the distillation system after 25 years.

Fuel Used for Extraction

While numerous extraction methods for ylang-ylang oil are discussed in available literature, the most practiced form of oil abstraction is steam distillation. Fuel sources for steam distillation alembic systems consist of either wood burning or petrol. As noted in scientific literature, choice of heating fuel has a significant impact on distillation time and oil quality (Salomon, 1979; Benini et al., 2012). It is also expected to have a large impact on biogenic CO2 emissions and CO2 uptake.

- Base scenario: 3m³ of firewood, equating to 2740.6 kg for 20 hours of distillation
- Petrol scenario: 50.82 L of fuel oil for 14 hours of distillation

Sensitivity analysis for this factor was conducted with ReCiPe 2016 Midpoint (H) and the Greenhouse Gas Protocol assessments.

A 2016 industry report conducted by the Mayotte Directorate of Food, Agriculture and Forestry (DAAF) reports that petrol-based distillation systems required 80L of oil per 20-24 hours of distillation. If this logic is applied to the lower hours needed for extraction explained by Salomon (1979), an oil-to-hour ratio of 3.63 L of fuel oil per hour can be applied to 14 hours of distillation time.

The conversion hours were also applied to water consumption, as the distillation time needed for fuel oil-based extraction is nearly 3/4ths that of wood-based extraction.

Sensitivity Analysis for Fuel with ReCiPe 2016

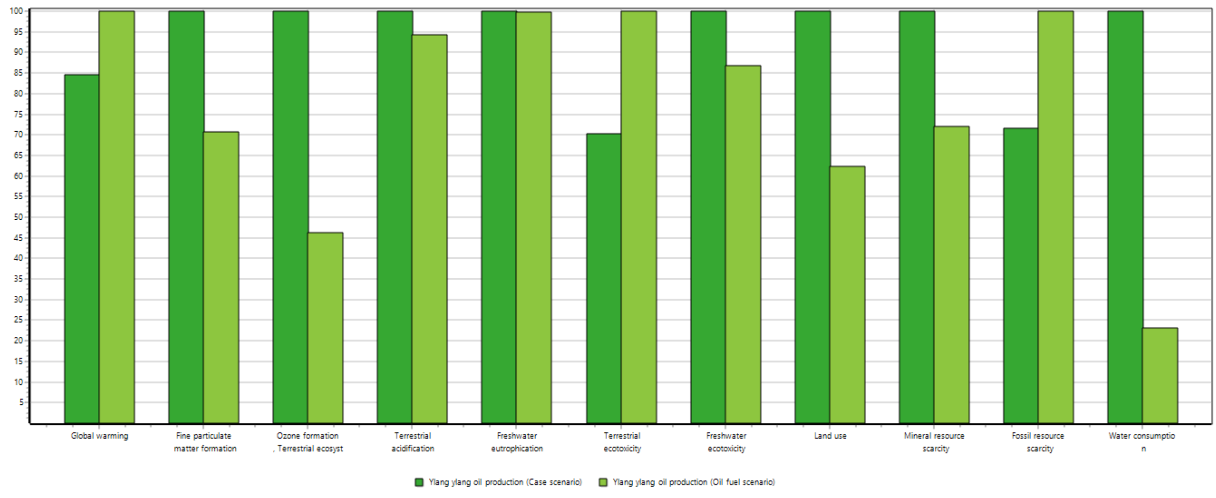

Figure 18 : ReCiPe 2016 Midpoint Impact Comparison for fuel. Case scenario (wood fuel): dark green; Oil fuel scenario: light green. Categories follow the same order that they are presented in the Impact Assessment Methodology.

ReCiPe 2016 Midpoint assessment displays significant differences in terms of global warming, terrestrial ecotoxicity, land use, fossil resource scarcity, and water consumption. Oil fuel produces 10 kg of CO2 equivalent more than wood fuel, totaling to 66.3 kg CO2 eq and 56.1 kg CO2 eq respectively. Fossil resource scarcity was also relatively higher for oil fuel, with 13.5 kg oil eq compared to wood fuel's 9.6 kg oil eq. Exploration determined that wood fuel's impact for this category was largely due to infrastructure used for cutting trees. The largest divergences were reported for terrestrial ecotoxicity and land use: oil fuel contributed 241.3 kg 1.4-DCB eq for terrestrial ecotoxicity, compared to 169.5 kg 1.4-DCB eq from wood fuel. Oil fuel had a smaller impact on land use however, contributing 39.6 m^2 crop eq compared to wood fuel's 63.5. Water consumption from the Technosphere was also higher for wood fuel, consuming 44.7 m^3 compared to oil fuel's 10.3.

Sensitivity Analysis for Fuel with GHG Protocol

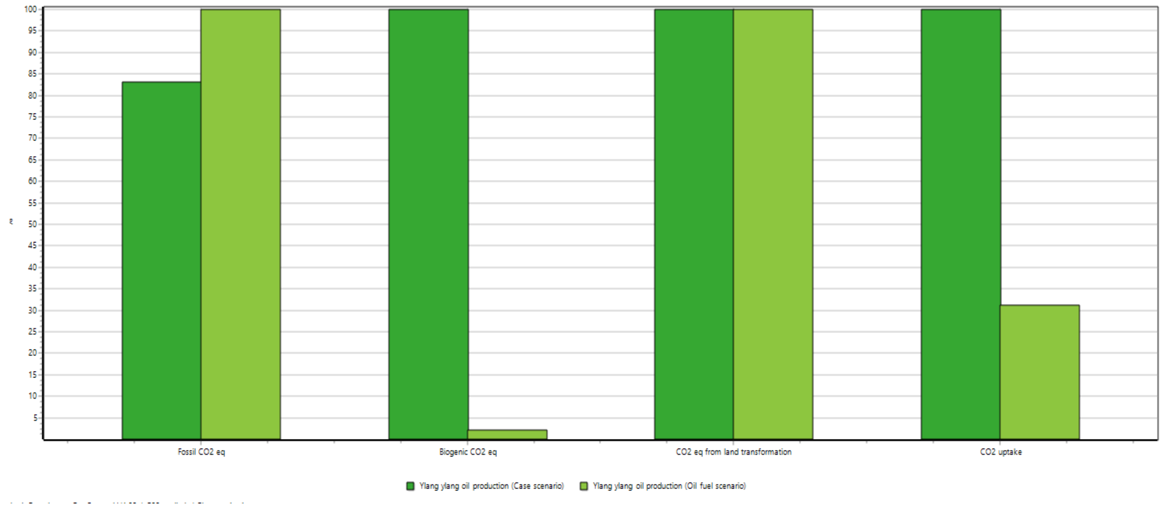

Figure 19 : GHG Protocol Impact Comparison for fuel. Case scenario (wood fuel): dark green; Oil fuel scenario: light green. Categories from left to right: Fossil CO2 eq, Biogenic CO2 eq, CO2 eq from land transformation, CO2 eq uptake.

The GHG Protocol impact assessment demonstrates a significant difference for both the biogenic CO2 emissions and the CO2 uptake categories. Wood fuel has a significantly larger biogenic CO2 impact with 112.44 kg of CO2 eq compared to 2.3 kg CO2 eq of oil fuel. Fossil fuel impacts did not vary as dramatically as expected, with oil fuel only emitting roughly 10 kg CO2 eq more than wood fuel. CO2 uptake is far higher however for wood fuel than oil fuel.

Discussion

Analysis with the ReCiPe 2016 Midpoint Assessment analysis exhibits significant contributions to global warming (climate change), terrestrial ecotoxicity, water use, and land use categories. Fossil resource scarcity also displayed important numbers. Sensitivity analyses showed significant variability for fuel and fertilizer choices.

Climate Change and Greenhouse Gas Emissions

For the impact category of global warming (climate change) of ReCiPe 2016, crude ylang-ylang oil complete production emits 56.1 kg of CO2 equivalent per liter of oil. This is unexpectedly principally due to cultivation, which accounts for 62.4% of total impact. Given that machetes and buckets were not included in SimaPro due to insignificant impact weight, the high impact levels associated with the cultivation stage are exclusively due to the significant amount of poultry manure fertilizer used per tree each year, as this is the only product that has been added in the SimaPro inventory from the Technosphere. Direct emissions to air from poultry manure, particularly dinitrogen monoxide (N2O) and methane (CH4) emissions, are heavily responsible for these high numbers. Distillation and extraction accounted only for 8.2% of total emissions for this category despite previous assumptions. Transportation had a lower contribution to global warming emissions than expected, totaling to 20.7% ylang-ylang's total impact for this category.

The Greenhouse Gas Protocol Assessment provides a more detailed analysis of the oil's greenhouse gas impact, notably in terms of biogenic CO2. According to this assessment, ylang-ylang oil emits 53.1 kg CO2 eq of fossil fuel resources, and 122.4 kg CO2 eq of biogenic fuel resources. This is balanced by 162.1 kg CO2 eq of CO2 uptake, which is largely attributed to the use of hardwood logs for fuel. Again, CO2 uptake of ylang-ylang trees themselves is not included in the inventory due to a lack of information in existing visited literature; the planting of ylang-ylang trees may increase CO2 uptake and create carbon stocks, which may prove beneficial depending on land transformation particularities. Transportation's share of impact can be contributed in large part to road transportation via pickup truck rather than emissions from air transportation as previously thought. While this is likely due to the calculation of t/km units for aircraft transportation as opposed to simply km units for the pickup truck in SimaPro, these results do raise the question of emission differences between transport options. It is important to note however that CO2 emissions per km can vary broadly depending on the mode of transportation, applied vehicle emission norms, vehicle age, and size, among countless other variables (Sims et al., 2014). This is not only in terms of amounts emitted, but also by emission type. The question of fuel type and fuel sourcing can also heavily influence total emission rates (Sims et al., 2014), and can contribute in varying degrees to environmental impact categories. The results presented here can therefore vary depending on the mode of transportation used and are therefore expected to change considerably from one production site to another.

Sensitivity analysis for global warming and greenhouse gas emissions presents alterability of these impact categories to fertilizers and choice of fuel source during distillation. This was also the case for the flower yield sensitivity analysis to a lesser degree. Use of chicken manure for the base scenario emitted a significantly higher level of kg CO_2 eq for the global warming indicator in ReCiPe 2016 as opposed to the synthetic fertilizer and no fertilizer scenarios, due to high levels of CH_4 and N_2O emissions per kg. While these GHG's naturally occur from agricultural practices in general, the intensification of agricultural systems and animal-based products can significantly contribute to the trapping of heat in the atmosphere and thus contribute to climate change (Glovett, 2016; Johnson et al., 2007). Emissions to air are significantly lower for synthetic fertilizer, as methane is not produced in large quantities for mineral based fertilizers. The notable differences between these two scenarios is also most likely due to the greater amount of manure applied than that of synthetic fertilizer in the scenario studied, as well as the capital goods and resources needed for raising poultry. While the amount of synthetic fertilizer used is assumed to vary these results, this is a thought-provoking outcome that is interesting to consider when choosing fertilizer types. Synthetic fertilizers can however be a significant source of N_2O emissions (Kazafy, 2015), and therefore must not be considered as a superior alternative; their use can significantly impact soil nutrient balances and lead to other negative impacts such as soil acidification and biodiversity loss (Hermary, 2007; Khanal, 2009).

The global warming indicators in ReCiPe 2016 are noticeably higher for oil fuel use as compared to wood fuel in sensitivity analysis. Greenhouse Gas Protocol reported lower biogenic CO_2 emissions for oil fuel when the two were compared however, although oil fuel had far less kg of CO_2 uptake than wood fuel. The incoherencies between these two methods is undoubtedly due to the differences regarding types of sourcing and emissions between the two fuel scenarios, as well as the consideration of biogenic fuel sources taken into account by the Greenhouse Gas Protocol assessment.

In comparison with the results of orange and lemon essential oils, Beccali et al. (2010) situate ylang-ylang oil at a value between orange's 72.5 kg CO_2 eq and lemon's 43 kg CO_2 eq. Beccali et al. report that the impact values of these two products are directly linked to the use of fertilizer, similarly to the case of ylang-ylang. These findings further confirm the massive contribution of fertilizer choice to the overall global warming emissions of agriculture-based products. Normalization with IMPACT 2002+ shows that climate change is by far not the oil's biggest impact contribution. Ylang-ylang's global warming emissions can therefore be considered to be within a normal range for essential oils that have been studied. While these numbers may seem high, the comparison of ylang-ylang oil's global warming contribution compared to that of an entire soap product shows that the oil contributes only to an extremely minor fraction of the product's overall CO_2 eq emissions. While further research is needed, the results of this comparison lead to the conclusion that ylang-ylang oil is not a significant contributor to the overall global warming emissions of finalized cosmetic products.

Fossil Resource Consumption

The fossil resource impact category for ylang-ylang oil production amounted to 9.6 kg oil eq with ReCiPe 2016. While transportation accounted for a significant proportion of this impact category as expected with 38.4% of the total impact, it was the cultivation stage that held the most weight, attributing to 46.6% of total impact. Distillation and extraction accounted for 7.92% of total impact. Sensitivity analysis confirmed the significant contribution of chicken manure to this impact compared to the other scenarios. Further study concludes that these values can be largely attributed to the capital goods and feed used during poultry rearing, as well as processes that are specific to European production systems for these inputs. It is therefore difficult to take the results for this analysis as fact due to the plethora of variabilities in production and feed sourcing for poultry manure production between Africa and Europe. The results for fossil resource consumption must therefore be taken lightly and should not be considered as representative for the overall impact of ylang-ylang production.

Sensitivity analysis showed variability for fuel choice as well, as did yield to a lesser extent. As anticipated, oil use had a higher rate of fossil resource consumption than that of wood fuel, but not as significantly as expected. Oil fuel use contributed 13.5 kg oil eq to the fossil resource, compared to the 9.6 kg oil eq emitted by wood fuel use. This seemingly minimal variation is due to the smaller percentage of this impact attributed to the distillation stage. Given the relative scantiness of distillation impact however, a rise of 4 kg CO2 eq between these two fuel sources could be considered significant overall. This assumption is supported by the differences in greenhouse gas emission types described for climate change.

Like the global warming impact category, the majority of fossil resource consumption is unexpectedly attributed to the poultry manure utilized during the cultivation stage, further emphasizing the weight of fertilizer choice for overall impact values despite potential skewing of results due to background data limitations. Another surprising discovery was the impact contribution for the components of the transportation stage which was mostly due to transport in Ghana via pick-up truck rather than intercontinental transport by air as previously expected. While the proportion of air transportation is likely to increase for ylang-ylang sourced from countries farther away from Europe like Madagascar and the Comoros, these results raise an interesting point on the contribution of air travel to a product's overall impact. Although focus regarding the intercontinental transportation and importation of goods is important, more attention should be attributed to ground transportation methods.

Unfortunately, existing assessments of similar products do not disclose the fossil fuel impact in their studies, leaving no point of reference to be compared to. Normalization with IMPACT 2002+, however, situates ylang-ylang at a relatively low impact contribution for resource consumption compared to climate change and ecosystem quality damage categories.

Fertilizers, Emissions to Soil, and Emissions to Freshwater

The values for the impact categories of terrestrial ecotoxicity, terrestrial acidification, freshwater eutrophication, and freshwater ecotoxicity can all largely be attributed to the use of poultry manure during the cultivation stages and hardwood log burning during distillation, although transportation does count for a significant percent for terrestrial and freshwater ecotoxicity. Fertilizer choice tested during the sensitivity analyses shows dramatically greater values for chicken manure in comparison to the synthetic and no fertilizer scenarios. There were also considerable differences between wood fuel use and oil fuel use. For the base scenario, the terrestrial ecotoxicity category displayed high numbers with 170 kg 1.4-DCB emitted per L in ReCiPe 2016. The cultivation and distillation steps contributed the most to this impact, accounting for 26.2% and 52.1% of total impact respectively. Transportation also contributed a significant 18.1%. Further research upholds that transportation's impact is largely due to road transport by diesel pickup, for which brake wear emissions are notably to blame. Indeed, the majority of these impacts can be attributed to manufacturing processes for capital goods sourced from the Technosphere, meaning that the total impact of this emissions category is largely situated in these producing countries rather than on the farm itself. This was also the case for the production of poultry manure, where the brake wear emissions for tractors used to produce animal feed are the most responsible for its impact. For ecotoxicity as a whole however, the burning of wood logs is the greatest contributor. While the specific ecotoxicity emissions pertaining to burning wood are not disclosed by SimaPro, further research concludes that the incomplete combustion of firewood can lead to the leaching of harmful particulate matter such as trace metals and inorganic ions (Costa et al., 2018). It is important to note however that the direct emissions of heavy metals to soil from foreground data have not been included for this dissertation. The presence of these metals is particularly impactful and could very well significantly alter the results presented here.

Terrestrial acidification counted for a small 0.7 kg SO2 eq, and while this value is less than 1, the impact of fertilizer for the other categories justifies its examination. As expected, acidification is chiefly due to chicken manure, which accounts for 42% of this impact value. Ylang-ylang oil has a slightly higher impact level for this category when compared to orange and lemon oil, which hold 0.5 and 0.3 kg SO2 eq respectively. Soil pH levels require particular attention, as an increase in acidified nutrients can lead to the reduction of soil fertility and in turn affect plant growth and productivity (Azevedo et al., 2016). While acidifying forms of nutrients such as nitrogen and sulfur are known to be the main culprit of acidification (Azevedo et al., 2016; Roy et al., 2014), the three acidified nutrients nitrogen oxide (NOx), sulfur dioxide (SO2), and ammonia (NH3) are not presented when assessing process contribution for this impact category. Further research shows that this is because the system process of poultry manure in Ecoinvent does not include direct emissions to soil, although NH3 direct emissions are present in the poultry manure process but as an emission to air. This is also the case for the process of burning wood taken from Ecoinvent as well. The lack of direct emissions calculated for this impact assessment presents a significant handicap for the calculation of terrestrial acidification, and the results expressed here cannot be taken as concrete.

Freshwater eutrophication and freshwater ecotoxicity impacts accounted for smaller magnitudes, hovering around 0.3 kg P eq and 1.4 kg 1.4-DCB eq respectively. These are both largely due to the cultivation stage, although transport contributed 41% of total impact to freshwater ecotoxicity. Runoff of nutrients such as nitrogen and phosphates contribute heavily to freshwater eutrophication (Pal, 2017), and are principally caused by fertilizer use and agricultural practices (Burcharth, 2007). Indeed, 87% of eutrophication can be attributed to the cultivation stage, largely due to direct emissions of nitrogen, phosphorus, and phosphorus pentoxide calculated according to the FAO rates of poultry emissions for Ghana (FAO, 2005). Eutrophication was calculated differently for Beccali et al. (2010)'s orange and lemon oils, presented in grams of phosphate eq. Once phosphate emissions are calculated for ylang-ylang oil, comparison of the three essential oil shows lemon and ylang-ylang oil to have relatively low scores in comparison to orange oil. Based on these findings, ylang-ylang can thus be concluded to have relatively similar eutrophication levels to that of other essential oils that have been assessed.

As for freshwater ecotoxicity, this value is notably due to the production and waste production of capital goods used for poultry manure production and road transportation by diesel pickup truck. The direct emissions related to freshwater ecotoxicity like zinc sulphate and ethanol (ECETOC, 2016) are not applied to foreground processes like the alembic system, making this score for freshwater eutrophication largely dependent on background data emissions. A concrete emissions value for these two impact assessments can therefore not be determined for this particular study.

Sensitivity analysis for fertilizer use displayed the most significant impact differences between studied scenarios. It should be noted that soil emissions zinc, lead, and cadmium are included in the synthetic fertilizer input, which is not the case for that of chicken manure. Nevertheless, one can note dramatic differences in values for all impact categories discussed in this section. The elimination of chicken fertilizer leaves wood burning as the main culprit for terrestrial acidification and ecotoxicity for both synthetic and no fertilizer scenarios. The contribution of the cultivation stage to freshwater ecotoxicity and eutrophication diminishes significantly in the synthetic and no fertilizer scenarios. Synthetic fertilizer is advantageous as it applies pre-calculated nutrient ratios that can be absorbed immediately by plants (Kazafy, 2015), meaning that lower quantities are needed to produce the same effect as that of natural fertilizers like animal manure. The readily available concentrations of fertilizers such as nitrates, phosphates, and potassium are however more susceptible to increase nitrate levels in soils and leach into water systems, thereby creating fertilizer pollution and increasing direct freshwater and ecotoxicity levels, as well as terrestrial acidification and freshwater eutrophication. Plants grown in overly fertilized soils also form deficiencies in nutrients such as zinc, copper and protein (Kazafy, 2015), which can hinder their growth and productivity. Their use can also disrupt natural nutrient conversion processes by bacteria and microorganisms naturally present in soil (Hermary, 2007; Kazafy, 2015). While the emissions for poultry manure are far greater than those of synthetic fertilizer for this study, it is important to not judge mineral fertilizers as superior, as the impacts on nutrient balances in and around farm area can be seriously damaging (Hermary, 2007).

Sensitivity analyses comparing fuel sources shows very little differences for terrestrial acidification, freshwater eutrophication, or freshwater ecotoxicity. Where results do diverge dramatically however is for terrestrial ecotoxicity, where oil fuel contributes 241 kg 1.4-DCB eq as opposed to wood fuel's 170 kg 1.4-DCB. The larger value is attributed to the use of light fuel oil in the oil fuel scenario, which is principally due to extraction of crude oil according to Singh et al. (2014). The emissions for oil fuel from Ecoinvent are also well documented for the chosen process, which also may influence this result. Heavy metal emissions also seem to be included for oil fuel.

Water Consumption

Results from ReCiPe 2016 point to the distillation and extraction step as the main source of ylang-ylang oil's water consumption. While this was initially assumed to be due to the large quantities of water needed to distill and cool heated water vapor during the extraction process, further examination of results proved that this outcome was largely attributed to background data impacts. Water consumption that was recorded as an input from nature does not seem to be included in the calculations recorded by ReCiPe 2016, despite the copious amounts of freshwater drawn from onsite underground water sources for cooling. Capital goods from the Technosphere found in the Ecoinvent databases are also based on European information and particularities, which do not necessarily apply to the farm's location. In an attempt to counter this, other assessment methods were explored, but unfortunately all single method water footprint impact assessments available in SimaPro were deemed to be inapplicable in this case. Therefore, the water demand from nature was added to the ReCiPe Technosphere calculations by hand for each step in the foreground order to attain a better idea of water consumption.

Total Blue Water Consumption of 1 L of Ylang-ylang Oil in M³

Consumption from Technosphere	Consumption from Nature: Nursery Stage	Consumed from Nature: Field Establishment	Consumed from Nature: Distillation and Extraction	Total Blue Water Footprint
44,7	3.8	60.5	550.4	**659.4**

Figure 20: Table summarizing total blue water footprint - water consumption from nature and the Technosphere for ylang-ylang oil.

It is important to note that these numbers account only for what is defined as ylang-ylang oil's blue footprint, and that green and grey footprints described by UNESCO (Hoekstra et al., 2011) are not accounted for in this particular assessment. Evapotranspiration is also not included in these values either, as it is particularly difficult to differentiate between evapotranspiration from blue water footprint and from green water footprint (Hoekstra et al., 2011). One can attest to a dramatically greater level of cubic meters consumed, particularly for the distillation and extraction and field establishment phases. The contrast between field establishment and cultivation stages is based on the assumption that Cananga Odorata trees are exclusively rainfed after their third year.

The comparison of water consumption to orange and lemon essential oils reveals a radically higher expenditure for ylang-ylang oil. This is notably due to divergences in extraction and processing – orange and lemon oils are typically extracted by exerting mechanical cold pressing on peels from the fruits before submitting the resulting liquid to centrifuging, a process that demands far less water than hydrodistillation (Ferhat et al., 2007). Direct water consumption of orange and lemon essential oils is therefore mostly due to irrigation and crop cultivation, as opposed to their processing like ylang-ylang.

While numbers decreased in the sensitivity analysis for extraction with oil fuel at 560.28 m^3, the extraction of ylang-ylang oil requires significant amounts of water regardless of the fuel source used. This can be attributed to the large amounts of water used in the cooling polytank to return oil-saturated water vapor back to its liquid state. The farm does practice frequent recycling of water on site, both in the collection of water vapor and wastewater. This contributes significantly to the reduction of its blue water consumptive footprint (Hoekstra et al., 2011). These results coincide with the statements reported by Benitez Cortez et al. (2016). High numbers are presented despite frequent recycling of water for multiple distillations, however. This impact is compounded by the water consumption for the production of capital goods used during the oil's processing.

It is important to note that further study of the process contribution for the water footprint values presented by SimaPro from background data is largely based on hydropower-based electricity sources used to power hardwood transformation, although details to where this electricity is applied during processing is not clear. A significant limitation to this calculation consists of the fact that calculations for the hardwood log combustion processes available in Ecoinvent and SimaPro are based on central European conditions. While hydropower is relatively abundant in Ghana and aliments roughly a fourth of all electricity consumption in the country (USAID Power Africa, 2018), there is no proof that the energy sources recorded in the Ecoinvent hardwood log process reflect the reality of hardwood processing in Ghana or other countries outside Europe. Personal observation in the field and accompanying of farm management during a wood sale confirms that the chainsaws used by hardwood providers are powered by diesel, and thus do not consist of the same production steps and impacts in the inventory for this particular production site.

Nevertheless, water consumption is by far ylang-ylang's largest impact category. Comparison of ylang-ylang's blue water footprint to that of Franke et al.'s soap bar shows a dramatically higher consumption of water than for the entire cosmetic product as a whole. It can thus be concluded that ylang-ylang oil demands a significant amount of water per liter of oil produced, particularly for the distillation stage, and that its water footprint increases the overall impact values for the cosmetic products that it is included in. Further research regarding the oil's impact in terms of blue, green, and grey water footprints (Hoekstra et al., 2011) would aid in providing a more complete understanding of ylang-ylang's water consumption, as would calculations regarding evapotranspiration. This impact requires particular attention as more focus turns towards the rational use of water in agricultural systems, a sector that consumes 70% of freshwater withdrawals globally (UN Water, 2018). Given that water scarcity is expected to increase in coming years, the ylang-ylang market could significantly contribute to and be affected by the diminishing of water sources. Further research in terms of extraction development and technology accessibility for smaller scale producers is thus strongly recommended.

Land Use

Analysis with ReCiPe 2016 Midpoint revealed land use caused by ylang-ylang production accounted for 63.5 m^2 crop eq. Cultivation and distillation contributed the most to this impact, with 54.5% and 37.7% of total impact respectively.

While the high impact levels for cultivation were thought to be due to ylang-ylang trees' permanent land occupation and the large amounts of space required by them to grow at full production capacity, this only contributed to 13% of cultivation's impact. The rest of the land use impact was dedicated to growing feed for chicken manure production. Sensitivity analyses for fertilizer choice showed significant differences between the base scenario and the synthetic fertilizer and no fertilizer scenarios, with poultry manure requiring almost triple the m^2 crop eq of land than the other two. Given that the background data for the chicken manure input is based on European data, these quantities cannot be confirmed to be the reality of this assessment. This does however raise the question of the importance of environmental impacts contributed to the use of animal-based products and co-products in agriculture discussed by Garnett (2011).

In regard to distillation, land used to source wood fuel for the extraction process accounts for 40% of its impact. Another 14% is due to the diesel consumption of the chainsaw used for cutting down logs. Sensitivity analysis between fuel and wood sources showed significant differences for this impact category with wood fuel occupying 24 m^2 crop eq more than oil fuel use. This coincides with the concerns raised by Benini et al. (2010) regarding deforestation caused by sourcing wood logs for fuel during the extraction stage. The long periods of distillation for small yields is largely to blame for ylang-ylang distillation's significant wood consumption and overall CO_2 emissions. This effect may be counteracted with the extraction alternatives listed in studies by Mahfud et al (2017), Haluk (2005), and

McGaw et al. (2016) that decrease extraction time and improve overall distillation capacities. There are however numerous considerations to ponder when comparing fuels and extraction techniques; differing sources, required capital goods, and economic and social implications associated with each fuel source are considerable elements that must be taken into account.

It can thus be concluded that fertilizer and fuel choice have notable effects on the impact of land use. This impact is also influenced by the nature of land use change implicated on an area to make room for ylang-ylang cultivation. While the land used for the plantation studied for this assessment had already been converted to farmland prior to ownership, this is not always the case in ylang-ylang producing countries such as the Comoros and Madagascar or other areas in Ghana where forest area is compromised to make room for cash crop cultures (Benini et al., 2010; Appiah et al., 2009).

Deforestation caused by land use change for agricultural production is a topic of prime concern that has been addressed in a plethora of available scientific literature. The effects of land intensification due to agricultural systems in general have been well documented as well. The issue of deforestation caused by ylang-ylang distillation has been raised by Benini et al. (2012) and Salomon (1979) in the case of the Comoros Islands, as well as in a report issued by UNEP (2009). As for Ghana, the country's natural tropical forest cover represents less than 20% of the original numbers recorded during the early 1900's (Appiah et al., 2009). While this drastic reduction is due to numerous causes such as mining and urbanization, the increase in agricultural practices and their impact on these figures is far from negligible.

In contrast, the planting of essential oil cultivation areas could prove useful in reducing the effects of desertification. Given the rustic nature of the plants, ylang-ylang trees can survive in a number of different soil conditions, provided that said soils are deep. Their planting in arid areas could possibly aid in the stabilization of areas at risk of dry spells and desertification, provided that they have enough water. While this has been a topic discussed by Rajeswara Rao (1999) in regard to using essential oil plantations to stop desertification in India, it is not known if has been attempted with ylang-ylang trees, much less if it is possible. The impact of land use must therefore be developed further.

Biodiversity

For this particular assessment, the ReCiPe 2016 impact categories can give insight into the potential effects of ylang-ylang oil production on biodiversity. The sensitivity analyses for fuel use and fertilizer may also aid in understanding of ylang-ylang oil's impacts.

Issues regarding biodiversity impacts are relatively similar to those concerning land use. The extension of farmland dedicated to ylang-ylang production threatens species biodiversity by accelerating habitat fragmentation and isolating species populations (Tscharntke et al., 2005). Again, this can have particularly damaging effects in cases of deforestation described in the previous section. The majority of ylang-ylang oil's impact related to this category can be attributed to crop production for poultry feed. Here, the issue regarding SimaPro input data arises again; land use change inputs available in SimaPro are calculated based on European realities, meaning that the chicken manure inventory input available in Ecoinvent databases is based on land use change related to European land for European agriculture. Europe however has very few purely natural ecosystems left that are not submitted to human control (Tscharntke et al., 2005), which is not the case for the areas in which ylang-ylang is cultivated. This control does implicate developed conservation and land scheme strategies in developed countries (Lambin et al., 2011). In contrast, between 1980 and 2000 more than half of transformed land for agriculture in tropical areas was done at the expense of intact forests (Lambin et al., 2011). These forests are complex natural ecosystems that are rich sources of biodiversity and require strict land preservation norms and strategies for their survival. It can be assumed that the effects of land use change in tropical areas where ylang-ylang is farmed could have an even higher impact than what is reported in this assessment. Fertilizer choice and wood fuel for the distillation of ylang-ylang oil both contribute significantly to deforestation and therefore biodiversity loss, and thus require specific attention when assessing the oil's impact.

Sensitivity analysis shows that use of chicken manure as fertilizer has significantly higher impact values across the board than synthetic fertilizer for the reasons described beforehand. While this may lead to the conclusion that synthetic fertilizer should be prioritized over animal manure, it should be noted that the question of biodiversity is not limited to the conservation of forests and natural ecosystems; it is also relevant in the case of agricultural land, which is territory that provides a significant contribution to biodiversity rates (Tscharntke et al., 2005). The question of biodiversity also applies to agricultural soil, in which exchanges between soil biota directly influences crop yield and quality, as well as the presence of soil-borne pests, diseases, and beneficial organisms (Brussard et al. 2007). Soil biodiversity is strongly influenced by moisture levels in addition to the presence of microorganisms and nutrients (Brussard et al. 2007). Balanced levels of inorganic substances and the diversity of organisms is crucial for the durability and resilience of crop systems. The addition of organic or inorganic fertilizers affects the levels of these characteristics which results in significant impacts on soil biodiversity as a whole (Hermary, 2007). This can also influence freshwater eutrophication and biodiversity. Organic farming as is practiced on most ylang-ylang farms has been described as an aid in increasing soil biodiversity within agricultural landscapes (Bengtsson et al. 2005; Khanal, 2009). Species richness is also higher with organic farming (Bengtsson et al., 2005). This is the case for both fertilizer choice and use of pesticides, although the latter has not been considered for this particular assessment. Personal observation of the organic ylang-ylang farm studied contests to a rich diversity of species richness both on the ylang-ylang fields and in the surrounding uncultivated areas including small mammals and birds. What was most surprising as the number and diversity of insects present within the fields and on the ylang-ylang trees themselves. While a specific biodiversity assessment was not conducted for this dissertation, one can conclude by sheer observation that the ylang-ylang fields are home to a plethora of animal species that coexist together with the trees within farm boundaries.

It can thus be concluded that the use of organic animal manure has its strengths and weaknesses depending on the impact category assessed, and that its environmental effects are largely due to the quantity applied to fields during cultivation. The study of necessary fertilizer ratios is crucial so that only the necessary quantities are applied to ylang-ylang fields to reduce excess emissions and impacts.

The question of ideal quantities can also be applied to the overconsumption of wood fuel in traditional distillation systems due to inefficient wood burning, a topic that is brought up frequently by Benini et al. (2010) and Salomon (1979). Sensitivity analyses with the GHG Protocol shows notable differences between biogenic CO2 emissions for wood fuel compared to oil fuel. This is most likely due to the rustic nature of wood fueled distillation systems that contribute to yield inconsistency and the longer distillation times required in comparison to oil fueled systems, which in turn consumes greater quantities of wood than otherwise necessary. The overconsumption of wood to make up for lower oil yields contributes greatly to deforestation (Benini et al., 2012) and threatens biodiversity and genetic diversity (Loo, 2016). However, while the use of oil fuel for distillation may reduce impacts to deforestation and biodiversity in the area in proximity to the plantations, this may cause issues in other areas, and contribute more to global warming than the use of wood fuel over time. Fuel choice is by no means an nonaligned decision and requires careful consideration.

Limitations

The limitations of this analysis are abundant and diverse, beginning with the nature of the assessment in itself. LCA's conducted for agricultural products often suffer from a multitude of uncontrollable variables that are dependent on natural processes and weather conditions (Beccali et al., 2010). This makes it particularly difficult to assess the exact impacts of agricultural products, as these depend heavily on the state of natural conditions and vary from year to year. Given that this assessment was based on an optimum yield scenario described in the methodology section, the variability associated with these natural processes is not accounted for, and therefore the results given only represent a particular production scenario that is very unlikely to be consistent overtime.

This LCA also suffers as the results have not been subject to a complete comparison with a product of similar nature to characterize their value. This is largely due to a general lack of LCA's on essential oils and cosmetic products in general available in scientific literature. The lack of time and resources required to study another essential oil made it so that the independent assessment of another similar product for comparison was not possible for this dissertation. This means that there is no base study or impact values to compare ylang-ylang to. While there was an attempt to counter these limitations and compare available impact categories with those studied for citrus essential oils by Beccali et al. and a soap bar by Franke et al., neither of these studies assessed the same impacts as those discussed for this study, and comparison was therefore limited to the common categories discussed. While this aided in situating the effects of ylang-ylang oil for some impacts, it by no means covered all the categories studied for this dissertation, leaving a number of gaps in information and difficulty situating the oil's impact in its entirety.

The location of the farm studied also makes it difficult to assess the impact of the majority of ylang-ylang production. The farm in Ghana is located in an area with notable differences in climate, territorial characteristics, and agricultural practices compared to the Comoros and Madagascar. The difference in location also affects the contribution of air travel on the total impact of ylang-ylang production, as Ghana is far closer to Europe where ylang-ylang oil production is finalized. While the results presented in this dissertation may aid in identifying impact hotspots and relative impact categories, they are unable to reflect the exact environmental pressure contribution of ylang-ylang production in general. This is however often the case with LCA product assessments, as changes in practices and techniques can significantly change overall results.

The specificity and particular techniques used on the farm studied may also have affected the results, as cultivation and distillation techniques can differ from one farm to another. This makes it difficult to confirm impact results for ylang-ylang production in general. This also contributed to difficulties regarding inventory inputs during the use of SimaPro. The distillation and cultivation techniques practiced on the farm studied are rustic in nature, and while this does reflect the majority of ylang-ylang production techniques, this makes it difficult to assess in terms of available processes in LCA software.

The significant drawback to this study consists of its dependency on background data available in SimaPro databases which is principally calculated based on studies conducted on European production systems and other developed countries. There are little to no available processes created for the global south, much less the African continent, making the calculation of precise numbers for a production process based in Ghana particularly difficult. The same problem arises when focusing on the bigger ylang-ylang producing countries like the Comoros Islands, as these are located in Africa as well. The use of European inputs skews the results of applied impact assessments by accounting for European capital goods and energy sources that do not necessarily reflect the realities of product production in Ghana. This can be observed in the particularities of the water impact included from the Technosphere, which cannot be proven to be the same in the Ghanaian context. While this had a significant impact on the final results in SimaPro that had to be adjusted with manual calculations, other small divergences like fuel used and sources of feed for manure can have a significant impact on final results.

Available impact assessments are also concentrated on data from developed countries, particularly Europe, leaving assessments on products produced outside this territory notably difficult. All impact results documented in this dissertation have thus been skewed and do not totally reflect the realities of ylang-ylang production. The incapacity to perform a normalization calculation with the global impact assessment ReCiPe 2016 was considerably challenging, compounding the lack of studies on essential oils available for comparison. Without this normalization, it was impossible to situate the entirety of impact categories related to ylang-ylang oil in comparison to other available products. While it was attempted to counter this as well with the use of IMPACT 2002+ and its normalization function, the results of this method technique are based on European calculations and cannot be applied to African production systems.

The lack of data from the African continent raises a particular issue that is far greater than the subjects included for this dissertation: As these countries begin to rapidly develop, analysis and tracking of goods and services produced in these countries is essential in the efforts to support their sustainable development. Attempts to assess the nature of the impacts are hindered by the lack of available data and impact processes available in LCA software. Given the abundance of ingredients, goods, and services sourced from Africa, it is surprising how little has been done in terms of tracking the environmental effects of their production. A quick review of processes available in inventories shows that this is not only the case for agricultural systems based in Africa, but the case of materials destined for industrial use hailing from this continent as well. There is a huge informational gap for Africa that is in dire need of development as these countries move forward economically. The limitations described here relate to an issue far larger than the scope of this study, but they are proof of a deeper issue regarding data imbalances between global regions that must be addressed in the battle against severe climate change and environmental degradation.

Due to the limitations cited above, it can be established that the results of this study are to be used purely as an illustration of the impacts of ylang-ylang essential oil due to these issues. This study has however allowed for the identification of significant impacts pertaining to ylang-ylang oil, as well as the steps within its production system that are the biggest contributors to these effects. The results presented here allow for a better idea of ylang-ylang oil's true impact to environmental systems, and raise particular recommendations regarding its production to limit its environmental footprint.

Recommendations and Future Research

Due to the limitations described, the results of this dissertation cannot be taken as absolute fact. They can however be considered as one of the first steps in understanding the environmental effects of ylang-ylang oil on the environment. Based on the results of this LCA, one can conclude that ylang-ylang oil has a notable impact on global warming and greenhouse gas emissions. It also has a significant impact in terms of terrestrial ecotoxicity. Based on comparisons with orange and lemon oil, however, the impacts related to ylang-ylang oil can be situated as similar to that of citrus essential oils. The oil also seems to contribute very little to the carbon footprint of finalized cosmetic products based on comparison with Franke et al.'s bar of soap, although this largely depends on ingredients. IMPACT 2002+

normalization shows that the majority of ylang-ylang oil's impacts can be situated in the ecosystem quality damage category. This is notably due to ecotoxicity and land occupation. Land use change and biodiversity can be directly affected by ylang-ylang production depending on its location, choice of fertilizer, and choice of fuel.

Ylang-ylang oil's greatest impact however is by far the quantity of water needed per L of oil, principally due to steam distillation, which overshoots the quantities expressed not only for lemon and orange essential oils, but also for the entirety of soap bar production described by Franke et al (2013). Particular attention is thus needed in terms of distillation techniques and the quantities of water used during this production step. Alternative distillation systems that consume less water are recommended to be considered. Given that steam distillation continues to be the cheapest and most practiced form of distillation in all ylang-ylang producing countries however, it is difficult to assess how realistic their implementation can truly be. If the possibility to adapt these alternative techniques is not available or possible, it is then recommended that the water used for the distillation process is frequently recycled over numerous distillations to reduce this impact as much as possible. Appropriate measures to dispose of this water or use it for other products should be thoroughly researched and applied as necessary, a subject noted by Benitez Cortes et al. (2016). Further studies on the green and grey water footprint of ylang-ylang oil can aid in pinpointing water saving strategies to reduce its consumption.

The differences between wood fuel and oil fuel are also notable in terms of land use and greenhouse gas emissions, the latter particularly when assessed with the Greenhouse Gas Protocol assessment. While the global warming impact value is higher for wood fuel than oil fuel in ReCiPe 2016, overall net fossil emissions are higher for oil fuel when calculated with Greenhouse Gas protocol data. This is largely due to the greater amount of CO2 eq uptake contributed to wood fuel use. On the other hand, land use is notably higher in value for wood fuel compared to oil fuel due to the land occupation of hardwood trees. While wood use is preferred from a global warming emissions perspective, problematic effects on the immediate environment are significant and should be considered when choosing fuel sources. The use of fossil fuels to power distillation systems is not completely neutral however and contains its own share of impacts that could prove detrimental to the environment as a whole. While alternative distillations do exist, infrastructure costs and relatively similar oil yields overall are significant obstacles to their implementation on a larger scale. Given that wood fuel is the most common form of energy for the majority of ylang-ylang production sites, the sourcing of sustainable wood sources is essential to preserving forest areas and the biodiversity contained within them. Investing in updated and efficient furnaces can have a significant impact on wood consumption as well.

Overall, a significant proportion of ylang-ylang oil's impacts (excluding water consumption) can be attributed to the capital goods and fertilizers used throughout its production. Their accountability in overall impact is due to the assessment method chosen for this dissertation. While these impacts are difficult to control for producers, it is highly recommended that they make informed decisions and invest in quality, durable, and efficient equipment to the extent that is possible. As stated before however, this is easier said than done, particularly for small-scale producers in Madagascar or the Comoros with limited funds or access to such infrastructure. Here, companies buying ylang-ylang oil can intervene by imposing standards and offering aid to producers from which they source their oil to abet these initiatives in these situations.

Poultry manure used for Cananga Odorata trees is the cause of the majority of ylang-ylang oil's total impacts. This is largely due to the land use and resources needed to create chicken feed, as well as the terrestrial ecotoxicity caused by its application in the ylang-ylang fields. The majority of greenhouse gas emissions and the oil's global warming impact is directly related to this as well. It is thus important to take the impacts related to animal rearing into account when choosing animal derived fertilizers or products, notably due to their high greenhouse gas emission levels regarding CH4, N20, and NH3. Despite results showing that the use of artificial fertilizers has a significantly lower impact compared to chicken manure, it is not recommended to replace this fertilizer with synthetic alternatives, as these can cause significant short- and long-term complications to the farm, its water sources, and to the surrounding environment. The use of synthetic fertilizers would also go against the organic certifications held by the Ghana farm in general and is thus not an option in any case for this particular production site. More research regarding alternatives such as nitrogen fixing crops and the possibility to grow them under the ylang-ylang trees should thus be looked into. Studies regarding optimum fertilizer quantities could also prove interesting to determine ideal fertilizer ratios for ylang-ylang trees and to avoid applying more manure than is necessary.

As stated by Doyen (2006), the majority of ylang-ylang oil production sites operate according to organic standards, despite not being labeled as such. Further studies are needed to compare the environmental impacts of organic and inorganic ylang-ylang oil production, as well as the differences between fertilizers employed during this practice. Study and documentation focusing on yield differences between plantation and comparisons of their techniques could also aid in better understanding the nature for this plant, for which known information is dominantly based on indigenous knowledge held by producers in Indonesia, Madagascar, and the Comoros Islands (Benini et al., 2010). More research on the environmental impacts of ylang-ylang production in general are necessary in order to collect concrete data, particularly in its mass-producing countries that are particularly subject to climate change.

As LCA's begin to become more commonplace, the necessity to develop region specific databases on African goods and services is essential and urgently needed. Current applications of LCA software such as SimaPro and its available databases are not equipped to calculate the true impact of products hailing from these regions. These limitations, coupled with the lack of available LCA's on similar products and the lack of normalization functions for global assessment methods, make it difficult to assess ylang-ylang oil's environmental impact in its entirety. These issues are compounded by a significant lack of assessments on cosmetic products and agricultural products in general, although the latter has enjoyed steady development over the past few decades. Ingredient choice and ingredient dosage have the potential to have a bigger impact on overall emissions that product production itself (Secchi et al., 2016). This proves the point that LCA's are a crucial tool in green chemistry and product manufacturing to fight cosmetic greenwashing and assess the true nature of products deemed as "natural" (Secchi et al., 2016).

Conclusion

The purpose of this dissertation was to establish a primary assessment identifying the significant environmental impacts linked to the production of ylang-ylang essential oil as well as hotspot steps within its production that contribute the most to its overall environmental footprint. This was carried out in a perspective to increase this product's transparency and assess marketing claims that it is "green" and "natural". Based on the results of this study, one can conclude that ylang-ylang oil contributes to the global warming, terrestrial ecotoxicity, land use, and water consumption impact categories. When compared with information on the environmental impacts of other essential oils and cosmetic products available however, the oil's impacts are relatively similar to those of like products. The oil's water consumption due to extraction via steam distillation is significantly high however, and therefore requires particular attention.

Surprisingly, the majority of impacts were sourced in large part from the cultivation stage due nearly exclusively to the use of chicken manure as fertilizer – this is the case for both the significant categories as well as the smaller impacts. Distillation had a smaller effect in most of the categories contrary to what was expected. This was also the case for transportation. Overall, the majority of ylang-ylang's impacts can be attributed to the capital goods and fertilizers used throughout its production. The impact associated with the production of these goods seem to largely occur in their respective production locations rather than on the farm itself. The particular cultivation of ylang-ylang flowers studied for this dissertation seems in contrast to have a relatively positive effect on the immediate surrounding environment in terms of biodiversity. This however depends on production techniques and whether cultivation is organic or not. It also depends on the type of land use change imposed on an area to make room for farmland and whether this change causes deforestation or significant damage to the delicate ecosystems inhabiting the area. Unfortunately, the staggeringly high levels of water consumption could be a threat to neighboring water bodies and resources despite frequent recycling. Adopting alternative or more efficient distillation techniques during the extraction stage could aid in reducing the oil's overall blue water expenditure.

Given that there are no synthetic alternatives for ylang-ylang's scent, and given the rising market demand that the product has enjoyed over the past few years, its production is expected to increase in the future. The cosmetics sector is extremely competitive however (Secchi et al., 2016), and as demand for green cosmetics continues to rise, ylang-ylang oil must find its place in a constantly changing market. The question of the sustainability of producing natural products arises in this case (Sahota, 2014). Despite its natural origins, ylang-ylang oil can have a significant environmental impact depending on cultivation and extraction techniques. Its water footprint is particularly important in the case of steam distillation. The choice of ingredients used in a cosmetic product can sometimes have a greater weight in total environmental impacts than the production of the product itself; Ylang-ylang's reputation as a eco-friendly perfume alternative must therefore be considered accordingly. Production techniques for the oil can have a significant effect on overall environmental impacts - the importance of product transparency and the sharing of information and best practices regarding cultivation and distillation is therefore essential to reducing the oil's environmental footprint. This of course depends on availability and access for producers, namely in the financial sense.

The list of limitations for this study is quite long, and further research on other ylang-ylang production practices and other essential oil products is necessary to compare and situate ylang-ylang oil with other cosmetic products of similar nature. An increase in database information for products created outside of developed countries would also aid in further understanding its true environmental impact. There is a dire need to develop life cycle analyses and databases for African products, as a significant amount of the world's resources are sourced from the continent, including ingredients used in the cosmetics industry. There is also an urgent need to develop and study more cosmetic products to assess if the green marketing schemes used across the sector are truly genuine and reliable.

In some cases, the most sustainable form of cosmetic production is not sourced from nature (Sahota, 2014). The resources of the earth are not limitless, and the demand for natural ingredients such as ylang-ylang oil can potentially result in further resource depletion causing significant long-term damage. Nevertheless, this cannot be determined without a significant increase in product assessments like LCA, particularly in a sector that is plagued by void claims and cosmetic greenwashing (Sahota, 2014; Secchi et al., 2016). This dissertation is a small attempt to counteract the effects of cosmetic greenwashing and increase scientific knowledge and awareness of ylang-ylang oil production, one of the countless ingredients used in cosmetic product manufacturing. It is destined to be used as an illustrative guide and information source regarding ylang-ylang oil production, as well as a point of comparison for future research on essential oils in general. The genuine "greening" of the cosmetics sector and ecologically responsible production is an essential step towards sustainable production systems and the conservation of the planet as a whole. As the cosmetic industry adapts to numerous economic and environmental pressures, and as companies and consumers become more aware of product origins and impacts, the contribution of small product LCA's such as this one are some of the first steps on a long journey to understanding the environmental impact of the cosmetics industry.

Erratum

A significant miscalculation regarding water consumption impact values has been discovered after the printing of this dissertation due to a unit conversion error.

As stated on page 56, process contribution analysis for the ReCiPe 2016 Midpoint assessment of water consumption was determined to be exclusively linked to background data and did not account for the water sourced from nature used directly in the inventory in SimaPro. The 44.7 m^3 of water consumption presented by ReCiPe therefore did not include the large quantities of water used on site during the distillation process. It was thus decided to include the water consumption for the Nursery, Field Establishment, and Distillation and Extraction steps manually to counterbalance this. Unfortunately, the values set for water consumption from nature in liters were never converted and were thus added to the ReCiPe 2016 Midpoint value as cubic meters themselves. After correction, the quantity of 659.4 m^3 printed in this dissertation should therefore be replaced by 45.3 m^3.

Total Blue Water Consumption of 1 L of Ylang-ylang Oil in M^3

Consumption from Technosphere	Consumption from Nature: Nursery Stage	Consumption from Nature: Field Establishment	Consumption from Nature: Distillation and Extraction	Total Blue Water Footprint
44.7	0.0038	0.0605	0.5504	**45.3**

One can attest to a far less dramatic value for the water consumption impact for ylang-ylang oil, particularly when compared with the values presented for orange and lemon essential oils by Beccali et al. (2010). With corrected values, ylang-ylang oil's consumption falls between that of orange and lemon essential oils, with values similar to that of lemon, reporting roughly one cubic meter more.

Essential Oil Comparison of Water Consumption in M^3

Impact	Orange Essential Oil	Lemon Essential Oil	Ylang-ylang Essential Oil (ReCiPe 2016)
Water Consumption	**90.0**	44.2	45.3

In this case, orange consumes the greatest quantity of water, nearly double that of the other two essential oils. The contrast between the three oils is significantly reduced compared to the results presented in the dissertation. Ylang-ylang oil continues to differ from the other essential oils however in where water is consumed during production: As stated in the original text, the majority of water consumption for orange and lemon oils is attributed to the irrigation at cultivation stages as opposed to processing. The extraction of orange and lemon oils by cold pressing consumes far less water than steam distillation extraction used for ylang-ylang. However, process contribution for the water consumption at the distillation stage continues to attribute this impact to hydropower-based electricity use for hardwood transformation in accordance with European specificities, which cannot be confirmed as fact for the production used for this farm in Ghana. The overall water impact presented by SimaPro must therefore be considered with caution due to the limitations expressed in the original dissertation.

Comparison of Blue Water Footprint for Ylang-ylang Oil and Soap Bar Production

	Ylang-ylang Oil (3% of total – 13.5 ml per bar)	**Macadamia Bar Soap (450 g)**
Water Consumption	**0.612**	0.095

The impact contribution of ylang-ylang oil in comparison to Franke et al. (2013)'s bar soap is also dramatically reduced after correction, with the 8.90 m³ consumed by 13.5 ml of ylang-ylang oil originally presented replaced by 0.612 m³. Despite this, the proportion of ylang-ylang oil defined by the IFRA for soap products still consumes more than the entire soap by a factor of 6. While this is a far cry from the faulty data presented in the original text, this value still upholds the conclusions presented in the Discussion and Conclusion sections that the water footprint of ylang-ylang oil is significant, and that the ingredients chosen for cosmetic products can have a greater impact on overall emission values than the production of the cosmetic itself, as stated by Secchi et al. (2016).

While the total value of water consumption has been significantly reduced, ylang-ylang continues to have a considerable blue water footprint with 45.3 m³ consumed per liter of oil. This value presented by SimaPro is the result of European data however, and therefore cannot be attributed to the oil produced in Ghana with full certainty. The sizably lower contribution of direct consumption from nature with correct conversions further increases doubt regarding this value, as it gives more weight to European data for the overall impact. More pointed and location-based research is therefore necessary to determine the water consumption of ylang-ylang oil correctly.

No new bibliographic sources have been added to this Erratum. Sources cited can be found in the bibliography of the original document.

Acknowledgements

The writing of this dissertation would not have been possible without the support and assistance that I have received from the people around me. For this, I would like to express my sincerest gratitude to:

Professor Wouter Achten, my supervisor;

Professor Vanessa Zeller, for helping me learn the particularities and special features of SimaPro;

My dear friend Danielle Driggers, for editing and spell-checking this dissertation, and for her words of encouragement;

Philippe Lambert, my father, for translating my abstract from English to French;

My family and loved ones, both in Belgium and elsewhere, for their moral support;

The Narval-Gaignage family, for their reassurance and helpful suggestions;

Professor Pierre D'Ans, for his course on Circular Economics that got me interested in LCA's in the first place, and his time and reassuring words towards the end of writing this dissertation when I needed them the most;

Professor Benjamin Ofori, who organized the initial trip to Lush Inc. Farms during an internship during the summer of 2018, and without whom I would not have found the subject of my thesis;

To all of the employees working at Lush Inc. Farms who welcomed me, particularly the farm manager Gladys for her tireless help and delicious cooking;

Most of all to Merjim Groen, farm owner of Lush Inc. Farms. Thank you for opening your farm and home to me. Thank you for your generosity, for your patience despite my endless questions, for your photographs of the farm, and for your swift email replies whenever I was missing information despite being a continent away. Without you, this dissertation could not have been completed. Words cannot express my gratitude for your aid throughout this process.

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Appendices

1. Ylang-Ylang Oil Production Methodology by Step

This description of ylang-ylang production is based on the steps practiced on the ylang-ylang farm studied. Information is also alimented from available scientific literature. As stated within this dissertation, this cultivation and distillation process follows European and North American organic standard regulations.

Nursery

Seeds are harvested from the fruits of the Cananga Odorata trees growing on the farm. A plastic tarp is lain in an area on the farm that receives partial sunshine. Recycled single-use plastic sachets that are normally used for drinking water are cut open on one side, then filled with 1 kg of wet, black, fertile soil, also harvested around the farm. The seeds are embedded into the soil and the plastic sachets are placed on the plastic tarp to impede the roots from breaking through the plastic and pushing into the soil. However, some older plants push through the tarp and burrowing deep into the ground. The fragility of the roots makes that once this happens, the tree can no longer be moved or transported. It is thus considered "lost product." No losses are reported at this stage by farm management.

Figure 21: Young ylang-ylang saplings growing during the Nursery stage of cultivation.

The soil is then watered every three days as the saplings mature. The trees are ready to plant once they reach approximately 1 foot (30.5 cm), which takes around 4 months. However, they are not transferred immediately to be planted once they reach the required size; plants that have matured enough stay on the tarp until planting season in April. For this study however, it will be assumed that all seeds planted sprout and grow at the same rate and that this step takes 4 months from start to finish. Input quantities reflect this assumption.

Field Establishment

10 workers minimum are needed for this process. Just before the rainy season (April), the designated area is weeded by hand. Once the land ready, trees are planted six by six meters apart in line with the necessary spacing needed for optimal production capacity (Parotta, 2014; Manner et al., 2006). The bottom of the plastic bag where the sapling was planted is ripped open to allow the roots to grow, and is placed in a hole dug with a machete. The plastic lining the sapling is buried with the plant. After the sapling is placed within the hole, the dirt is placed back into the hole and covered. The area is watered to keep the soil moist. Watering continues every 3 days, with regular weeding. The planting process takes around 2 to 3 weeks depending on the size of the area.

Figure 22: Right - Ylang-ylang flowers at various stages of growth.

Cultivation

Trees are watered every 3 days until they turn 3 years old. Then, they are watered only when needed, usually during long dry spells during the dry season. Trees start producing flowers after 2-3 years in small amounts. The flowers become abundant only after 5 years, when the trees are considered mature. After maturity, ylang-ylang trees on this farm will continue to produce around 5 kg of trees over the span of their productive lifetime. Over the years, some weeding is preformed around the base of the tree in order to keep the roots in good condition. 15 kg of chicken manure is also applied to each tree per year. After distillation, wood ashes from the furnace and cooked flowers from the extraction process are distributed around the base of the tree as fertilizer. This continues as long as the tree lives and produces flowers.

Harvesting

Workers begin to harvest ylang-ylang early in the morning, around 7 AM, and continue to harvest until late in the afternoon depending on the yield. Morning is the ideal time for picking, as the flowers are most fragrant at this time. Farm employees go out into the fields and collect the picked flowers in plastic buckets or rice sacks. All harvesting is done entirely by hand. After 30 minutes of harvesting, the workers must return to the distillation site and dump the flowers on the ground; if the flowers are kept in the sacks, they begin to emit heat and turn brown. This affects the smell and quality of the oil. 1 person can collect up to 50 kilos of flowers per day. The flowers are put in crates and weighed, then placed in the oven to cook. The flowers must be distilled the same day that they are picked.

Figure 23: Harvested ylang-ylang flower petals waiting to be distilled. The flowers have been placed in piles on the ground to stop the flowers from browning, which affects the oil's scent.

Extraction (Distillation)

Flowers are placed into the upper chamber of a 1-ton capacity sterling steel cucurbit, the vessel in which liquid is heated in an alembic. The cucurbit is divided into two chambers that are separated by a steel separation grid that allows steam to pass through. The flowers are dumped into the chamber via an opening at the top of the cylinder, which is closed during distillation. Water is then filled into the lower chamber below the grid. Flowers are then placed into the upper chamber. The flowers cannot touch or be immersed in water during the steam distillation, as any contact would boil the flowers and cause the oil contained within them to dissipate.

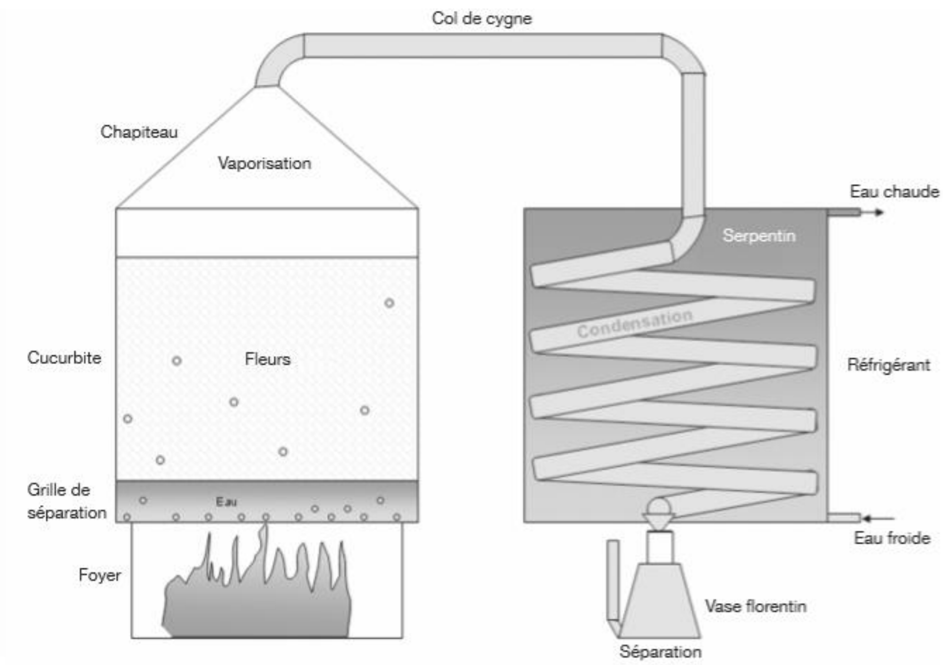

Figure 24: An illustration of the components of a traditional steam-distillation alembic system. Retrieved from Benini et al. (2010).

Firewood is bought from outside the farm is placed inside the oven beneath the metal cylinder and is set on fire with matches. A fire is ignited underneath the cucurbit in the concrete furnace oven. The fire heats the water in the cylinder, which evaporates and passes through the metal netting and up through the flowers as water vapor, extracting and distilling the small quantities of oil within the flowers and carrying the molecules up with it. The steam then rises up to the top of the chamber, which is often cone-shaped, that directs the vapor towards an opening at the top of the cucurbit and into a pipe that leads it into a refrigerant which is in this case a large 10000 L polytank filled completely with water. A serpentine pipe runs through the refrigerant in a twisting formation down to an opening which connects the pipe to a Florentine vase. Cold water is pumped into the polytank which cools the outside of the serpentine pipe, condensing the infused hot water vapor inside it back to a liquid state. The pipe is twisted inside the refrigerant to increase its surface area in contact with the cold water to maximize condensation. Hot water that has been heated by the pipe rises to the top of the refrigerant where it is expelled. Water circulates in the refrigerant throughout the distillation process.

Once having passed through the refrigerant, the condensed ylang-ylang infused water passes into the Florentine vase. This recipient often has two evacuation openings – one at the top for the oil and one at the bottom for water. Water collects within this recipient until it is full and drains through the pipe at the bottom. It takes about 1 hour for the bucket to fill completely. The oil, being lighter than water, and which has since floated to the top of the recipient, is drained through the top pipe and collected in plastic water bottles. The drained water is recycled throughout the process or stored in 2 400-liter blue poly-tanks to await the next harvest and distillation. It takes around 20-22 hours to complete the process.

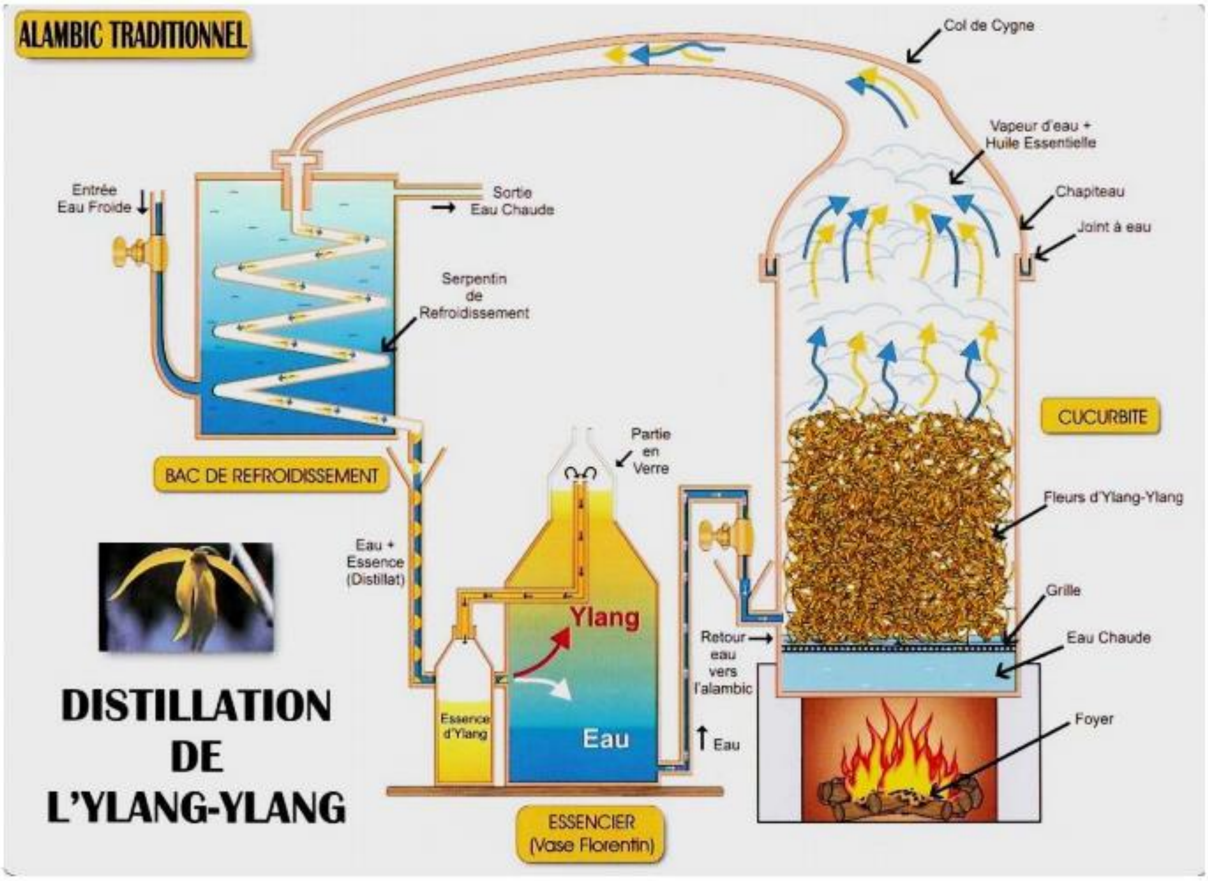

Figure 25: Another illustration of a traditional steam-distillation alembic system. Retrieved from de Bontin (2006).

The oil is allowed to sit and mature over the course of several months before it is shipped to factories in the United Kingdom for further processing.

Transport

The crude ylang-ylang oil is packed in heavy duty plastic polyethylene 10L capacity packaging and is carried 147 km from the farm site to Kotoko International Airport in Accra, Ghana by a diesel pickup truck. The oil is then loaded into cargo of a passenger plane. The plane travels 5510 km between Accra, Ghana and London, United Kingdom, landing at London Heathrow. The package then travels its last 180 km to its processing factory in Poole via Southampton in a DHL delivery van.

2. ReCiPe 2016 Midpoint (H) Results

Case Scenario Assessment with ReCiPe Midpoint

Impact category	Unit	Total	Step 1. Nursury	Step 2. Field Establishment	Step 3. Cultivation	Step 5. Distillation and Extraction	Step 6. Transportation
Global warming	kg CO2 eq	56,136628	0,036413239	4,7828709	35,074387	4,6061949	11,636762
Fine particulate matter formation	kg PM2.5 eq	0,1938375	7,70E-05	0,013615239	0,099845086	0,06733947	0,012960682
Ozone formation, Terrestrial ecosystems	kg NOx eq	0,28234392	6,92E-05	0,008610296	0,063142167	0,16926388	0,041258374
Terrestrial acidification	kg SO2 eq	0,70465407	0,000123664	0,07186159	0,52698499	0,072233521	0,033450298
Freshwater eutrophication	kg P eq	0,33754171	1,71E-05	0,040145268	0,29439863	0,001533819	0,001446905
Terrestrial ecotoxicity	kg 1,4-DCB	169,5367	0,027296105	5,5360839	40,597948	91,58633	31,789041
Freshwater ecotoxicity	kg 1,4-DCB	1,4051305	0,00100992	0,07160005	0,52506703	0,22079603	0,58665748
Land use	m2a crop eq	63,558625	0,00042694	4,7278903	34,671195	23,989181	0,16993184
Mineral resource scarcity	kg Cu eq	0,18489907	3,19E-05	0,008169037	0,059906271	0,079923281	0,03686854
Fossil resource scarcity	kg oil eq	9,6658418	0,008314187	0,61454872	4,5066906	0,82066812	3,7156202
Water consumption	m3	44,720031	0,000218334	0,52755185	3,8687136	37,812594	2,5109528

3. IMPACT 2002+ Results

Case Scenario Assessment with IMPACT 2002+: Characterization Results

Impact category	Unit	Total	Step 1. Nursury	Step 2. Field Establishment	Step 3. Cultivation	Step 5. Distillation and Extraction	Step 6. Transportation
Terrestrial ecotoxicity	kg TEG soil	8769,7774	0,27335074	-93,254014	-683,86277	9320,4895	226,13133
Terrestrial acid/nutri	kg SO2 eq	5,496911	0,00048127	0,51834498	3,8011965	0,94242853	0,23445973
Land occupation	m2org.arable	44,798294	0,00028718	4,3316572	31,765486	8,5441584	0,15670463
Aquatic acidification	kg SO2 eq	0,77940798	0,00015298	0,07248659	0,53156832	0,12821206	0,04698803
Aquatic eutrophication	kg PO4 P-lim	13,152418	6,20E-06	1,5767008	11,562472	0,01128276	0,0019558
Global warming	kg CO2 eq	47,456896	0,03311183	3,9209063	28,753313	3,4042605	11,345305
Non-renewable energy	MJ primary	501,48716	0,46265666	31,088527	227,98253	65,933546	176,0199
Mineral extraction	MJ surplus	1,885647	0,00036376	0,08169181	0,59907325	0,76946729	0,43505089

Normalization Calculations for IMPACT 2002+

Damage category	Step 1. Nursury	Step 2. Field Establishment	Step 3. Cultivation	Step 5. Distillation and Extraction	Step 6. Transportation
Ecosystem quality	0,00242964	3,6173797	26,527451	68,063895	1,7888448
Climate change	0,06977243	8,262037	60,588271	7,1733736	23,906546
Resources	0,0919836	6,192273	45,410002	13,251215	35,054526

4. Greenhouse Gas Protocol Results

Case Scenario Assessment with Greenhouse Gas Protocol

Impact category	Total	Step 1. Nursury	Step 2. Field Establishment	Step 3. Cultivation	Step 5. Distillation and Extraction	Step 6. Transportation
Fossil CO2 eq	53,134898	0,03562574	4,5204898	33,150259	3,8643601	11,564163
Biogenic CO2 eq	112,44215	0,0005394	0,26585106	1,9495744	110,16445	0,06173487
CO2 eq from land transformation	8,6728251	5,77E-05	1,0402616	7,6285852	0,00025938	0,00366118
CO2 uptake	162,12793	0,00054357	6,0312941	44,22949	111,79265	0,07394941

5. Sensitivity Analysis Results

Flower Yield Scenarios

ReCiPe 2016 Midpoint (H) Results

Impact category	Unit	Case Scenario - 5kg per year	5,2 kg yield per year	9,78 kg yield per year	15,7 kg yield per year
Global warming	kg CO2 eq	56,136628	54,418984	36,189793	28,43269
Fine particulate matter formation	kg PM2.5 eq	0,1938375	0,18894909	0,13706883	0,11499212
Ozone formation, Terrestrial ecosystems	kg NOx eq	0,28234392	0,2792516	0,24643309	0,23246776
Terrestrial acidification	kg SO2 eq	0,70465406	0,67886507	0,40516894	0,2887025
Freshwater eutrophication	kg P eq	0,33754171	0,323137	0,17026121	0,10520769
Terrestrial ecotoxicity	kg 1,4-DCB	169,5367	167,5492	146,45603	137,48022
Freshwater ecotoxicity	kg 1,4-DCB	1,4051305	1,3793972	1,106292	0,99007703
Land use	m2a crop eq	63,558625	61,862257	43,858869	36,197853
Mineral resource scarcity	kg Cu eq	0,18489907	0,18196667	0,15084544	0,13760237
Fossil resource scarcity	kg oil eq	9,6658418	9,4449861	7,1010651	6,1036519
Water consumption	m3	44,720031	44,530738	42,521789	41,666917

Fertilizer use Scenarios

ReCiPe 2016 Midpoint (H) Results

Impact category	Unit	Ylang ylang oil production (Case scenario)	Ylang ylang oil production (synthetic fertilizer)	Ylang ylang oil production (no fertilizer)
Global warming	kg CO2 eq	56,136628	19,889555	16,27937
Fine particulate matter formation	kg PM2.5 eq	0,1938375	0,090697901	0,080377175
Ozone formation, Terrestrial ecosystems	kg NOx eq	0,28234392	0,2613837	0,21059146
Terrestrial acidification	kg SO2 eq	0,70465406	0,1249662	0,10580748
Freshwater eutrophication	kg P eq	0,33754171	0,002997808	0,002997808
Terrestrial ecotoxicity	kg 1,4-DCB	169,5367	127,05472	123,40267
Freshwater ecotoxicity	kg 1,4-DCB	1,4051305	0,80902859	0,80846343
Land use	m2a crop eq	63,558625	24,15954	24,15954
Mineral resource scarcity	kg Cu eq	0,18489907	0,11682376	0,11682376
Fossil resource scarcity	kg oil eq	9,6658418	4,5446025	4,5446025
Water consumption	m3	44,720031	40,323765	40,323765

Greenhouse Gas Protocol Results

Impact category	Unit	Ylang ylang oil production (Case scenario)	Ylang ylang oil production (synthetic fertilizer)	Ylang ylang oil production (no fertilizer)
Fossil CO2 eq	kg CO2 eq	53,134897	19,068996	15,464149
Biogenic CO2 eq	kg CO2 eq	112,44215	110,22672	110,22672
CO2 eq from land transformation	kg CO2 eq	8,672825	0,003978253	0,003978253
CO2 uptake	kg CO2 eq	162,12793	111,86714	111,86714

Generation Timeframe Scenarios

ReCiPe Midpoint (H) Results

Impact category	Unit	Ylang ylang oil production (Case scenario)	Ylang ylang oil production (Long Generation 30 yr)	Ylang ylang oil production (Ofra et al. (2009) Generation - 50 yr)
Global warming	kg CO2 eq	56,136628	56,130559	812,7731
Fine particulate matter formation	kg PM2.5 eq	0,1938375	0,19382466	0,19474235
Ozone formation, Terrestrial ecosystems	kg NOx eq	0,28234392	0,28233239	0,28313461
Terrestrial acidification	kg SO2 eq	0,70465406	0,70463345	0,70587618
Freshwater eutrophication	kg P eq	0,33754171	0,33753886	0,33764492
Terrestrial ecotoxicity	kg 1,4-DCB	169,5367	169,53215	173,70143
Freshwater ecotoxicity	kg 1,4-DCB	1,4051305	1,4049622	1,4179794
Land use	m2a crop eq	63,558625	63,558554	63,637569
Mineral resource scarcity	kg Cu eq	0,18489907	0,18489374	0,20734747
Fossil resource scarcity	kg oil eq	9,6658418	9,6644561	9,7592484
Water consumption	m3	44,720031	44,719995	44,839681

Fuel Choice Scenarios

Recipe 2016 Midpoint (H) Results

Impact category	Unit	Ylang ylang oil production (Case scenario)	Ylang ylang oil production (Oil fuel scenario)
Global warming	kg CO2 eq	56,136628	66,321003
Fine particulate matter formation	kg PM2.5 eq	0,1938375	0,13706564
Ozone formation, Terrestrial ecosystems	kg NOx eq	0,28234392	0,13087984
Terrestrial acidification	kg SO2 eq	0,70465406	0,6641963
Freshwater eutrophication	kg P eq	0,33754171	0,33658808
Terrestrial ecotoxicity	kg 1,4-DCB	169,5367	241,3457
Freshwater ecotoxicity	kg 1,4-DCB	1,4051305	1,2198839
Land use	m2a crop eq	63,558625	39,667408
Mineral resource scarcity	kg Cu eq	0,18489907	0,13323444
Fossil resource scarcity	kg oil eq	9,6658418	13,515604
Water consumption	m3	44,720031	10,363797

Greenhouse Gas Protocol Results

Impact category	**Unit**	**Ylang ylang oil production (Case scenario)**	**Ylang ylang oil production (Oil fuel scenario)**
Total	kg	12,121943	24,474271
Fossil CO2 eq	kg	53,134897	64,005931
Biogenic CO2 eq	kg	112,44215	2,3277784
CO2 eq from land transformation	kg	8,672825	8,6728468
CO2 uptake	kg	-162,12793	-50,532285

6. SimaPro Input Construction for Large Capital Goods

Components included for construction of capital goods within SimaPro inventory. All inputs are taken from the Ecoinvent 3 databases.

Furnace Oven

Products					
Outputs to technosphere: Products and co-products	**Amount**	**Unit**	**Quantity**	**Allocation %**	**Category**
Distillation System Furnace Oven - for distillation system	1	p	Amount	100 %	Autres
Add					
Outputs to technosphere: Avoided products	**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Add					

Inputs						
Inputs from nature	**Sub-compartment**	**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Add						
Inputs from technosphere: materials/fuels		**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Cement, unspecified {CH}| market for cement, unspecified | APOS, U		50	kg	Undefined		
Cast iron {GLO}| market for | APOS, U		1,9	kg	Undefined		
Shavings, hardwood, measured as dry mass {GLO}| market for | APOS, U		10	kg	Undefined		
Add						

- 70 Sawdust bricks: (included in distillation system inventory)
- 1 50kg bag cement: *Cement, unspecified (CH), market for cement, unspecified, APOS, U.*
- 1 2m iron rod (0,5 inch diameter): *Cast Iron (GLO), market for, APOS, U.*
- 1 10L bucket of wood chipping: *Shavings, hardwood, measured as dry mass (GLO), market for, APOS, U.*

10,000 L Capacity Polytank

Outputs to technosphere: Products and co-products	**Amount**	**Unit**	**Quantity**	**Allocation %**	**Category**
Distillation System Polytank (10000L Capacity) - for distillation system	1	p	Amount	100 %	Autres
Add					
Outputs to technosphere: Avoided products	**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Add					

Inputs						
Inputs from nature	**Sub-compartment**	**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Add						
Inputs from technosphere: materials/fuels		**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Polyethylene, high density, granulate {RoW}| production | APOS, U		200	kg	Undefined		
Blow moulding {GLO}| market for | APOS, U		200	kg	Undefined		
Add						
Inputs from technosphere: electricity/heat		**Amount**	**Unit**	**Distribution**	**SD2 or 2SD**	**Min**
Add						

Weight calculations based on polytankghana.com.

200 L capacity Polytank

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Distillation System Polytank (400L Capacity) - for distillation system	1	p	Amount	100 %	Autres

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Polyethylene, high density, granulate {RoW}| production | APOS, U	8	kg	Undefined			
Blow moulding {GLO}| market for | APOS, U	8	kg	Undefined			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max

Weight calculations based on polytankghana.com.

Distiller (1-ton capacity)

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Ca
Rustic Home-made Alembic - for distillation system	1	p	Amount	100 %	Au

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD
Steel, chromium steel 18/8 {GLO}| market for | APOS, U	400	kg	Undefined	
Packing, fibre cement product {GLO}| market for | APOS, U	600	kg	Undefined	
Wood pellets, u=10%, at storehouse/RER U	1000	l	Undefined	
Plywood, outdoor use, at plant/RER U	109710	cm3	Undefined	
Plywood, outdoor use, at plant/RER U	87782,4	cm3	Undefined	
Steel, chromium steel 18/8 {GLO}| market for | APOS, U	47,2	kg	Undefined	

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD

Steel cylinder comprised of two parts welded together: *400 kg steel, chromium steel 18/8 (GLO) market for, APOS, U.*

- $9m^2$ x 3mm steel
- $4m^2$ x 6 mm steel

Steel circular metal grate, 1.6 m diameter x 3 mm: *47.2 kg steel, chromium steel 18/8 (GLO) market for, APOS.*

12 50 kg cement bags. *600 kg packing fibre, cement product (GLO) market for, APOS, U.*

1 ton of wood chipping: *1000 L Wood pellets u=10%, at storehouse/RER U.*

30 wooden beams, $3657cm^3$ each: *$109710cm^3$ plywood, outdoor use, at plant/RER/U.*

*Welding used to fuse steel parts together will not be accounted for in the analysis.

7. SimaPro Inventory Inputs: Baseline Scenario

Ylang-ylang Oil Production Inventory

Process attribution calculated for 1 L/25 productive years.

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Ylang ylang oil production (Case scenario)	1	l	Volume	100 %	Autres
Add					

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min
Add					

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min
Add						

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Step 1. Nursury	0,72	p	Undefined		
Step 2. Field Establishment	0,72	p	Undefined		
Step 3. Cultivation	0,72	p	Undefined		
Step 5. Distillation and Extraction	1	l	Undefined		
Step 6. Transportation	1	l	Undefined		
Add					

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min
Add					

Step 1. Nursery Inventory

All calculations for the care of 1 sapling for 4 months.

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %
Step 1. Nursury	1	p	Amount	100 %
Add				

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD
Add				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD
Water, well, in ground, agri, GLO	in ground	5,4	l	Undefined	
Soil	in ground	1	kg	Undefined	
Add					

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD
Extrusion of plastic sheets and thermoforming, inline {GLO}| market for | APOS, U	4,75	g	Undefined	
Extrusion of plastic sheets and thermoforming, inline {GLO}| market for | APOS, U	0,038	kg	Undefined	

Water: 4 months (0,15 L/tree x every 3 days).

Plastic sachets: 10cm² x 0,05 mm thickness. Multiplied volume x weight. Calculator: http://asm.matweb.com/tools/weight-calculator.asp.

Plastic Tarp: 2m² of Pe plastic sheet, divided by 100 trees. Volume x weight. Calculator: http://asm.matweb.com/tools/weight-calculator.asp.

Step 2. Field Establishment Inventory

Calculations for the care of 1 tree for the first 3 years of life.

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Step 2. Field Establishment	1	p	Amount	100 %	Autres
Add					

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add						

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Transformation, from permanent crop, non-irrigated, extensive,	land	0,0040	ha	Undefined			
Water, well, in ground, agri, GH	in water	84	l	Undefined			
Occupation, permanent crop, non-irrigated, UG	in ground	0,012	ha a	Undefined			
Add							

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Poultry manure, fresh {GLO}| chicken production | APOS, U	45	kg	Undefined			
Add						

Emissions to air	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add							

Emissions to water	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add							

Emissions to soil	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Phosphorus pentoxide	agricultural	0,81	kg	Undefined			
Potassium	agricultural	0,225	kg	Undefined			
Nitrogen	agricultural	0,99	kg	Undefined			
Phosphorus	agricultural	0,36	kg	Undefined			
Add							

Water: 84 L = 3 yr (700 ml/tree x 40 days)

Poultry manure: 45 kg = 3 yr (15kg/tree)

Emissions to air and water already included in *Poultry, manure, fresh (GLO) – Chicken Production.* Emissions calculations based on FAO (2005) data and Chickenfuel.com.

Step 3. Cultivation Inventory

All calculations for 1 tree, multiplied by generational productive timeframe (25 yr- 3 yr field establishment).

		Inputs		
Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Occupation, permanent crop, non-irrigated, extensive, GLO	land	0,088	ha a	Undefined
Add				
Inputs from technosphere: materials/fuels		Amount	Unit	Distribution
Poultry manure, fresh {GLO}| chicken production | APOS, U		330	kg	Undefined
Add				
Inputs from technosphere: electricity/heat		Amount	Unit	Distribution
Add				
		Outputs		
Emissions to air	Sub-compartment	Amount	Unit	Distribution
Add				
Emissions to water	Sub-compartment	Amount	Unit	Distribution
Add				
Emissions to soil	Sub-compartment	Amount	Unit	Distribution
Phosphorus		2,64	kg	Undefined
Phosphorus pentoxide		5,94	kg	Undefined
Potassium		1,65	kg	Undefined
Nitrogen		7,26	kg	Undefined
Add				

Poultry manure: 330 kg = 22 yr(15kg/tree)

Emissions to air and water already included in *Poultry, manure, fresh (GLO) – Chicken Production.* Emissions calculations based on FAO (2005) data and ChickenFuel.com.

Step 5. Distillation Inventory

All calculations for distillation of 10 L of ylang-ylang oil. Capital good impacts are amortized for 25 yrs of use, 40 distillations per year.

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Water, unspecified natural origin, agri, GLO	in ground	5500	l	Undefined
Water, well, in ground, GLO	land	4	l	Undefined
Add				
Inputs from technosphere: materials/fuels		**Amount**	**Unit**	**Distribution**
Rustic Home-made Alembic - for distillation system		0,001	p	Undefined
Distillation System Furnace Oven - for distillation system		0,001	p	Undefined
Distillation System Polytank (10000L Capacity) - for distillation system		0,001	p	Undefined
Distillation System Polytank (400L Capacity) - for distillation system		0,001	p	Undefined
Light clay brick, at plant/DE U		0,1582	kg	Undefined
Extrusion, plastic pipes {GLO}| market for | APOS, U		0,012	kg	Undefined
Steel, chromium steel 18/8, hot rolled {GLO}| market for | APOS, U		2,47	g	Undefined
Plastic 2,5 L bottle		0,666	p	Undefined
Add				
Inputs from technosphere: electricity/heat		**Amount**	**Unit**	**Distribution**
Logs, hardwood, burned in furnace 30kW/CH U		10962,4	MJ	Undefined

Water: 5500 L - Water used in cooling polytank, used multiple times. 100,000 L used a year x 22, divided by 400 L of oil produced per year.

Water: 4 L - 400L per distillation (for 10L), recycled - changed every 10 distillations, so 4 times per year. 400L water/100 (10L x 10 times) oil.

Bricks: standard brick = 2.26 kg. 2.26kg x 70 pieces = 158.2. Divided by 1000 distillations. https://www.andersonsmasonry.com/uploads/9/5/6/9/9569629/brick_sizes_and_weights.pdf

Plastic piping: Circle polyethylene plastic -1 inch diameter x 25 m with 0.95 density = 12.03 kg. Does not account for inside diameter of tube, only inside. Divided by 1000 distillations http://asm.matweb.com/tools/weight-calculator.asp.

Distiller: Standard metal 25L bucket x 2 (1= 1235 g). = 2470 g. Divided by 1000 distillations (self-weighted).

Plastic collection bottle: 4 used per distillation, Used 2x year for 3 years. 18g per 500 ml (self-weighted).

Wood logs: 3m³ of orange wood = 2740.6 kg. Sustainable Energy Development Office (SEDO) 1kg wood = 4 kWh, so 2740.6 = 10962.4 MJ.

Step 6. Transportation Inventory

All calculations based on the transportation of 10L of oil.

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Step 6. Transportation	10	l	Volume
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Transport, aircraft, freight, intercontinental/RER U	50,1	tkm	Undefined
Transport, passenger car, large size, diesel, EURO 4 {GLO}| market for | APOS, U	147	km	Undefined
Transport, van <3.5t/RER U	1,6	tkm	Undefined
HDPE bottles E	360	g	Undefined

Aircraft Transportation: 5110 km between Accra and London, x 10 kg oil (10L). Distance (5110 km) x mass in tons (0,01t). Passenger craft, but units unavailable in SimaPro thus choice of freight craft. https://planetcalc.com/4316/

Transport, passenger car: Combination of all transport in Ghana, with same pickup truck.

Transport, van: 160 km from London Heathrow to Poole UK via Southampton. Distance (160 km) x mass in tons (0,01t) in delivery van.

HDPE 10 L capacity packaging : 1x 10L L HDPE plastic bottle - 500ml = 18g approximately (self-weighted).

8. SimaPro Inventory Inputs: Sensitivity Analysis – Flower Yield

All process attributions have been adjusted according to flower yield/tree and amortized by generation contribution. Distillation and Transportation stay the same.

Benini et al. (2010) Scenario – 5,2 kg/yr

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Ylang ylang oil production (Benini et al. (2010) 5,2 kg yield per year)	1	l	Volume	100 %	Autres
Add					

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add						

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add							

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Step 1. Nursury	0,689	p	Undefined			
Step 2. Field Establishment	0,689	p	Undefined			
Step 3. Cultivation	0,689	p	Undefined			
Step 5. Distillation and Extraction	1	l	Undefined			
Step 6. Transportation	1	l	Undefined			
Add						

Parotta (2014) Base Scenario – 9,78 kg/yr

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category	Com
Ylang ylang oil production (Parotta (2014) base scenario - 9,78 kg yield per year)	1	l	Volume	100 %	Autres	90 k
Add						

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add						

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add							

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Step 1. Nursury	0,36	p	Undefined			
Step 2. Field Establishment	0,36	p	Undefined			
Step 3. Cultivation	0,36	p	Undefined			
Step 5. Distillation and Extraction	1	l	Undefined			
Step 6. Transportation	1	l	Undefined			
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add						

Parotta (2014) Extreme Scenario 15kg/yr

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Ylang ylang oil production (Parotta (2014) extreme scenario - 15,7 kg yield per year)	1	l	Volume	100 %	Autres
Add					

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min
Add					

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min
Add						

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Step 1. Nursury	0,22	p	Undefined		
Step 2. Field Establishment	0,22	p	Undefined		
Step 3. Cultivation	0,22	p	Undefined		
Step 5. Distillation and Extraction	1	l	Undefined		
Step 6. Transportation	1	l	Undefined		
Add					

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min
Add					

9. SimaPro Inventory Inputs: Sensitivity Analysis – Generation Timeframe

All cultivation steps are amortized for generational timeframe differences. Distillation and extraction is also amortized for the 50 year scenario, as it is supposed that its infrastructure lasts 25 years. All emissions have been adjusted accordingly.

30 Year Generation Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Ylang ylang oil production (Long Generation 30 yr)	1	l	Volume
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Step 1. Nursury	0,6	p	Undefined
Step 2. Field Establishment	0,6	p	Undefined
Step 3. Cultivation - 30 year generation	0,6	p	Undefined
Step 5. Distillation and Extraction	1	l	Undefined
Step 6. Transportation	1	l	Undefined
Add			

Cultivation Inventory: 30 Year Scenario

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Occupation, permanent crop, non-irrigated, extensive, GLO	land	0,088	ha a	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Poultry manure, fresh {GLO}| chicken production | APOS, U	405	kg	Undefined
Add			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution
Add			

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distribution
Add				

Emissions to water	Sub-compartment	Amount	Unit	Distribution
Add				

Emissions to soil	Sub-compartment	Amount	Unit	Distribution
Phosphorus		3,24	kg	Undefined
Phosphorus pentoxide		7,29	kg	Undefined
Potassium		2,025	kg	Undefined
Nitrogen		8,91	kg	Undefined

50 Year Generation Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Ylang ylang oil production (Ofra et al. (2009) Generation - 50 yr)	1	l	Volume
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Step 1. Nursury	0,36	p	Undefined
Step 2. Field Establishment	0,36	p	Undefined
Step 3. Cultivation - 50 year generation	0,36	p	Undefined
Step 5. Distillation and Extraction - Ofra et al. 2009 50 year generation	1	l	Undefined
Step 6. Transportation	1	l	Undefined
Add			

Cultivation Inventory: 50 Year Scenario

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Occupation, permanent crop, non-irrigated, extensive, GLO	land	0,088	ha a	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Poultry manure, fresh {GLO}| chicken production | APOS, U	705	kg	Undefined
Add			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution
Add			

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distribution
Add				

Emissions to water	Sub-compartment	Amount	Unit	Distribution
Add				

Emissions to soil	Sub-compartment	Amount	Unit	Distribution
Phosphorus		5,64	kg	Undefined
Phosphorus pentoxide		12,69	kg	Undefined
Potassium		3,525	kg	Undefined
Nitrogen		15,51	kg	Undefined

Distillation Inventory: 50 Year Scenario

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Water, unspecified natural origin, agri, GA	in ground	5500	l	Undefined
Water, well, in ground, GLO	land	4	l	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Rustic Home-made Alembic - for distillation system	0,002	p	Undefined
Distillation System Furnace Oven - for distillation system	0,002	p	Undefined
Distillation System Polytank (10000L Capacity) - for distillation system	0,002	p	Undefined
Distillation System Polytank (400L Capacity) - for distillation system	0,002	p	Undefined
Light clay brick, at plant/DE U	0,3164	kg	Undefined
Extrusion, plastic pipes {GLO}| market for | APOS, U	0,024	kg	Undefined
Steel, chromium steel 18/8, hot rolled {GLO}| market for | APOS, U	4,94	g	Undefined
Plastic 2,5 L bottle	0,666	p	Undefined
Add			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution
Logs, hardwood, burned in furnace 30kW/CH U	10962,4	MJ	Undefined

10. SimaPro Inventory Inputs: Sensitivity Analysis – Fertilizer Choice

Synthetic Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Ylang ylang oil production (synthetic fertilizer)	1	l	Volume
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Step 1. Nursury	0,72	p	Undefined
Step 2. Field Establishment - Synthetic Fertilizer	0,72	p	Undefined
Step 3. Cultivation - synthetic fertilizer	0,72	p	Undefined
Step 5. Distillation and Extraction	1	l	Undefined
Step 6. Transportation	1	l	Undefined
Add			

Field Establishment: Synthetic Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Step 2. Field Establishment - Synthetic Fertilizer	1	p	Amount
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Transformation, from permanent crop, non-irrigated, extensive, (	land	0,0040	ha	Undefined
Water, well, in ground, agri, GH	in water	84	l	Undefined
Occupation, permanent crop, non-irrigated, UG	in ground	0,012	ha a	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Fertilising, Chemical fertilizer ylang-ylang study	0,036	ha	Undefined
Add			

Cultivation: Synthetic Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Step 3. Cultivation - synthetic fertilizer	1	p	Amount
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Occupation, permanent crop, non-irrigated, extensive, GLO	land	0,088	ha a	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Fertilising, Chemical fertilizer ylang-ylang study	0,264	ha	Undefined

Emissions are considered to be accounted for in the chemical fertilizer input.

Fertilizer, Chemical fertilizer, ylang-ylang study

Emissions to air	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD
NMVOC, non-methane volatile organic compounds, unspecifiec	low. pop.	0,0143	kg	Lognormal	1,52
Nitrogen oxides	low. pop.	0,231	kg	Lognormal	1,52
Carbon monoxide, fossil	low. pop.	0,021	kg	Lognormal	5,01
Carbon dioxide, fossil	low. pop.	16,5	kg	Lognormal	1,21
Sulfur dioxide	low. pop.	0,00533	kg	Lognormal	1,21
Methane, fossil	low. pop.	0,000683	kg	Lognormal	1,56
Benzene	low. pop.	0,0000386	kg	Lognormal	1,56
Particulates, < 2.5 um	low. pop.	0,0208	kg	Lognormal	3,05
Cadmium	low. pop.	0,0000000529	kg	Lognormal	5,05
Chromium	low. pop.	0,000000265	kg	Lognormal	5,05
Copper	low. pop.	0,000009	kg	Lognormal	5,05
Dinitrogen monoxide	low. pop.	0,000635	kg	Lognormal	1,56
Nickel	low. pop.	0,00000037	kg	Lognormal	5,05
Zinc	low. pop.	0,00000529	kg	Lognormal	5,05
Benzo(a)pyrene	low. pop.	0,000000159	kg	Lognormal	5,05
PAH, polycyclic aromatic hydrocarbons	low. pop.	0,0000174	kg	Lognormal	3,05
Heat, waste	low. pop.	240	MJ	Lognormal	1,11000000000(
Ammonia	low. pop.	0,000106	kg	Lognormal	1,56
Selenium	low. pop.	0,0000000529	kg	Lognormal	1,56
Add					
Emissions to water	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD
Add					
Emissions to soil	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD
Zinc	agricultural	0,000897	kg	Lognormal	1,52
Lead	agricultural	0,00000149	kg	Lognormal	1,52

All emissions account for the application of 1ha of chemical fertilizer by spraying.

Not pictured: Emissions to soil – Cadmium, 0,00000034 kg.

No Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Ylang ylang oil production (no fertilizer)	1	l	Volume
Add			
Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs				
Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				
Inputs from technosphere: materials/fuels		Amount	Unit	Distribution
Step 1. Nursury		0,72	p	Undefined
Step 2. Field Establishment - no fertilizer		0,72	p	Undefined
Step 3. Cultivation - no fertilizer		0,72	p	Undefined
Step 5. Distillation and Extraction		1	l	Undefined
Step 6. Transportation		1	l	Undefined
Add				

Field Establishment: No Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation %	Category
Step 2. Field Establishment - no fertilizer	1	p	Amount	100 %	Autres
Add					

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Add						

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Transformation, from permanent crop, non-irrigated, extensive, (	land	0,0040	ha	Undefined			
Water, well, in ground, agri, GH	in water	84	l	Undefined			
Occupation, permanent crop, non-irrigated, UG	in ground	0,012	ha a	Undefined			
Add							

Cultivation: Synthetic No Fertilizer Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity
Step 3. Cultivation - no fertilizer	1	p	Amount
Add			

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Occupation, permanent crop, non-irrigated, extensive, GLO	land	0,088	ha a	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Add			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution
Add			

11. SimaPro Inventory Inputs: Sensitivity Analysis – Fuel Choice

Oil Fuel Scenario

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	A
Ylang ylang oil production (Oil fuel scenario)	1	l	Volume	1
Add				

Outputs to technosphere: Avoided products	Amount	Unit	Distribution
Add			

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Step 1. Nursury	0,72	p	Undefined
Step 2. Field Establishment	0,72	p	Undefined
Step 3. Cultivation	0,72	p	Undefined
Step 5. Distillation and Extraction (fuel SA)	1	l	Undefined
Step 6. Transportation	1	l	Undefined
Add			

Distillation Inventory: Oil Fuel Scenario

Inputs from nature	Sub-compartment	Amount	Unit	Distribution
Water, unspecified natural origin, agri, GA	in ground	5500	l	Undefined
Water, well, in ground, GLO	land	2,8	l	Undefined
Add				

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution
Rustic Home-made Alembic - for distillation system	0,001	p	Undefined
Distillation System Furnace Oven - for distillation system	0,001	p	Undefined
Distillation System Polytank (10000L Capacity) - for distillation system	0,001	p	Undefined
Distillation System Polytank (400L Capacity) - for distillation system	0,001	p	Undefined
Light clay brick, at plant/DE U	0,1582	kg	Undefined
Extrusion, plastic pipes {GLO}| market for | APOS, U	0,012	kg	Undefined
Steel, chromium steel 18/8, hot rolled {GLO}| market for | APOS, U	2,47	g	Undefined
Plastic 2,5 L bottle	0,666	p	Undefined
Add			

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution
Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	1656,732	MJ	Undefined

Water, 2.8 L: Time difference accounted for. 280L per distillation (for 10L), recycled - changed every 10 distillations, so 4 times per year. 280L water/100 (10Lx 10 times) oil.

Oil Fuel: 50,82 L of petrol used for 15h of distillation, 1 L of petrol = 32,6 MJ (https://deepresource.wordpress.com/2012/04/23/energy-related-conversion-factors/)