



Use of LCA and design to study sustainable alternatives to plastic takeaway cutlery and crockery

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Use of LCA and design to study sustainable
alternatives to plastic takeaway cutlery and crockery

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Abstract

This thesis looks on alternatives to plastic takeaway cutlery and crockery from areca palm and coconut tree by products. Most of the take away materials used today are made of plastic that is disposed of upon single use. This presents a huge challenge in terms of waste management and pollution. It is widely known that plastic is produced from polymers generated by fossil oil that is explored from the soil and whose natural reserves are limited. Due to its nature, it takes several hundred to thousand years to decompose plastics, releasing toxic substances in the process.

This work focuses on reviving the methods and knowledge that existed in the southern and central parts of the Indian subcontinent for producing sustainable goods used in everyday life, aiming to make sustainable cutlery and crockery. The materials that are under study are palm areca sheaths, coconut fibre, shells and banana fibres. A market analysis, design, life cycle analysis and deeper research on the fabrication was made.

The life cycle analysis (LCA) was conducted from data obtained from the Eco invent v2 database. CML 2000 method was used to assess and compare the data. Existing data from the database was considered to estimate the final impact through weighted averages. The results show that the materials under study perform better than conventional plastic materials with respect to emissions and other parameters. The main impact involved in the production of the various products was found out to be transportation. When imported and produced in bulk, costs and impacts of the suggested alternatives are lower than those of the conventional products.

Comparing results for cardboard and palm areca boxes for example the Global warming potential for the alternatives were $7.07E-02$ compared to $11.2E-02$ kg CO₂ equivalent for the conventional products. Similarly, when plastic plates and palm plates were compared $7.46E-08$ and $4.62E-09$ kg CFC 11 eq were the values for ozone layer depletion. Most other results follow the same route which is a clear indication that most of our alternatives have a good environmental performance for a lower or the same price

Keywords

CML2000, crockery, cutlery, eco-friendly, LCA, sustainability

Resumo:

Esta tese analisa as alternativas de talheres plásticos para uso doméstico e louças de palmeiras areca e coqueiros por produtos. A maioria dos materiais removíveis utilizados hoje são feitos de plástico que é descartado em uso único. Isso representa um enorme desafio em termos de gerenciamento de resíduos e poluição. É amplamente conhecido que o plástico é produzido a partir de polímeros gerados por óleo fóssil que é explorado a partir do solo e cujas reservas naturais são limitadas. Devido à sua natureza, leva várias centenas a mil anos para decompor os plásticos, liberando substâncias tóxicas no processo.

Este trabalho centra-se na revitalização dos métodos e conhecimentos que existiam nas partes do Sul e central do subcontinente indiano para a produção de bens sustentáveis utilizados no cotidiano, com o objetivo de fazer talheres e louças sustentáveis. Os materiais que estão em estudo são bainhas de areca de palma, fibra de coco, conchas e fibras de banana. Uma análise de mercado, design, análise do ciclo de vida e pesquisas mais profundas sobre a fabricação foram feitas.

A análise do ciclo de vida (LCA) foi realizada a partir de dados obtidos do banco de dados Eco invent v2. O método CML 2000 foi utilizado para avaliar e comparar os dados. Os dados existentes do banco de dados foram considerados para estimar o impacto final através de médias ponderadas. Os resultados mostram que os materiais em estudo são melhores que os materiais plásticos convencionais em relação às emissões e outros parâmetros. O impacto principal envolvido na produção dos vários produtos foi considerado transporte. Quando importados e produzidos a granel, os custos e os impactos das alternativas sugeridas são inferiores aos dos produtos convencionais.

Comparando resultados para caixas de papelão e caixas de palma, por exemplo, o potencial de aquecimento global para as alternativas foi $7.07E-02$ em comparação com $11.2E-02$ kg de equivalente de CO₂ para os produtos convencionais. Da mesma forma, quando as placas de plástico e as placas de palma foram comparadas, $7.46E-08$ e $4.62E-09$ kg CFC 11 eq foram os valores para a depleção da camada de ozônio. A maioria dos outros resultados

seguem a mesma rota, o que é uma indicação clara de que a maioria de nossas alternativas tem um bom desempenho ambiental por um preço inferior ou igual

Palavras-Chave

ACV, CML2000, cutelaria, ecologico louça, sustentabilidade

Declaration:

Anirudh Murildharan Gautam declares, on a commitment of honor, that this work is original and that all non-original contributions have been duly referenced, with identification of the sources

31 October 2017

Anirudh Muralidharan Gautam

Signature

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Nomenclature

A.D.	–	Anno Domini
Approx	–	Approximate
B.C.	–	Before Christ
Cm	–	Centimetres
eq	–	Equivalent
INR	–	Indian National Rupees
ml.	–	Millilitres
MW	–	Megawatts
kg	–	Kilograms
km	–	Kilometres
kW	–	Kilowatts
N.A.	–	Data Not available

1. Introduction

The last few decades have seen the plastic industry take us by storm, and nowadays most of the products and food consumed use plastic packaging. One of the most important examples is the take away and the disposable cutlery and crockery industry.

McDonalds serves more than 3.8 million customers per day in the UK, corresponding to the consumption of millions of burger boxes and disposable cups and wraps in the UK every day [1]. When the whole world is considered, several millions of containers are being used and disposed every day. Most plastic is non-biodegradable and its improper utilization and disposal can be dangerous to the environment and result in adverse human health issues [2]. As an example, currently very small particles of plastics of various types, microplastics, are accumulating in the oceans, already having a significant impact in wild life and potentially in human health through fish consumption. The problem is particularly acute in the North Pacific, as it is surrounded by heavily industrialized countries (China, US and Japan) [2]. It is estimated that Americans throw away 25 billion Styrofoam coffee cups every year, and 2.5 million plastic beverage bottles every hour [3], most of them non-biodegradable and hard to recycle. Moreover, the plastic cutlery is also a problem of similar magnitude. According to the Clean Air Council [4], the amount of paper and plastic utensils that are thrown away every year is enough to circle the equator 300 times. Circa 40 billion individual plastic utensils, representing 14 and 18 billion plastic spoons are estimated to be produced every

year [4]. It is estimated that 64 billion paper and 73 billion Styrofoam & plastic cups and plates were thrown away in 2003 in the USA, whereas single-use food/drink containers are estimated at about 140,000 each second [5].

A few decades back, in southern India plastic was rarely used, people were using natural products that were sustainable and had minimal environmental impact. This thesis aims to analyse how the environmental performance of products from the disposable cutlery and crockery industry can be improved by using renewable materials, biomass, waste materials native to South India. Both the fabrication and the design of the new products will be considered, and their environmental impacts will be assessed using the Life Cycle Assessment (LCA) methodology. The products analysed are mostly disposable cutlery namely plates, take away containers, cups and other crockery.

1.1. Objectives

The main objectives of this work are to analyse the utilization of new raw materials, in particular biomass, to produce cutlery and crockery disposable products that should have lower environmental impact when compared to existing options, mainly based in plastic. This study comprehends performing a life cycle analysis of the products, to quantify its environmental performances and factors. The study allows to compare the life cycle impacts from conventional products and the suggested alternative materials, showing that the materials suggested have a better environmental performance than the conventional materials. Consequently, it is presented and discussed a business plan on how to sell this product in existing market conditions dominated by plastic products. The business plan is mainly focused on replacing plastic containers from the takeaway and the home supplies industries.

1.2. Outline of the study

To fulfil the objectives of the thesis, it was planned a series of activities that will be briefly described before presenting the work.

- **An overview into the material that is suggested as alternatives:** A basic outline of the tree or plant from which the material is extracted, why and where the plant / tree is grown, what is the main product from the plant or tree (chapter 2);
- **How the goods have been produced and used:** This section deals with how the materials were fabricated traditionally using both traditional and modern methods. It also dives into

how much can be produced per day in a small production center (chapter 3);

- **Possible designs with the materials discussed:** This part provides certain designs that are existing in the market for conventional products and applies them to the products from the alternative materials discussed specifically for the take away and the home supplies industry (chapter 4);
- **Life cycle approach:** The life cycle approach gives a detailed insight into the impact caused by each activity involved in the production process and assuming that the product would be sold in Portugal. Data sets from the Eco Invent 2.1 Database and the CML2000 method was used for assessing the impacts. This section will later compare the results from similar studies made for conventional plastic materials with the impacts that were calculated for the alternative materials suggested (chapter 5);
- **Business plan:** This section discusses how to device a business plan to sell this product initially in Europe, especially Portugal, with the existing market conditions and hurdles. Several products and studies from prominent economists were applied in this section (chapter 6);
- **Conclusions:** This section presents the main conclusions of this work (Chapter 7).

The following materials were considered:

- Palm areca (*Areca catechu*) sheaths;
- Sal (*Shorea robusta*) leaves;
- Coconut (*Cocos nucifera*) shells and fibre;
- Banana (genus *Musa* in particular *Musa Acuminata*) fibers.

1.3. Phases of the work

The realization of the objectives led to the following phases of work. This includes a set of tasks; these are defined principally in several phases:

- *Creating Links:* Establishing connections with companies and self-help groups, obtaining links and information, taking an average of all information required;
- *Methodology and design:* Obtaining information on the methods currently practiced for manufacturing, establishing a middle ground for the information, contacting

designers for information and ideas and making simple designs for the new versions of the products;

- *Life cycle analysis*: Collecting data from the database. Obtaining secondary data from organizations. Calculations for impact analysis and comparisons;
- *Business analysis*: Case studies, brainstorming. Documenting the methods and ideas;
- *Documentation*: Documenting all the above steps

2. Raw Materials

There are several materials that were discussed to produce sustainable cutlery and crockery; they are the following: Palm areca sheaths and leaves, Sal leaves and coconut shells, fibres and banana fibres. The origins of the materials are discussed below.

2.1. Areca Catechu palm

Areca, *Areca Catechu*, is derived from a local name from the Malabar Coast of India and catechu is from another Malay name for this palm. Areca is an erect, unbranched palm reaching heights of 12-30 m, depending upon the environmental conditions. The stem, marked with scars of fallen leaves in a regular annulated form, becomes visible only when the palm is about 3 years old. Girth depends on genetic variation and soil conditions. The adult palm has 7-12 open leaves, each with a sheath, a rachis and leaflets. The leaf stalk extends as the midrib until the end of the leaf and ends as leaflets [6]. The beetle nut palm tree of the Areca nut family is generally cultivated in the south of India to produce betel nuts. The seed of the betel palm (*Areca catechu*), is one of the most widely used materials in areas of the western Pacific and parts of Africa and Asia. It is prepared with other substances as a mixture for chewing and is used as a mild stimulant by more than 200 million people [7].

References to the betel nut appear in ancient Greek, Sanskrit, and Chinese texts from 100 B.C. Its prevalence in Persia by 600 A.D. is documented by Persian historians. Its use in

different parts of the Arab world by the eighth and ninth centuries is also well documented, and it had become an important aspect of the economy and social life in India, Malaysia, the Philippines, and New Guinea. Betel was brought to Europe by Marco Polo, around 1300, it soon proved to be an important commodity in the western Pacific and a source of tax revenue for the Dutch in the mid-1600s. It is commonly consumed as a food product in the southern peninsula of the Indian subcontinent [8].

Figure 1 presents a photograph of an Areca Palm plantation. The trees are mainly cultivated for beetle nut production. The rough part of the leaves is used for making slipper soles, hats and as pulp for paper. The sheath that covers those leaves are extracted and used as a base for making several products like bags, plates, cups and wrapping. The sheath is attached to the leaves, once collected they are generally dried in shade to remove excess moisture and sent for processing [7].



Figure 1 - An Areca nut plantation in Kerala India, 2008. Image source Wikipedia, *Areca catechu*

This process of extraction from the plantations would be more sustainable if the resulting wastes could be used as a raw material in other processes. To make the process more sustainable, one could use the method of cultivating areca palms using permaculture. The common price for one sheath (dried) is around 0.02 Euro and a plate 0.07 Euros.

2.2. Coconut tree

The coconut tree (*Cocos nucifera*) is a member of the family Arecaceae (palm family) and the only species of the genus *Cocos* [9]. The term coconut can refer to the whole coconut palm or just the fruit. India is one of the major world coconut producers, producing 11.1

million tons a year. Traditional areas of coconut cultivation in India are the states of Kerala, Tamil Nadu, Karnataka, Puducherry, Andhra Pradesh, Goa, Maharashtra, Odisha, and West Bengal, and the islands of Lakshadweep and Andaman and Nicobar. As per 2014-15 statistics from Coconut Development Board of Government of India, four southern states combined account for almost 90% of the total production in the country: Tamil Nadu (33.84%), Karnataka (25.15%), Kerala (23.96%), and Andhra Pradesh (7.16%) [10]. This situation represents a huge potential in terms of harnessing the secondary material as raw materials to obtain other products or even to generate energy. Figure 2 gives an idea of the quantity of coconut residues, in this cases husks resulting from the process of obtaining the coconut shells, where it is visible the large amount that are generated.

Figure 2 - Coconut husks near a plantation. Image from www.palmpringusa.com



Coir (also known as “Kokos” or “Coco”) is a natural seed-hair fibre obtained from the outer shell (endocarp), or husk, of the coconut, extensively grown in tropical countries. Coir yarn has been produced in the coastal belt of Kerala from ancient, but the first coir factory for the manufacture of coir products was established in Kerala during 1858. Coir or coconut fibre belongs to the group of hard structural fibres and is lignocellulosic [11].

The fibres extracted directly from the dried husks are rough and can be used as ropes for domestic and some commercial use. The fibre extracted through the retting process can be used for mattresses and other products such as mats, carpets and sponges for cleaning through coarse and smooth fibres. The coconut is generally dehusked before export or being used in most cases. The shell of the coconut is also used in making bowls, ladles and other simple day to day products. Additional materials can be obtained from fallen coconut leaves.

Some applications include the construction of temporary shelters, and the hard part of the leaf can be used for making broomsticks, cases, buttons and other similar products. Since most of the products that we discuss about would end up in trash, the products would only involve labor costs. A kilogram of retted coir costs nearly INR 8. Coconut shells cost close to INR 1000 per tonne.

2.3. Banana fibers

The banana plant is the largest herbaceous flowering plant. The banana is an edible fruit – botanically a berry produced by several kinds of large herbaceous flowering plants in the genus *Musa*. All the above-ground parts of a banana plant grow from a structure usually called a "corm". What appears to be a trunk is a "false stem" or pseudo stem. The base of the petiole widens to form a sheath; the tightly packed sheaths make up the pseudo stem, which is all that supports the plant. The edges of the sheath meet when it is first produced, making it tubular. As new growth occurs in the centre of the pseudo stem, the edges are forced apart [12]. Figure 3 shows a typical banana plantation, where it is possible to observe banana stems drying for further utilization as raw materials.



Figure 3 - Banana stem fiber being dried inside a plantation. Image credits bananafibereg.com

India leads the world in terms of banana production, with around 18% of the worldwide crop of 139 million metric tons (2012). Maharashtra and Tamil Nadu are the leading banana producing states. Although about 500,000 hectares are under banana cultivation, only 10% of the banana stem waste is used. Typically, in banana cultivation, the stems of the plants are chopped off and thrown away once the fruits are sold. These wasted stems typically lay around in the farm, and clearing them from the land would cost a farmer about INR 3000 on average. If farmers decide to supply banana stems to these fiber processing units, they would

not only clear waste without any cost, but also would sell them as it represents an extra revenue source. They can set up a small-scale unit at a cost of INR 110,000, that would employ a few semi-skilled workers [13]. The banana leaf is waterproof and has been used for serving food, packing food, takeaway for several decades in South India because it imparts flavor. Both fresh and dried banana leaves are used for takeaway food. The stem of the banana plant is usually consumed in the states of Tamil Nadu and Kerala (South India), but the outer part is thrown away. Retting of the other part of the stem through chemical or mechanical methods can result in extraction of the fibers of the banana plants that could be used as an alternative to even clothing and the packing industry. The fibers could also be redesigned to use other materials for the making of several packings and take away materials. The fiber could be processed to make take away cases and even packing materials by extracting and compressing the fiber of the material.

2.4. Sal tree leaves

Sal (*Shorea robusta*) forests cover over 11 million hectares in India, Nepal and Bangladesh, and these forests are conventionally managed for timber. Recently, interest in producing multiple products from Sal forests has increased. Thus, a silvicultural regime for managing Sal forest for multiple products is currently an important issue [14].

It is evident that Sal forests have the potential to yield other forest products too. A Sal tree, in addition to timber and fuelwood, produces fodder, leaves for plates, seed for oil, resin or latex from heartwood, and tannin and gum from bark. Besides, other plants species commonly found in Sal forests are known to produce edible fruits, fodder and compost, fibres, leaves for umbrellas, medicinal plants, thatch, grass, brooms and many other products. The Sal tree has been cultivated in India for commercial purposes as it makes good timber wood. About 30 percent of all the forest land are Sal trees. Apart from this, the Sal trees also have tannin in their barks that can be used for tanning. Sal leaf products have been one of the most important commodities of the tribal communities in the east and midlands of India [14].

Sal seeds also have oil which has been used for both commercial and industrial uses. The Sal leaf plate and bowls production was mainly restricted to the small communities, but the industry started to boom in the late eighties when developers from Bengal came in and started to commercialize the process. This has given a lifeline to the landless and

marginalized tribal communities. Only the matured leaves are collected, hence making the process more sustainable, as shown in Figure 4. There are several stakeholders when it comes to analysing or mapping the process, with the leaf collectors being the primary stakeholders [14].



Figure 4 - A man collecting Sal leaves inside a Sal forest. Image by Somennath Mukhopadhyay in the world forestry congress 2015

The model that is currently adopted follows the example of financial, social and environmental sustainability. The issues currently are that there are middle men involved, who earn more money in the process, and there is no middle ground for the tribal families to earn more money.

3. Methods of extraction and processing

This chapter analyses the traditional methods of processing items from the materials listed in the previous section. This would also provide simplified insights on the current supply chains that are used for selling the products.

3.1. Areca palm products

Areca palm products are made using the areca sheaths covering the nuts of the areca palm tree. The tree also called as *Areca catechu* is grown in abundance. India is the highest producer of areca nut, with a production of around 330000 tonnes and a total area under cultivation of 264000 hectares. Over six million people are engaged in areca nut cultivation, processing and trade. More than 85 per cent of the area under cultivation is made up of small and marginal holdings [15]. Most of the plantations are near each other and exist within the same district. Areca nuts are gathered by minivans from different plantations. The sheath is a by-product of the tree that ends up in trash, unless used. Twenty leaf sheaths fall naturally per acre in a month. They are generally harvested using manpower and stored at the plantation site, as shown in Figure 5a. The sheath is then distributed to small self-help groups who manufacture plates using this material. In average one sheath is 1 to 2 INR. The plates

are manufactured using a manually controlled mechanical press. Initially, the plates are soaked in water for a few hours to increase the flexibility without breaking or damaging the material. Then they are pressed using a mechanical press with minimal heat of about 55 to 85 degrees. They can be pressed either manually or automatically (hydraulic), as shown in Figure 5b. The machines have a power range from 3 to 8 kW.



Figure 5 - (a) Areca nut sheath bundles near a plantation (b) Sheaths being processed

The shapes of the product depend on the shape of the pressing mold. The machines can produce up to 5000 to 8000 plates in a day. They are then dried under the sun. The end products are sold for about 3 to 5 INR in retail. They are packed in plastic wraps, and transported in boxes tied with coconut fibre ropes. The plates, if kept in a dry and clean place with no influence of moisture, can last from 12 to 18 months.

3.2. Coconut coir and shells

India is one of the leading coconut producers in the world, producing around 13 billion nuts per annum with a cultivation area of 1.91 million hectares [16]. Coconut is mostly cultivated in the coastal regions of the country. The overall production rate is increasing with an increase of around 25 % in the last decade. India accounts for 22.34 % of the world's coconut production and is one of the major players in the world's coconut trade.

3.2.1. Existing agricultural practice

As ripened coconuts fall from the tree, they may simply be picked up from the ground. The outer layers covering the coconut seed are processed and spun into fibers, commonly known as coir. Coconuts still clinging to the 40-100 feet (12-30 meters) tall trees are harvested by

human climbers. If the climber picks the fruit by hand, he can harvest fruits from about 25 trees in a day. If the climber uses a bamboo pole with a knife attached to the end to reach through the treetop vegetation and cut selected coconuts loose, he can harvest 250 trees per day. Figure 6a shows the pole harvesting method.

Ripe coconuts are husked immediately, but unripe coconuts may be seasoned for a month by spreading them in a single layer on the ground and keeping them dry. To remove the fruit from the seed, the coconut is impaled on a steel-tipped spike to split the husk, as shown in Figure 6b. The pulp layer is easily peeled off. A skilled husker can manually split and peel about 2,000 coconuts per day. Modern husking machines can process 2,000 coconuts per hour. Coconuts can be mechanically extracted to produce low quality fibre that is drawn and then used to make ropes for several purposes. High quality fibres are used for producing many fibres based products items. High quality fibres require the coconut fibres to be retted before they are extracted from the skin [17-19].

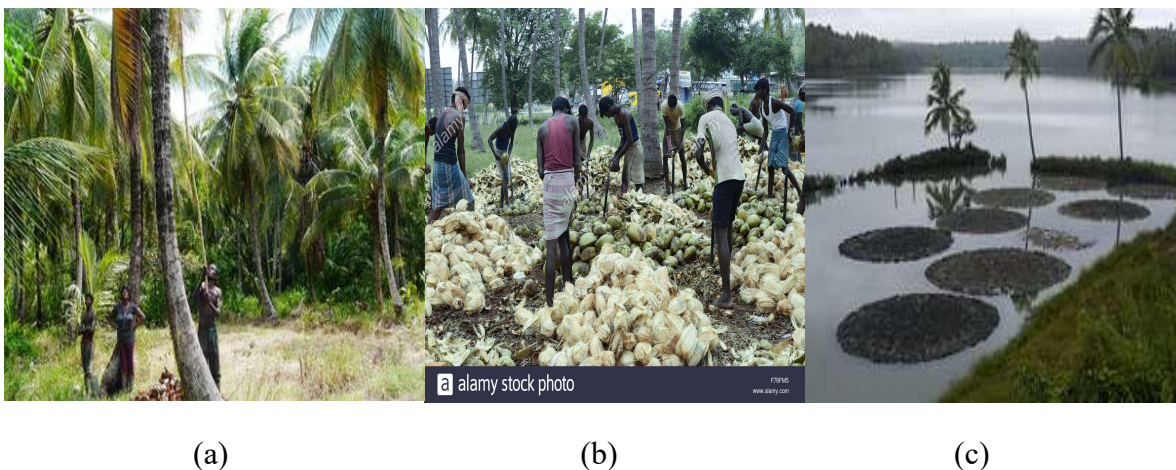


Figure 6 - (a) A worker extracting coconuts. Image credits: stabroeknews.com (b) Coconuts being dehusked. (c) Retting of coconuts in water. Image credits (b),(c): Alamy stock photos

3.2.2. Retting and extracting the fiber

Extracted coconuts are generally dehusked, the husks are then immersed in salt water pits or backwaters in nets tied with stones, as shown in Figure 6c. They are left to rest for a period of 6 to 8 months for the bristles of husk to soften. Traditionally, workers beat the retted pulp with wooden mallets to separate the fibres from the pith and the outer skin. In recent years, motorized machines with flat beater arms operating inside steel drums are being increasingly used. Separation of the bristle fibres is accomplished by hand or in a machine consisting of a rotating drum fitted with steel spikes.

Retting is a curing process during which the husks are kept in an environment that encourages the action of naturally occurring microbes. This action partially decomposes the husk's pulp, allowing it to be separated into coir fibres and a residue called coir pith. Freshwater retting is used for fully ripe coconut husks, and saltwater retting is used for green husks. Immature husks can be dry milled without any retting. After passing through the crushing machine, these green husks need only be dampened with water or soaked one to two days before proceeding to the defibering step. Dry milling produces only mattress fibre.

Separation of the mattress fibres from the pith is completed by washing the residue from the defibering process, and combing it by hand or tumbling it in a perforated drum or sieve. The clean fibres are spread loosely on the ground to dry in the sun; bristle fibers that will not immediately be further processed are rolled and tied into loose bundles for storage or shipment. More mechanized producers may use a hydraulic press to create compact bales. Similarly, mattress fibres and sponges may simply be baled with a hydraulic press. Figure 7 presents some of the steps of coir extraction and bundling process.



(a)

(b)

(c)

Figure 7 - (a) Extracted and bundled coir (b) coir being spun into ropes (c) coir ropes of different dimensions

The fibres are combed with mechanical or manual carding tools, then loosely twisted into a thick yarn (wick), and wound into bundles. Later, the wick can be re-spun into a finer yarn. Techniques vary from simple hand spinning to the use of a hand-operated spinning wheel, or a fully automated spinning machine. Depending on its intended final use, the yarn may be shipped to customers, or multiple strands may be twisted into twine and bundled for shipment. Both traditional manual and mechanical techniques are used to braid twine into

rope and to weave yarn into mats or nets. For some uses, such as upholstery padding, bristle fibre is loosely spun into yarn and allowed to rest. Then the fibres, which have become curly, are separated [17-19].

3.2.3. Coconut shells

Coconut shell cups have been traditionally used in the southern part of India and other south Asian countries. Most of the shells are discarded, but traditionally these outer shells can be used for making containers that could be used more than once. Once the copra or the white part of the coconuts is extracted the shells can be used to make other products. Initially, the outer part of the shell is soaked in water for a few hours. Once soaked the shells are taken and then scrubbed with an abrasive material / sand / silica paper to remove the fibrous parts, as shown in Figure 8. The soaking and scrubbing process is repeated until the rough parts of the coconut shells are removed, and the rough edges are cut. The most common and traditional usage for the shells is as bowls and cups.



(a)



(b)

Figure 8 - (a) Coconut shells being polished, image credits: <http://www.dsource.in> (b) Polished shells, Image credits: <https://www.pippi.co.uk>

3.3. Banana Fibers

The knowledge of extracting fibre and paper from banana is well known since the 13th Century when Japanese started to process it for various uses [20]. However, it was a time-consuming and costly process.

The stem is extracted by hand and then cut into halves. These sliced stem pieces are then machined on fixed platforms that cut the stems into smaller pieces. The shredded pieces are then cleaned and sun dried. Sodium hydroxide is then used while boiling the dried and cut banana stem pieces. After they are strained and washed with more water, they are then blended and mixed with a little water. This is then taken up on a mesh and left in the sun to dry. Once dried, the banana paper production is complemented. An example of the finished product is presented in Figure 9 [21].



Figure 9 - A sheet of banana paper. Image credits: www.techxlab.org

3.4. Sal leaves

The harvesting of the Sal leaves involves mainly the families of the tribes who live in and around the forests, who collect the leaves during the picking season, as shown in Figure 10a. One person can pick about 3000 leaves in 4 to 6 hours. Cutting the tree is prohibited. It takes about four to 6 hours per day to collect the leaves to make the plates until 2 pm during the afternoon next day. The peak season is from May to July for collecting the leaves. The leaves that are collected are then sorted out in village from afternoon until the evening. They are then stitched with cotton or coconut fiber using a sewing machine or stitched using a dried thick blades of forest grass, as shown in Figure 10a, b and c.

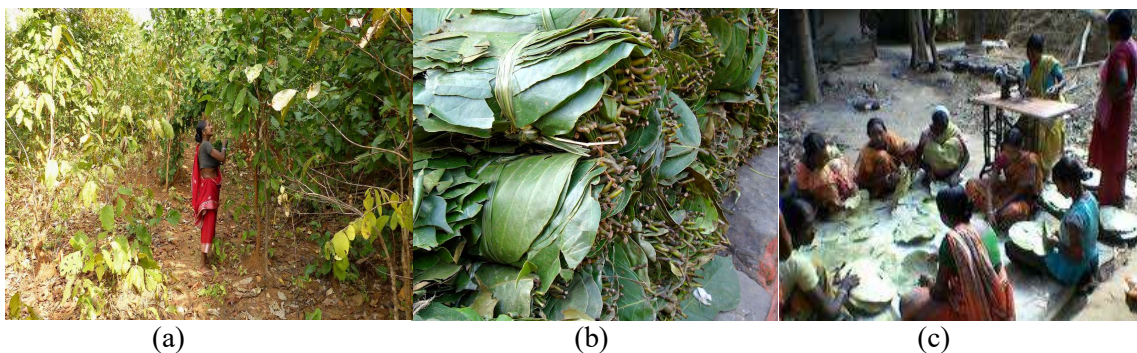


Figure 10 - (a) Sal leaves being picked by a woman. Image credits: Flickrriver (b) Bundled Sal leaves. Image credits: tasteofnepal.blogspot.pt (2012/03) (c) Leaves being stitched: Image credits: www.premagnetos.com

Then the plates that are made are left to dry in the process for the next few days under the sun with a weight in the process. The dried plates are generally bundled into groups of hundreds and then they are packed. These are half processed in this stage, they could be used further for pressing or they are used for wrapping or as flat plates as such. They can also be stitched to form cups, as shown in Figure 10c. The packed plates are then pressed. In the pressing units, sizably cut polyethylene sheets are placed in between two stitched plates. It is put under a manually or automatically operated heating die, heated through an electric presser of low consumption. Due to the heat, the leaves take up the form of the die. The heated die also serves as a disinfecting agent and makes them more hygienic to use. The pressed units are then cooled and bundled. If the un pressed plates are not used for a long time, they tend to dry out. They are then soaked in water for a few hours before they are pressed. The machines can take up different types of sizes and shapes as per the order's and the customer's wishes. The plates are generally 10 to 14 inches in diameter. In a similar way, there are cups that are made of 3 to 5 inches in diameter [22].

The leaf plates are packed in bags, as shown in Figure 11, and then transported to the final selling point, using the more appropriate transport forms. The initial extraction and making charges are of 20 to 30 INR for a thousand plates and sold at about INR 350 after final processing to the final store, and 1 plate costs close to 1 INR, depending on the place of process and point of sale.



Figure 11 - Sal leaf plates packed and ready for shipping. Image credits: tasteofnepal.blogspot.pt (2012/03)

3.5. Transport, marketing and stakeholder involved

Like for any other product, there are a lot of stakeholders involved in the process. Moreover,

the products are sold through various channels with involvement of middlemen. Figure 12 presents a simplified outlook of the logistic chain involved [23]. A stakeholder model taken from SEED 2013 Tambul, is used as an example, presented in Figure 13, highlighting the interdependences between the various stakeholders involved in the harvesting of raw materials, their pre-processing, product manufacture, final treatments and final expedition to the point of sale. It is clear from the figure the network like structure, involving not just the stakeholders directly involved in the product life cycle but also other stakeholders, such as consumers and regulatory/government bodies that have a direct interest and may benefit from product production and selling.

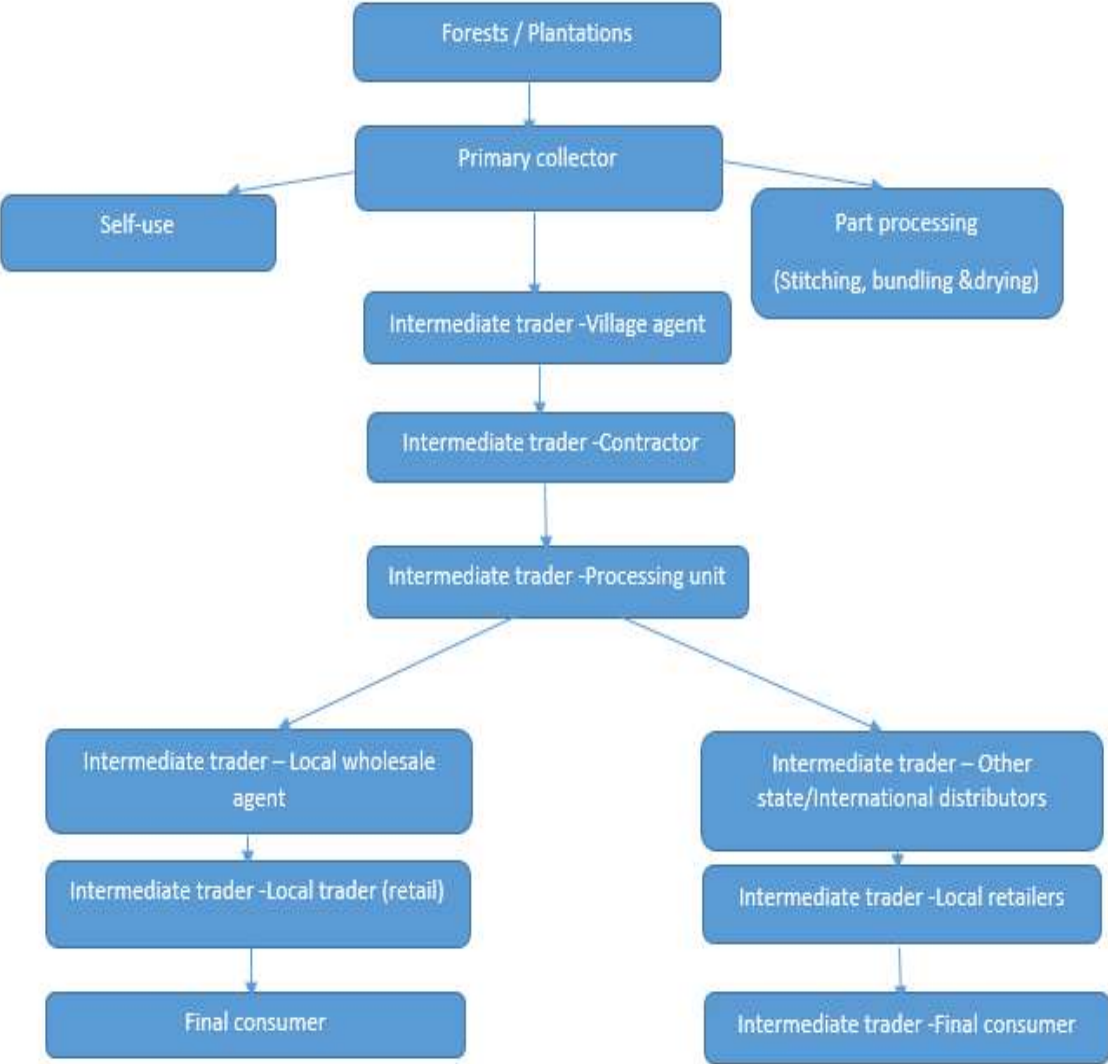


Figure 12 - Product logistical chain.

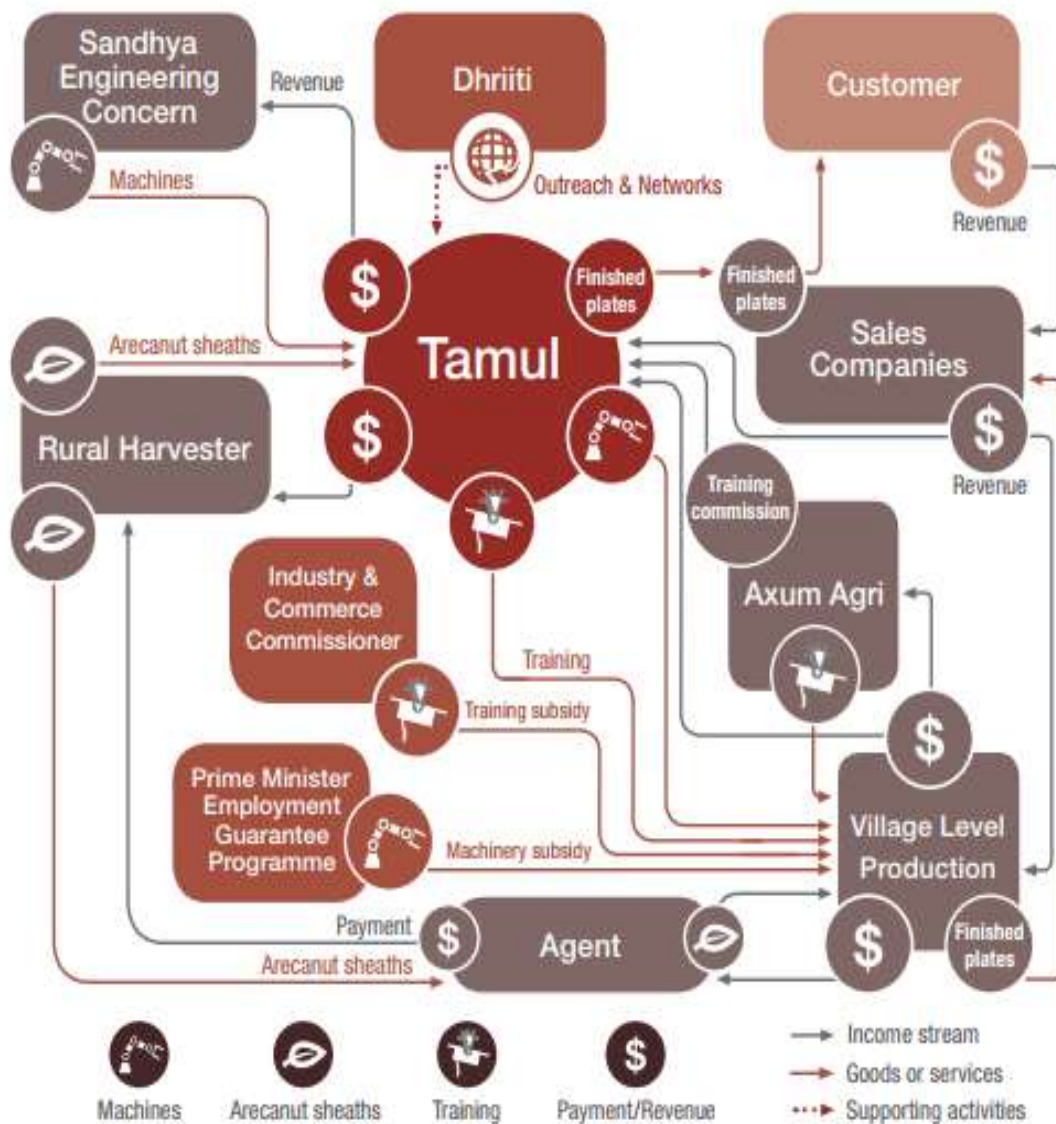


Figure 13 - Stake holder model from Tamul a palm plate company, Image credits: 2013 SEED Winner – India. Seed case studies: Insights into entrepreneurial solutions for sustainable development

4. Design for the Current Market

This chapter discusses how new and renewable materials can be used in cutlery and crockery industries to obtain more sustainable products, and the possible designs.

4.1. Containers and wraps

The main material used here is areca nut sheath/Sal leaf for boxes, cups and containers. An example is a normal sized standard hamburger bun with dimensions: 2.5 centimeters in height and 12 centimeters in width (Diameter) and 75 grams in weight, as shown in Figure 14a. An ideal box would be about 13 centimeters in length and breadth with the top part of the box, being 12 centimeters in width. The height of the box is approximately 6 centimeters. Depending on the size of the hamburger, the sizes could be altered and tweaked. A cone made from palm areca sheath or Sal leaves is represented in Figure 14b.

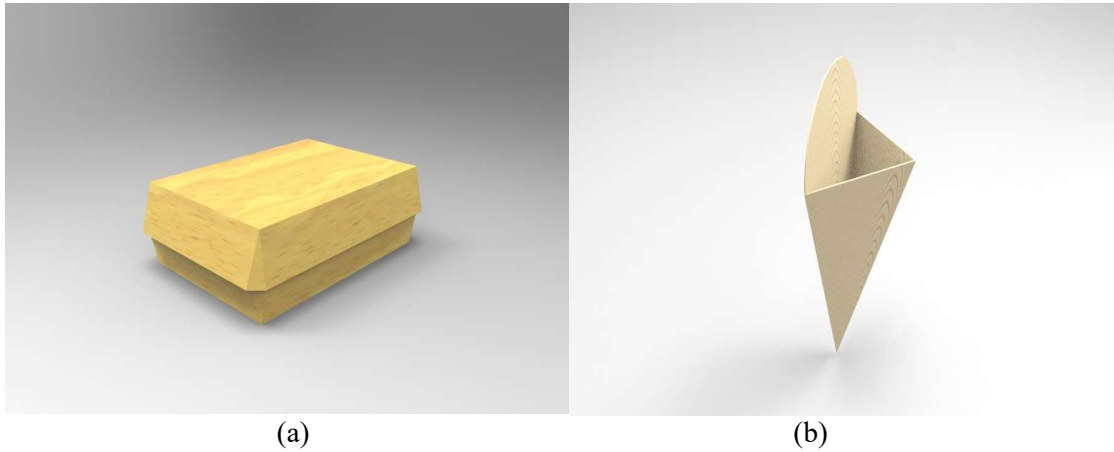


Figure 14 - (a) Burger box /box from Palm areca (b) A cone from palm areca

The wraps could be from banana fibre paper; to make them water proof to a certain extent, a wax coating could be provided. Sal leaf wraps can also be used for making wraps for the hamburgers as they are an excellent alternative to the banana fibre paper.

Areca nut 100 ml cups could be used for providing ice creams and smaller ones (15 ml) for sauces and dips. Normal containers of 500 ml to 1 litre can also be made using palm areca. Cubic and cuboid boxes both open and closed can be made using this material. An example is presented in Figure 15. It is like take away carton containers from fast food chains.

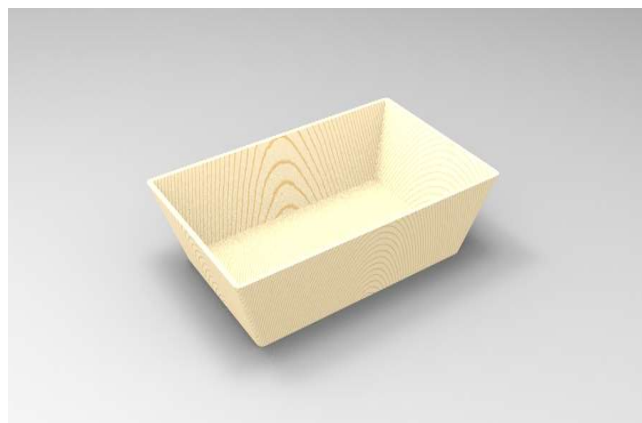


Figure 15 - Palm Areca container

4.2. Take away cups, plates and bowls

The main materials used here would be again areca nut cups, that would have capacities from 180 to 330 ml. In this study, 250 ml plastic would be used, as shown in Figure 16a. Plastic cups would be considered as they are used in most festivals and other events. The dimensions are as follows: top diameter 7 cm, height 9 cm and bottom diameter 4.5 cm.

Initially the cups are cut and then pressed. They are then sealed using bio resins / natural gum extracted from plants. Plates are also made from areca sheaths with dimensions for comparisons of plastic cutlery and crockery standard plastic containers and aluminium foil containers of 500 ml capacity, 4 inches and 8-inches diameter plates are considered), as shown in Figure 17b.



Figure 16 - (a) model for a palm areca cup (b) Finished plates and containers

Reusable cups made of coconut shells are approximately 250 to 350 ml in size, and they can be used in restaurants. Two examples, one using Sal leaves and the other based on coconut shells, are presented in Figure 17. They naturally vary in diameter and height, but portions of equal or similar sizes can be sorted. They can be used from 50 to 100 times making them perfect alternatives for PET cups, available in stores. Ladles are produced using imperfect or damaged shells, one side of the shell is attached with reclaimed wood.

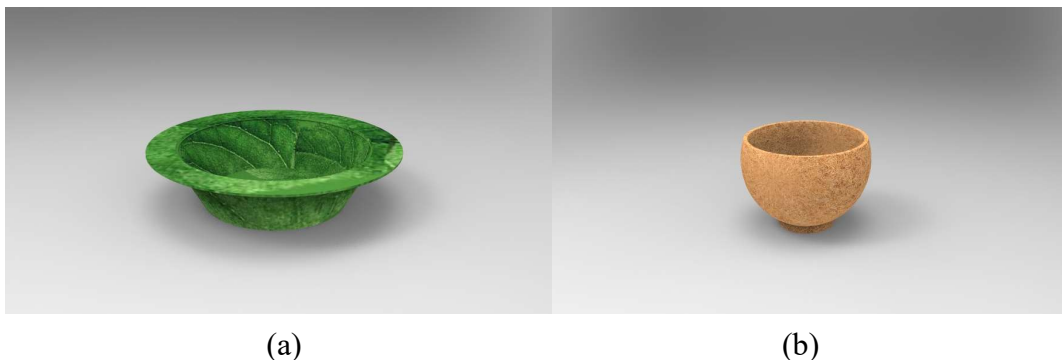


Figure 17 - (a) Sal leaf cup design (b) Coconut cup design

4.3. Coconut fiber sponges

A normal synthetic fiber sponge for cleaning surfaces and dishes is made from polyurethane

or cellulose, in most cases with dimensions of 7 cm × 5 cm × 2 cm. The same dimensions are considered for making coconut coir sponges using retted soft coir as shown in Figure 18. They have the same usage as the synthetic sponge but are eco-friendly and can be washed and used for growing plants after their life. They also can be incinerated, unlike plastic that needs to be treated or recycled. Data regarding synthetic sponges was unavailable.



Figure 18 - Design of the coconut fiber sponge

5. Life Cycle Assessment

5.1. Introduction

Life Cycle Assessment (LCA) is the currently leading methodology to quantify and/or compare the environmental impacts of producing, using and disposing of a product or providing a service throughout its life cycle. In other words, LCA identifies the material and energy usage, emissions and waste flows of a product, process or service over its entire life cycle to determine its environmental performance. Although there are no mandatory rules or requirements to perform a LCA study, normally the framework defined in the ISO standards ISO 14040 and 14044 [24-25] will be considered in this work, as they are consensual and widely used in practice. Besides supporting the work and calculations performed in a LCA study, they also allow a direct comparison between studies and the identification of hotspots for improvement. A complete description of the LCA methodology is beyond the goals of this study, and can be found elsewhere [26-27].

In this work, a LCA study of the production of plates, cups, wraps, boxes, containers, bowls and sponges produced using waste materials obtained from the processing of agricultural products areca Palm sheaths, Sal leaves, coconut coir and banana fiber, will be performed. These materials are widely available in the Southern part of the Indian subcontinent, and their utilization represents an opportunity to valorize a residue, while producing goods that should be more sustainable, when compared to existing products currently used and

produced using non-renewable resources. Whenever possible primary data is used combined with data from Life Cycle Inventory databases.

5.2. Goal of the study

The goal of this study is to assess the potential life cycle environmental impacts of various alternatives to currently used disposable cutlery and crockery, and a few products from the home industry. A comparison with existing products will be performed if data and results are available, those based on paper or plastics. The target audience for the report are the interested parties (stakeholders) such as fast food chains and retailers, environmental organizations, consumer organizations, as well as consumers themselves.

5.3. Scope

The scope of this work is to study the life cycle of the disposable cutlery and crockery products made from the materials suggested above and compare it with plastic and cardboard products existing in the. Ranging from material collection and transportation to processing facilities, including production and distribution to bulk consumers, and final disposal.

5.3.1. Functional unit

A comparison of life cycle environmental impacts of a product must be based on a comparable basis (the functional unit) to allow a fair comparison of the results.

The functional unit considered in this work is one ton of material shipped to Portugal. This represents several different total numbers of single elements produced since the amount of raw materials involved and the type and form of processing is different between them. In Table 1 the total number of elements corresponding to the functional unit is given.

Table 1 - Number of elements corresponding to the functional unit chosen in this work

Raw material	Product	Functional unit (Pieces/ton)
Areca palm nut sheath	Burger boxes / Boxes-Closed (500 ml)	16667
	Plates (20-25 cm dia)	25000
	Cups / Bowls(6 cm dia)	62500
	Open boxes(500 ml)	33334
Coconut shells	Halves(270 to 450 ml)	10000
Coconut coir	Ropes	one ton
	Sponges (6×5×3 cm ³)	25000
Sal leaves	Flat plates / Wraps (20 cm dia)	66667
Banana pulp	Paper wraps (30×20 cm ²)	22222

5.3.2. System Boundaries

The system boundaries include all significant life cycle stages from raw material extraction, manufacture, distribution use and reuse to the final management of the material waste. The boundaries are established to include all inputs and outputs of the system. The flows considered are materials or energy entering the product life cycle, and the emissions and waste generated. In this work, a cradle-to-gate study was performed, considering all life cycle stages and transportation steps from obtaining/extraction of raw materials to final disposal, as shown in Figure 19.

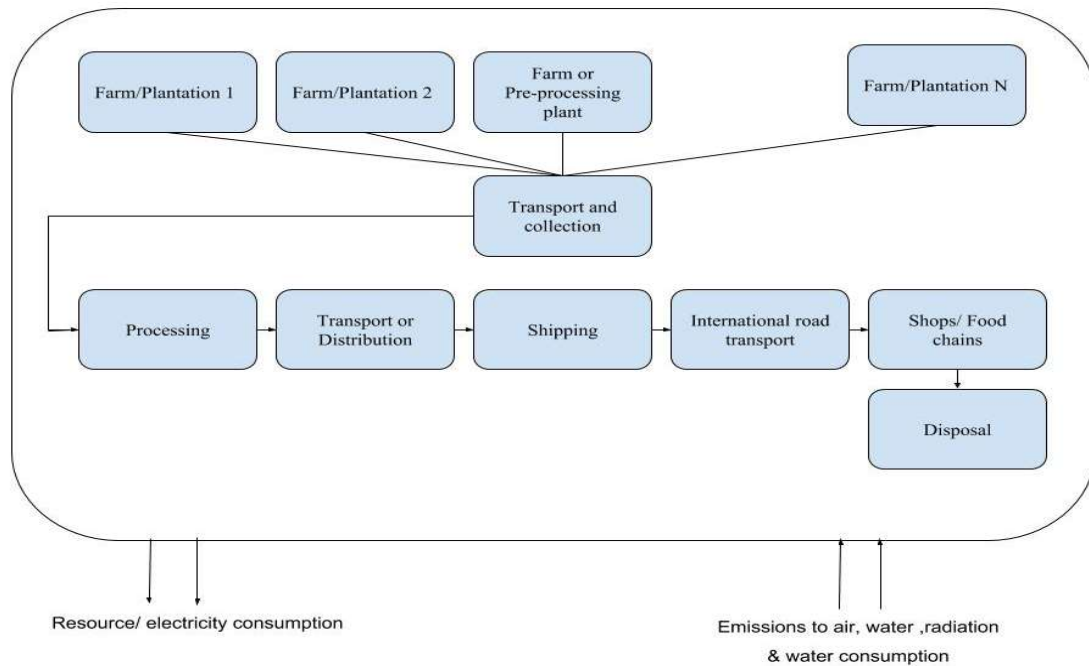


Figure 19 - System boundaries (simplified)

5.3.3. Processes included

According to Figure 19 and the availability of data/information, the following processes were considered in the LCA study:

- *Extraction/production of raw materials.* In this process, it was included the extraction of raw materials necessary to produce the products considered in this work, including forestry and agriculture practices, and the preprocessing of the raw materials.
- *Packaging.* Primary packaging was included in the transportation of each final products considered in this work. Secondary packaging (used for the distribution of the products from the importer to the supermarket distribution center) has been excluded due to consignments, being a mix of different supplies, depending on the needs of the client. Pallets have also been excluded due to lack of data about their material and reuse rates.
- *Production processes.* The conversion of the raw materials into finished products is included in the study, including energy consumption by the machines. It was assumed that raw materials and product losses are minimal, thus they were considered in the calculations.
- *Impact of cardboard boxes for transport:* The number of cardboard boxes were calculated accordingly for each product and a weighted average was taken to obtain the average impact. The data for the boxes were taken from a study made on corrugated cardboard boxes used for vegetables and fruits. Two types of boxes weighing 0.823 kg and 1 kg were considered for transportation [28].
- *Transport.* Several transportation steps are considered between the various life cycle stages. They include the transport of materials from their producer to the processing centers, the transport of the finished products from the manufacturer to the importer; the shipping to Portugal of 12320 kilometers and then to supermarket/client is included. Transportation by a municipal waste collection vehicle to a waste management facility has not been included due to lack of data.
- *End-of-life.* The management of wastes is included in the study. The choice of end-of-life process reflects the realistic options for the products, the most sensible being burning for energy production or landfilling. Twenty percent of incineration and eighty percent landfilling was considered. Recycling and composting has not been included as not enough data was found to support this process.

5.3.4. Excluded processes

Certain elements of the life cycle have been excluded, to ensure that the scope of the study remains feasible, due to the unavailability of data. Thus, the following materials and processes have been excluded from this study:

- *Inks/ dyes.* These materials are used to print the design/brand on each carrier and have been excluded from the study due to lack of information about the inks and dyes used and the small quantities required;
- *Retail storage of the carrier bags.* Any environmental impacts associated with storage activities at raw materials extraction and pre-processing sites, manufacture units, the importers and supermarkets have been excluded;
- *Transport from the supermarket to the consumer.* Consumer transportation to and from the supermarket with the carrier bags has been excluded from the study, because the weight of a carrier bag would have little or no effect on vehicle emissions and fuel efficiency. Moreover, wide variations in distance travel and means of transportation make it impossible to define an adequate value for the total distance travelled;
- *Equipment and Buildings.* The environmental impacts linked with the construction and demolition of buildings, and the manufacture of machines, equipment and vehicles should in effect be depreciated over the whole of their period of use. These impacts are negligible when compared to the operational burden. Therefore, the construction, maintenance and demolition of industrial buildings and the manufacture of machines, equipment and vehicles have been excluded from the data used in this study.

5.3.5. Data sources

A mix of primary data and secondary data obtained from the Eco Invent V2.1 life cycle inventory database, available in version 7.3.3 of SimaproTM was used in this work. The primary data regarding the process were obtained from the self-help groups and cottage industries who work with these kinds of materials.

The materials are extracted and processed in India, especially in the state of Tamil Nadu. No

datasets were identified for India in terms of the whole cycle. Thus, European average data was used, instead for the systems by adapting the values to the country of origin. The energy supply mix was taken from the state of Tamil Nadu.

5.4. Inventory analysis

Inventory analysis was carried out in several steps considering the life cycle stages included in this work. Almost all the products discussed have similar methods of production, therefore no separate analysis for each one will be presented.

5.4.1. Prime material extraction

The raw materials are generally harvested by hand, collected and stored. The only energy spent is manual labour. The raw materials obtained are a by-product of the cultivation and maintenance of the plantations. Thus, the potential environmental impacts due to the cultivation and maintenance of the trees or cultivars was not considered. People use their own transport methods, as they live generally in locals situated near the plantations. They walk to the site or they use bicycles for transport. The impact of these transportation means is minimal and was not accounted for. In some cases, some energy is accounted for pre-processing example, dehusking coconuts using a husking machine.

5.4.2. Transportation

The extracted materials are bundled and tied together using hand drawn coconut coir ropes, and then shipped for distribution. Usually minivans are used for transportation within the state or district. We assume that a ton of the material is transported in each trip for an average distance of 100, 150 & 70 kilometres for Palm areca products, coconut shell and coir products and Sal products, respectively. The emission norms of India are based on the European standards. Currently most of the vehicles are running on Bharat Stage (BS) IV standards, which has similar regulations to that of Euro IV [29].

5.4.3. Processing

Ground water drawn from wells is used to soak the materials, if needed, or they are retted in tanks of salt water near back waters or in back waters for several months. Since no data is available and the impacts are small, these impacts were not considered. The water that is used for soaking is used again several times, and if fresh water is used, it can be re used for

watering the plants and cleaning. If the processing methods are small scale and distributed in several villages, the impact would be low as the amount of water drawn from a single point would be very low. Considering the following information, we conclude that the impact with regards to water is low. The next step in processing would involve pressing/spinning /stitching and cutting. If heated presses are used they reach anywhere between 60 to 80 degrees. Palm areca products are pressed and cut using machines operated using three phase electricity that operates on 5.5 kW, Sal leaves are manufactured using semi-automated machines that use mechanical power. Coconut husks are dehusked using a machine that runs on 3.7 kW three phase electricity followed by pressing and cutting using a machine that operates on 18.5 kW, the loose coir can be also be spun into ropes using a machine that uses 2.24 kW for spinning. The coconut shells are polished using a small motor run machine that consumes about 0.25 kW. The banana paper is made from a unit that uses two machines that consume 4.5 kW for cutting and blending the mixture. Hours required to produce the functional unit of each product are mentioned in the annex.

5.4.4. Transportation and shipping

The processed materials are then packed and bundled as hundreds, tied down using coir ropes and then transported across the country through open mini vans, in boxes. Some agencies export them abroad, usually by ship. The minivans travel an average of 200 kilometers for all products except for Sal leaf wraps / plates / bowls, which travel 300 kilometers. A corrugated cardboard box of 0.823 grams is taken into consideration for the materials. Palm areca plates are shipped in a box of different dimensions, weighing 1 kg and the impact is extrapolated accordingly.

For international shipping, 12320 kilometres was considered for shipping to Portugal (Lisbon). Once in Lisbon they should be shipped throughout Portugal, assuming an average distribution distance of 100 km is considered since most of the population is near the coastal regions.

5.4.5. End of life cycle / disposal

The products are biodegradable and they could be collected to grow mushrooms or used as cattle fodder/gardening. In practice, they are collected and incinerated or disposed of in landfills. It was assumed 20 percent incineration and 80 percent land filling, valid for Portugal. Transportation from trash collection to points of incineration and landfills was also

included.

5.4.6. Energy mix

The electricity energy mix in the state of Tamil Nadu was used. The energy mix of Tamil Nadu is a mixture from state, central and private energy sources, and it is shown in Figure 20. To calculate the impact due to electricity the energy mix was considered, and the impact of all the types of electricity and a weighted average was taken, and the impact was calculated accordingly [30].

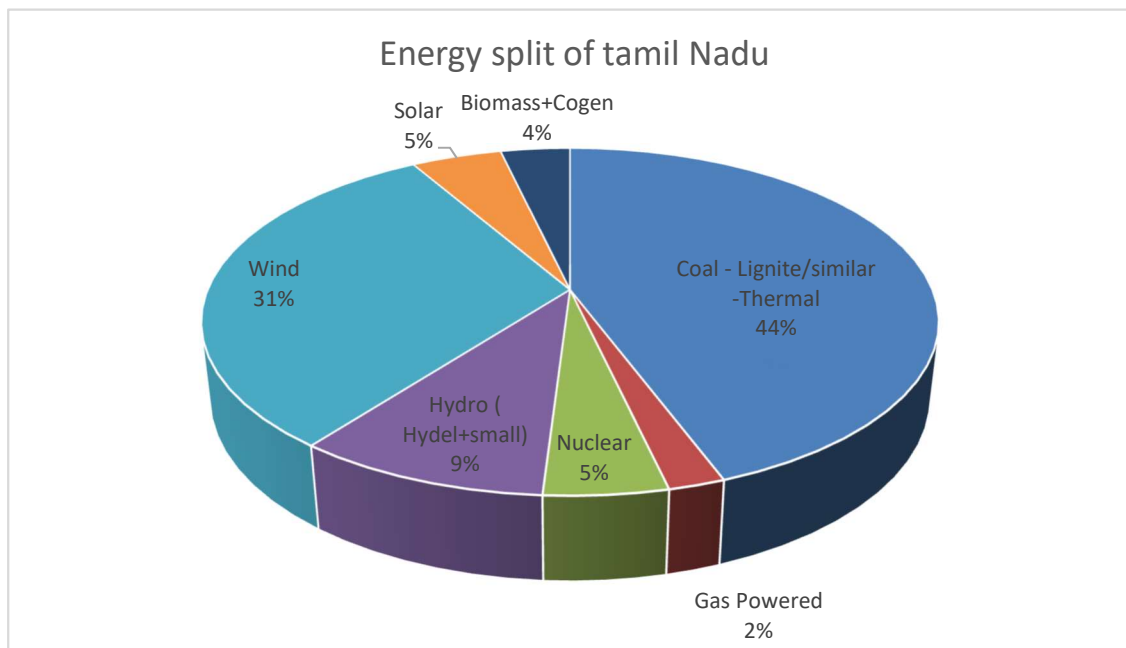


Figure 20 - Electricity energy mix of Tamil Nadu from the Power for All publication 2016

5.5. Environmental Impact Assessment

To assess the potential environmental impact the CML 2000 methodology was used [31-32]. The following environmental indicators were selected in this work, and the set include most of the indicators used in practice in LCA studies or products or services.

- *Global warming potential*: The Global warming potential, GWP, is a measure of total emissions greenhouse gases (for example, CO₂, methane, nitrous oxide). GWP is measured in terms of CO₂ equivalents. It is relevant in this work as the transportation steps and the machines energy consumption in processing is relevant;
- *Depletion of Abiotic Resources*: This impact category refers to the depletion of nonliving (abiotic) resources such as fossil fuels, minerals, clay and peat. Abiotic

depletion is measured in kilograms of Antimony (Sb) equivalents. As fossil fuels are used this indicator is relevant;

- *Photochemical oxidation:* The formation of photochemical oxidant smog is the result of complex reactions between NO_x and VOCs under the action of sunlight (UV radiation), which leads to the formation of ozone in the troposphere. It is measured using photo-oxidant creation potential (POCP) which is normally expressed in ethylene equivalents. As fossil fuels are used, this indicator is relevant;
- *Eutrophication:* This is caused by the addition of nutrients to a soil or water system which leads to an increase in biomass, damaging other lifeforms. Nitrogen and phosphorus are the two nutrients most implicated in eutrophication. Eutrophication is measured in terms of phosphate (PO₄³⁻) equivalents;
- *Acidification:* This results from the deposition of acids which leads to a decrease in the pH, a decrease in the mineral content of soil and increased concentrations of potentially toxic elements in the soil solution. The major acidifying pollutants are SO₂, NO_x, HCL and NH₃. Acidification is measured in terms of SO₂ equivalents;
- *Toxicity:* Toxicity is the degree to which something can produce illness or damage to an exposed organism. There are 4 different types of toxicity: human toxicity, terrestrial ecotoxicity, marine aquatic ecotoxicity and fresh water aquatic ecotoxicity. Toxicity is measured in terms of dichlorobenzene equivalents.

5.6. Results

This section presents and discusses the results obtained of the various environmental impacts for the several products considered in this work. Both single product and comparison between similar products made with different raw materials will be considered here.

In Figure 21 to Figure 27 the relative importance of the various life cycle stages for the various environmental indicators considered for each of the various products considered in this work are presented. From the figures, it is possible to identify which are the life cycle hotspots, which process is more relevant to each environmental indicator that should be considered first for improvement, thus supporting decision making.

Transportation and shipping are the main contributors to each environmental impact category. The utilization of vehicles with larger capacities, or using renewable fuels, or a more efficient logistical system, in the acquisition of the raw materials, may help reduce significantly the environmental impacts due to transportation and shipping. Other possibility involves processing the raw materials as close as possible from plantations.

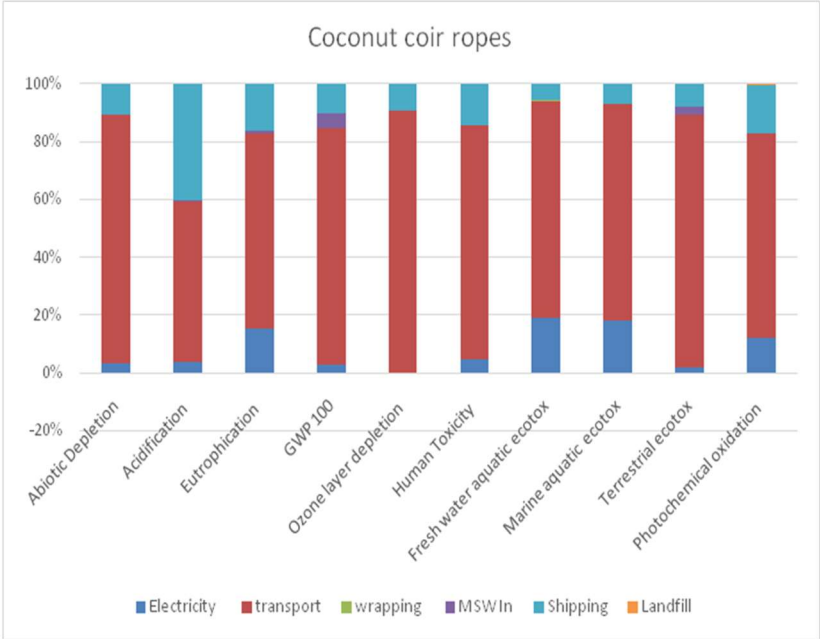


Figure 21 – Environmental impacts for each life cycle stage for coconut coir ropes

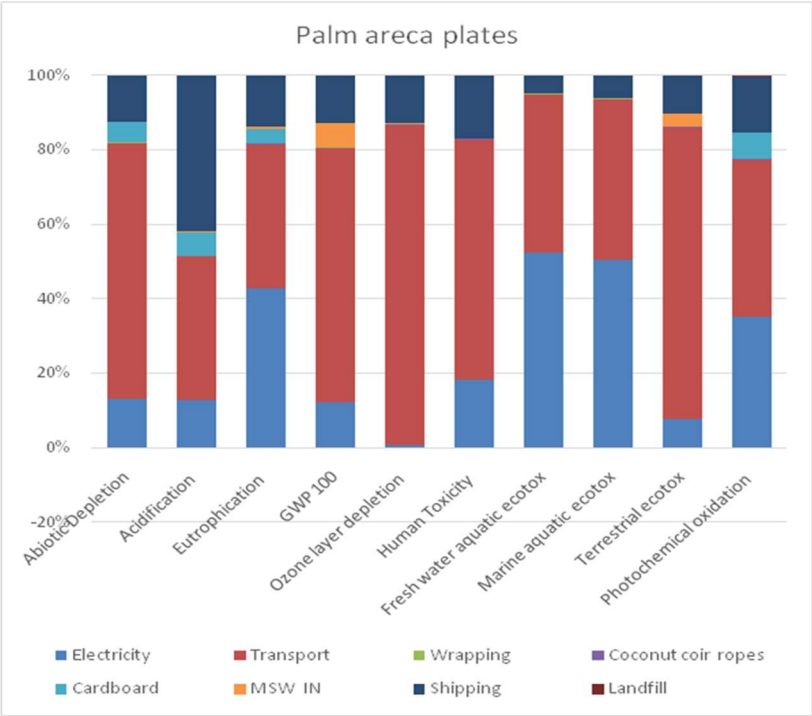


Figure 22 - Environmental impacts for each life cycle stage for palm areca plates

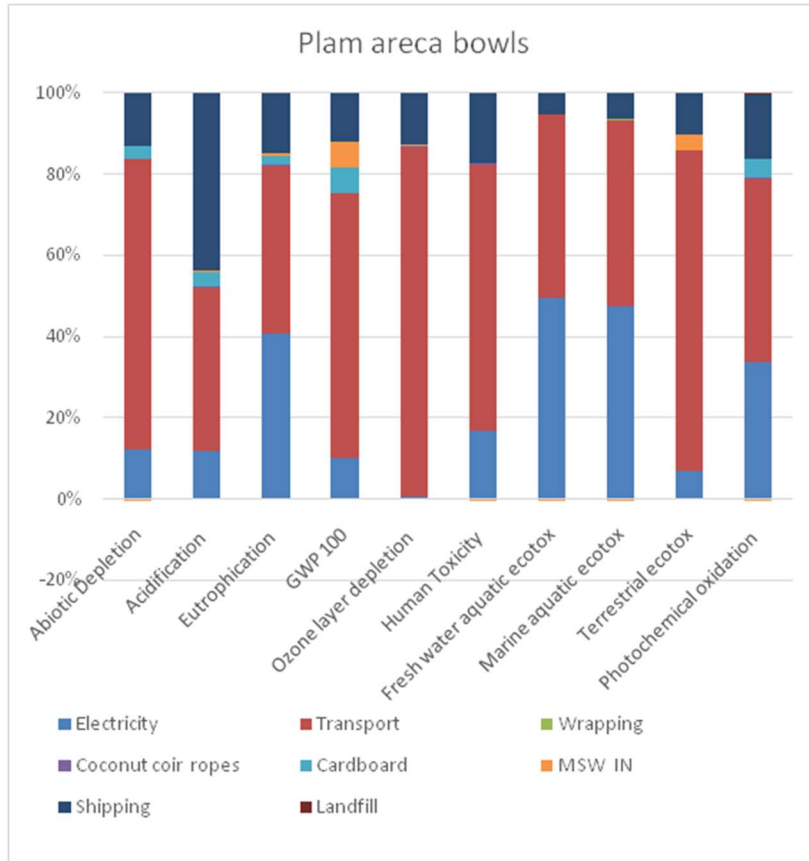


Figure 23 - Environmental impacts for each life cycle stage for palm areca bowls

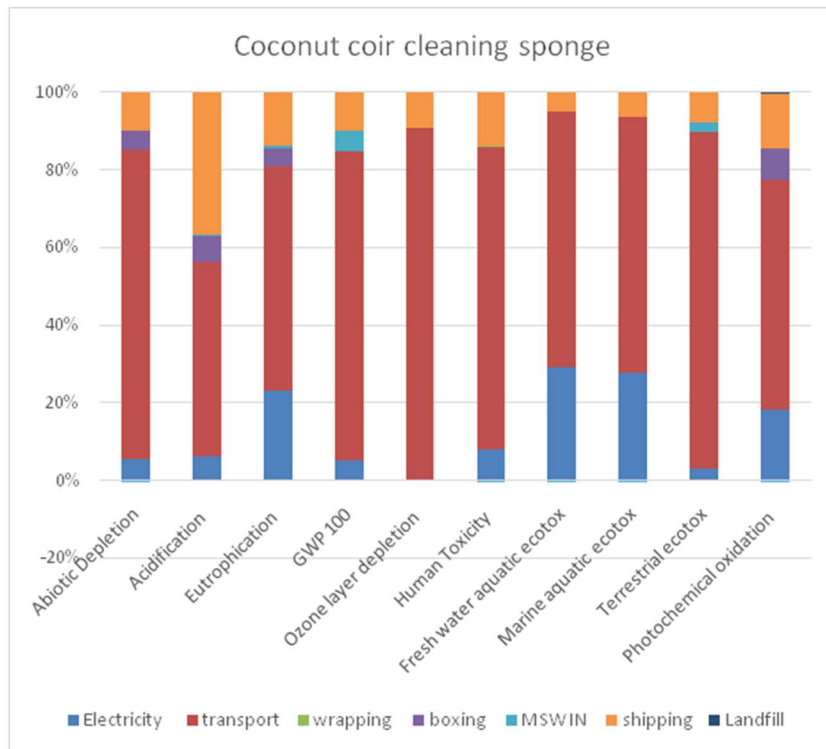


Figure 24 - Environmental impacts for each life cycle stage for coconut choir sponges

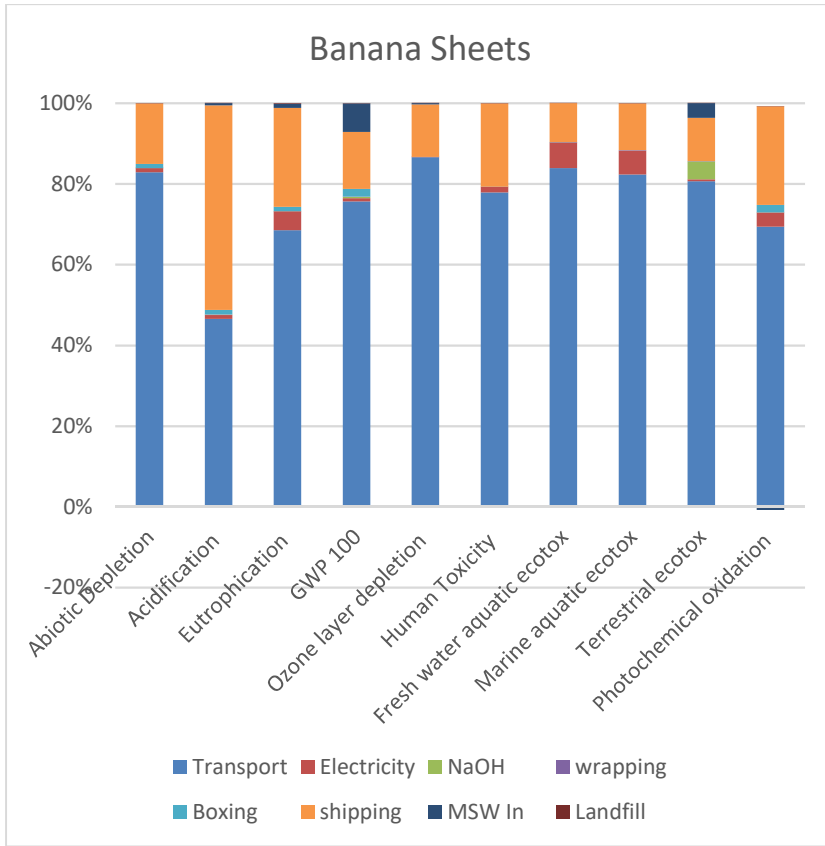


Figure 25 - Environmental impacts for each life cycle stage for banana sheets

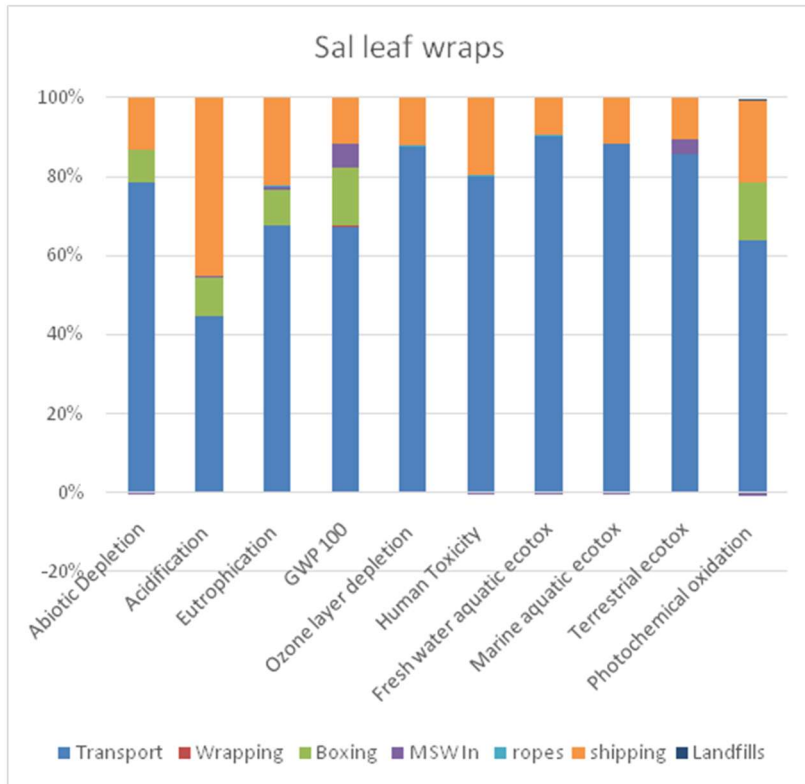


Figure 26 - Environmental impacts for each life cycle stage for coconut shell cups

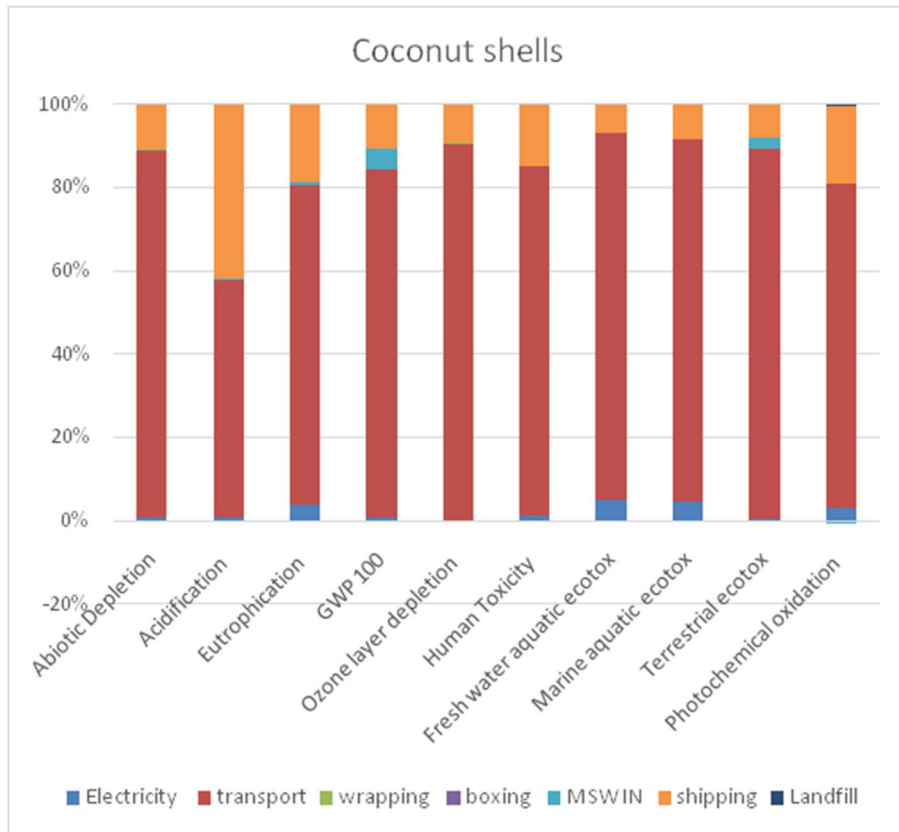


Figure 27 - Environmental impacts for each life cycle stage for coconut bowls

Small variations between the relative importance of the various life cycle stages can be seen between the various products. They are mainly due to differences in the production process, machinery used to process the raw materials and obtain the final products.

Table 2 indicate the results obtained from the life cycle analysis for the products and shows us the values in comparison with other materials. Some of the product's impact seem to be a bit higher than that of the conventional products, especially sal leaf wraps and flat plates in comparison with magazine paper, the impact of this product can be reduced greatly if procured and transported in bulk or when transported through trains from the points of production to the points of export. This could not be considered in this analysis due to the complexity of the process

Table 2. Impact values of the various materials considered

Impact	Unit	Magazine paper	Banana wraps	Sal leaf wraps/plates	Palm boxes	Cardboard box
Abiotic Depletion	kg Sb eq	Not available	2.53E-06	0.000100107	4.38E-04	0.000749651
Acidification	kg SO ₂ eq	0.003066667	2.48E-06	9.68E-05	4.32E-04	0.000519269
Eutrophication	kg PO ₄ eq	0.0000185	2.70E-06	2.13E-05	1.56E-04	0.000271869
GWP 100	kg CO ₂ eq	0.00765	3.45E-04	0.017010725	7.07E-02	0.113697606
Ozone layer depletion	kg CFC-11 eq	6.42E-10	2.41E-12	1.84E-09	6.95E-09	5.56E-09
Human Toxicity	kg 1,4-DB eq	Not available	2.68E-04	0.006908579	3.37E-02	0.055493039
Fresh water aquatic ecotox	kg 1,4-DB eq	Not available	4.35E-04	0.002316579	2.12E-02	0.018339193
Marine aquatic ecotox	kg 1,4-DB eq	Not available	8.69E-01	4.968627315	4.37E+01	79.64985933
Terrestrial ecotox	kg 1,4-DB eq	Not available	6.20E-07	4.42E-05	1.84E-04	0.000490151
Photochemical oxidation	kg C ₂ H ₄ eq	4.73E-05	6.05E-07	6.58E-06	4.11E-05	4.30E-05
Impact	Unit	Coconut sponge	Shell cups	Plastic plates	Palm plates	Palm cups and bowls
Abiotic Depletion	kg Sb eq	3.61E-04	8.15E-04	2.134844475	2.81E-04	9.02E-05
Acidification	kg SO ₂ eq	3.16E-04	6.98E-04	0.40978921	2.78E-04	8.88E-05
Eutrophication	kg PO ₄ eq	9.16E-05	1.72E-04	0.261561572	9.17E-05	2.86E-05
GWP 100	kg CO ₂ eq	5.27E-02	1.26E-01	Not available	4.13E-02	1.45E-02
Ozone layer depletion	kg CFC-11 eq	6.53E-09	1.63E-08	7.46E-08	4.62E-09	1.54E-09
Human Toxicity	kg 1,4-DB eq	2.60E-02	6.05E-02	0.649896947	2.12E-02	6.92E-03
Fresh water aquatic ecotox	kg 1,4-DB eq	1.17E-02	2.17E-02	2	1.21E-02	3.79E-03
Marine aquatic ecotox	kg 1,4-DB eq	6.11E+05	4.62E+05	0.709514182	2.50E+01	7.86E+00
Terrestrial ecotox	kg 1,4-DB eq	4.02E+00	3.91E+00	0.000134245	1.19E-04	3.94E-05
Photochemical oxidation	kg C ₂ H ₄ eq	6.52E-01	4.95E-01	0.027728679	2.47E-05	7.66E-06

5.7. Comparison with commercially available products

Following the definition of functional unit, when performing a comparison between different products, it is important to ensure that they perform the same tasks, either between the products considered in this work as the with other commercial available products. Thus, three comparisons were performed:

- Comparison between boxes made of palm areca and cardboard
- Comparison between wrapping materials, in this case banana sheets, sal leaf warps and paper.
- Comparison between plastic plates and palm areca plates.

5.7.1. Box comparison

Figure 28 compares the values of each environmental impact normalized by the largest value. The results show that palm areca boxes have lower environmental impacts when compared with cardboard boxes in most categories, with differences that can larger than 40%, as for example in the global warming potential and abiotic depletion. For two categories, ozone layer depletion and fresh water aquatic toxicity palm areca have larger impacts that may due to the energy mix and transportation means considered in the calculations. When transported in bulk it is expected that impacts will be lower for a single product, and could it can be argued that the differences will be much more significant than observed in Figure 28.

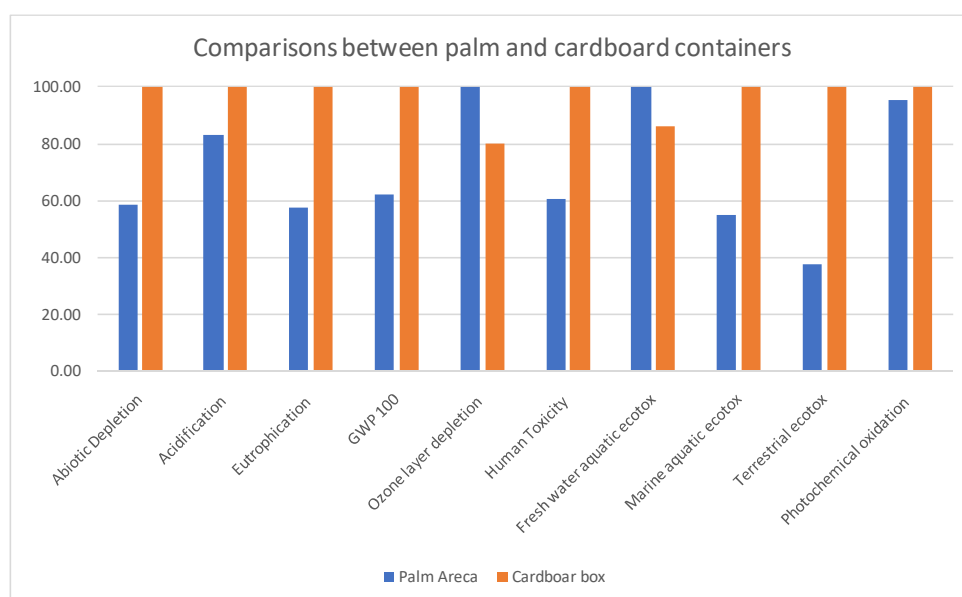


Figure 28 - Comparisons between palm areca boxes and cardboard boxes with plastic film.

5.7.2. Comparisons with wrapping materials

Magazine paper was considered to make the comparisons with banana paper and sal leaf wraps. The data available in the Printing & Writing Papers Life-Cycle Assessment Summary Report was considered. Magazine paper was considered as it was the closest to any wrapping paper in terms of thickness and material [33].

Figure 29 shows the results show the results of the comparison. For some environmental impacts, it is not possible to include in comparison magazine paper, as their values were not reported. Banana sheets are material with lower environmental impacts, when compared with Sal leaves wrap that are worse when compared with magazine paper. This is mainly due to the processing of the banana sheets that only involves manual labour without the use of much machinery, in which case the environmental impacts of energy production and emissions and impacts are minimal. It could be argued that banana papers seem to be less impactful, if done on a large scale they must be completely mechanised, resulting in a large impact compared to Sal leaves. The impact of Sal leaf wraps can also be brought down by transport through freight train which is the most popular method, the impact for this mode of transportation would be negligible and hence make it much more eco-friendly compared to magazine paper

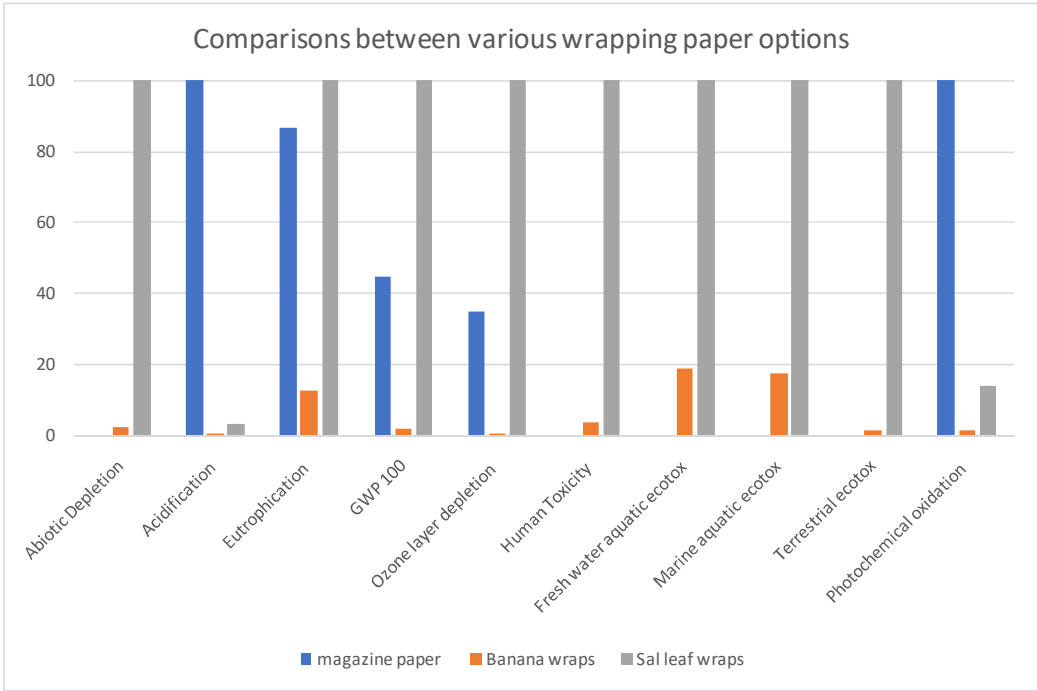


Figure 29 - Comparisons between polished magazine paper, Sal leaf wraps and banana sheets for wrapping

5.7.3. Comparisons with plates

Plastic plates are compared with palm areca plates in Figure 30. GWP was not considered, as the study used in the comparison report GWP20 and not GWP100 [34]. It can be concluded that for most environmental indicators the palm areca plates are clearly better than plastic plates. The exceptions are the ozone layer depletion and terrestrial ecotoxicity categories. Considering that the analysis for plastic plates excludes the impact of producing plastic from crude and transport of crude oil from the extraction points and refining the crude, it can be argued that the impact of the plastic plates would be much higher with their inclusion.

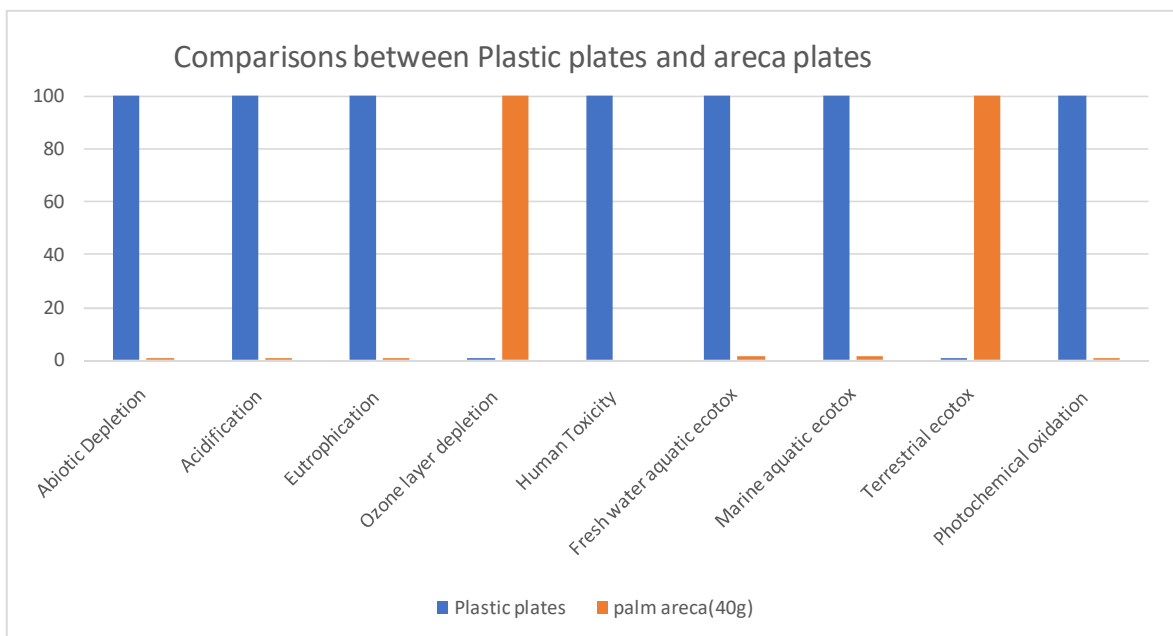


Figure 30 - Comparisons between palm areca plates and plastic plates

6. Business Plan

The introduction of any new or improved product or service in the market should be planned with care, to ensure its competitiveness and that a reasonable return of the investment is reached for the investment made. In this work, a preliminary business plan for the new products considered in this work is presented, considering its nature and target market, and using several tools/methodologies to fulfil this goal. This study would mostly examine the innovation, market, customer behavior, why products fail and several other factors. This would eventually draw an initial road map on how to capture the market or, in simple words, who to replace every disposable container with our product.

6.1. Introduction

Portugal has a population of 10.309 million (2016 estimate), with about 81.9% under the age of 65 [35]. Plastic cutlery and crockery has entered our lives in the form of disposable containers at shops and restaurants. It is estimated that a person in the USA uses an average of 500 cups and about 230 paper plates per year. [36] Assuming the same average for Portugal, and considering just 50 percent of the population under 65 use forms of disposable containers, around 2047.5 million disposable plastic/paper cups and 941.85 million paper/plastic plates a year would be used [36].

Most of these disposable materials are used only once and disposed of, many times directly

in the environment. Those which are put in the garbage are either incinerated or put in a landfill, resulting also in significant environmental impacts. Moreover, currently disposable containers are made using nonrenewable resources. Consumers are paying increasing attention to the environmental impacts resulting from the products they use or and/or consume, yet they are willing to change their way of life significantly to fulfill this goal. Thus, already used products need to be produced more efficiently, or renewable materials should be used instead. This provides us a huge business opportunity and also allows one to make earth a cleaner place to live in.

6.1.1. Innovation

Our products would be viewed as innovations and not as inventions. An invention is product creation; our product is an improvement on something that exists in the market. A more traditional definition of innovation is "an invention that is commercialized." Innovations can be broadly classified as:

- *Radical and incremental:* An incremental innovation is an improvement of an existing product whereas a radical innovation is often something completely new or substantially different with disruptive capabilities.
- *Radical/Disruptive Innovation:* For a product to be disruptive, it should have an impact on one or multiple market aspects: technology, business models, customer behavior, with the core focus on design and user experience.

The focus to make the product disruptive would be a key aspect in the business model. It would be based on a focus on sustainability and corporate social responsibility aspects, as shown in Figure 31.

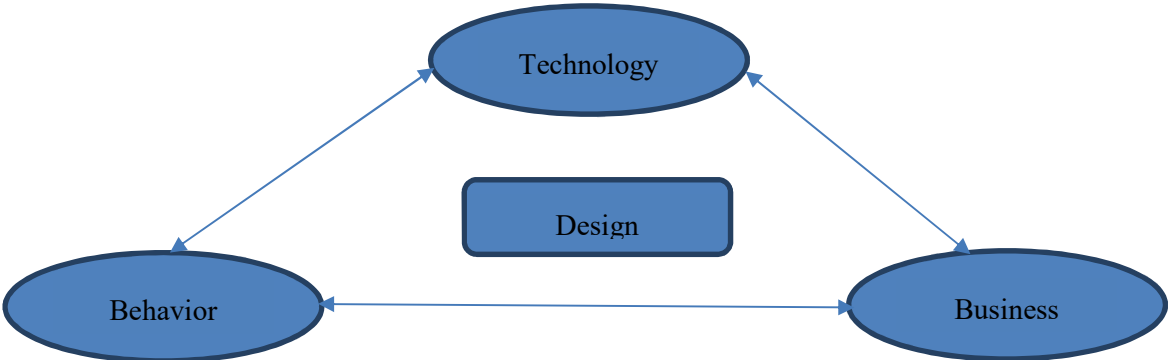


Figure 31 - Disruption factor model

6.2. What makes a product a hit?

6.2.1. Why most new products fail?[37].

Most of the new companies or products that are launched fail to make any significant impact. About 75% of consumer-packaged goods and retail products fail to make a profit in the first year. This is in part because of the intransigence of consumer shopping habits. The consultant Jack Trout has found that American families, on average, repeatedly buy the same 150 items, which constitute as much as 85% of their household needs; it's hard to get something new on the radar. Even bigwigs like P&G routinely whiff product rollouts. Less than 3% of new consumer packaged goods exceed first-year sales of \$50 million considered the benchmark of a highly successful launch. Moreover, products that start out strong may have trouble sustaining success [37].

This is mainly described by the 9× effect by Gourville, as shown in figure 29. Companies tend to overrate their products by a factor of three, and the customer tends to devalue the product or innovation by a factor of three leading to 3×3 effect, the main reasons behind these behaviors are presented in figure 29, are originated from the expected behaviors when faced to changes from the various economical agents involved. Even though the study 9× factor could be highly debatable, the factors that are mentioned are true. Upon thorough study of several products from many companies, there is a significant amount of evidence and truth behind how the customers and companies behave [38].

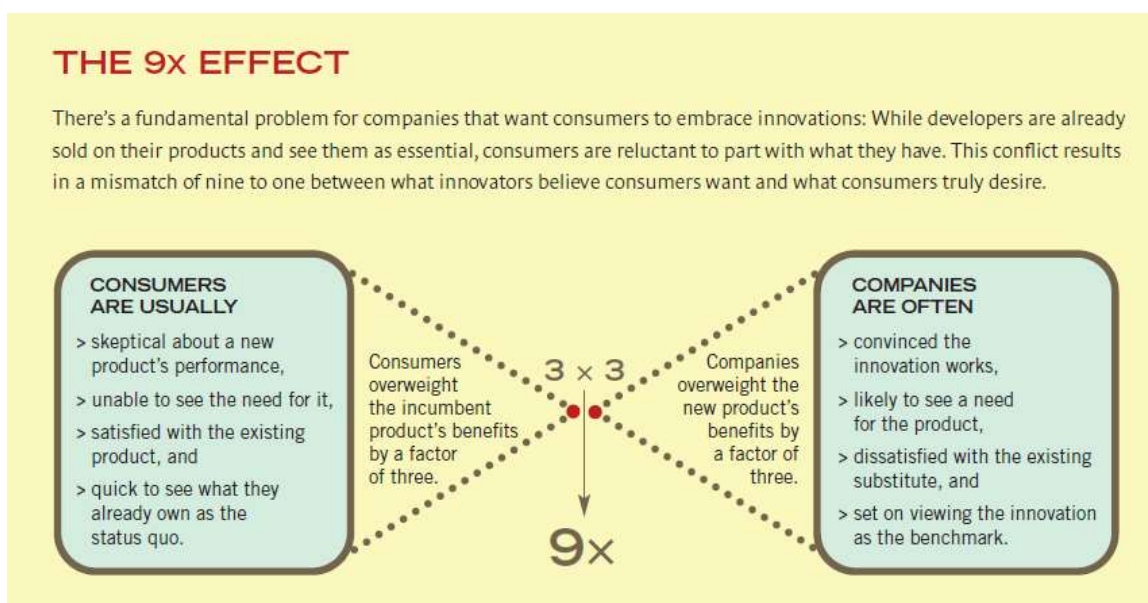


Figure 32 - The 9x effect explained by Gourville in Eager Sellers and Stony Buyers: Understanding the Psychology of New-Product Adoption. Harvard Business review, JUNE 2006

6.2.2. What makes our product a smash hit?

The way to tackle the resistance to change to a new process or to adopt innovation is either accept it or minimize it. Minimizing the resistance includes making behaviourally compatible products or finding believers for the product.

There is a wide range on where the product could end up even after the groundwork is done. Gourville’s behavioural framework [38] classifies a new product’s success or failure by grouping them under four categories, based on the amount of behavioural changes it might have on the customers with the other behaviourally compatible products in the market, and the product changes with respect to the existing products already available in the market.

One could say that upon analyzing the behavioral framework of the type of product that we offer, the product would fall under a smash hit as shown in Figure 33 [38]. This is because the product change that is present is radical in terms of the materials used with a simple design. The behavioral change that it brings is minimal because the products are simple cutlery and crockery with an emphasis on design and a newer material.

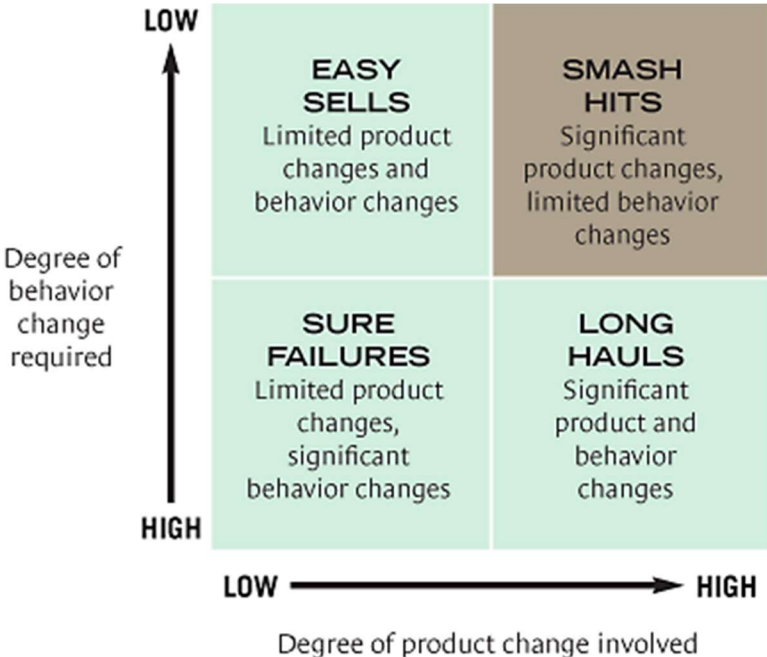


Figure 33 - Gourville’s Behavioral framework from Eager Sellers and Stony Buyers: Understanding the Psychology of New-Product Adoption. Harvard Business review, JUNE 2006

6.3. Market and crossing the chasm

A market is defined as the set of actual or potential customers for a given set of products or services who have a common set of needs or wants, and who reference each other when making a buying decision. The main issue when a product comes into a market is that it is not familiar to the potential customers. Hence, millions of dollars are spent on marketing. Making the product familiar involves several strategies, one of the most effective ways to capture the market is to find Believers in the market. This would give us a clear idea on whom to target first, how the market functions.

Many business plans are based on a traditional Product/Technology Adoption Life Cycle, in which the customers are divided in classes according to their behavior facing innovation and/or the introduction of new products: Innovators, Early Adopters, Early Majority, Late Majority, and finally Laggards [39]. In practice, the more appropriated way to develop a market is to work the curve from left to right, progressively winning each group of users, using each "captured" group as a reference for the next.

There are breaks in the curve, between each phase of the cycle, representing a disassociation between any two groups; that is, "the difficulty any group will have in accepting a new product if it is presented the same way as it was to the group to its immediate left." [39]. The largest break, so large it can be considered a chasm, is between the Early Adopters and the Early Majority, as shown in Figure 34. Many ventures fail trying to make it across this chasm. To cross the chasm Moore in his paper [39], advocates that a company focus on a single market, a beachhead, win domination over a small specific market and use it as a springboard to adjacent extended markets to win.

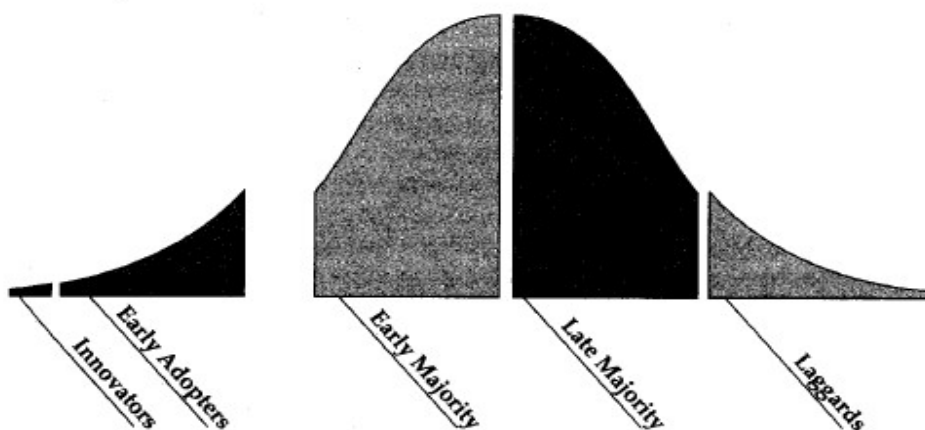


Figure 34 - Moore's representation of the product adoption cycle from his book, *Crossing the Chasm* 2001.

Briefly, the way to cross the chasm requires the following steps using the D day analogy for launching our product. Figure 35 represents all the phases that are described in detail below [39].

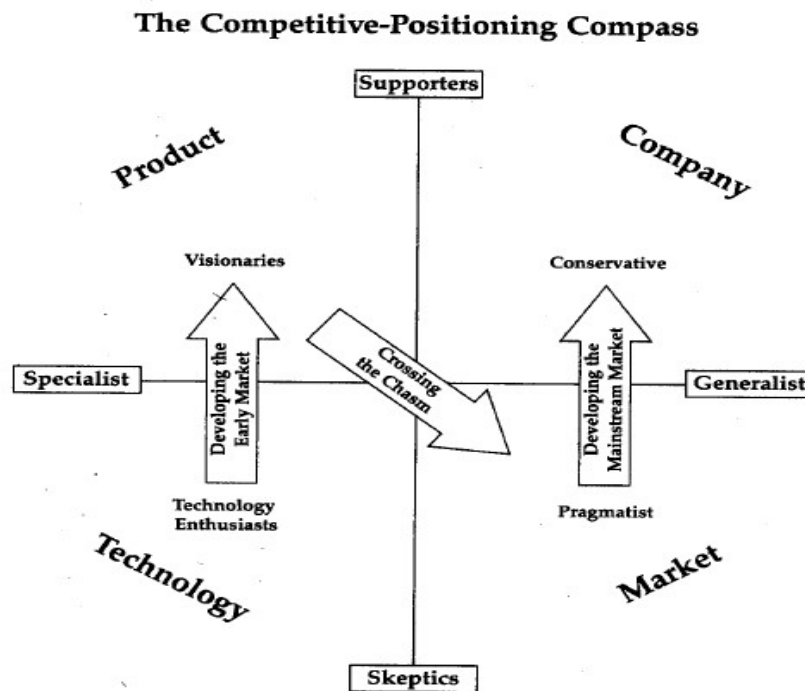


Figure 35 - A graphical version of crossing the chasm by Moore in his book, *Crossing the Chasm*, 2001

- *Target the point of attack:* "Target a specific market niche as your point of attack and focus all your resources on achieving the dominant leadership position in that segment." Includes identifying the primary market identifiers: target customer, reasons to buy, whole product and competition; and secondary market factors: partners and allies, distribution, pricing, positioning, next target customer. Early adopters would be the community who gives importance to sustainability and the environmental issues, and are trying to do something about it. Targeting the younger generations might be considered as an off move but could work wonders due to reference marketing and parties happening in the communities where our products could be promoted. Our identified niche would be through organic, vegan and ecofriendly stores /restaurants, with also a heavy emphasis on advertising on digital platforms.

- *Assemble an invasion force:* Create the whole product, the product should focus on tackling the consumer problems and the whole service should be centered around the product. Our motto should be to think as a customer and from there develop the overall package and the user experience. Our products would go hand in hand in helping maintain a clean environment and uplift local communities by actively engaging them.
- *Define the battle:* Create/Identify the competition, define positioning and segmentation, build this into all your company communications. [39]. Keep in mind competitors in every part of the customer curve, our main competition would be from plastic disposable cutlery and crockery. Secondary competition would be from paper cutlery and crockery (normal and recycled). From there, create the product on what a pragmatist buyer considers an overall package. Consider several a set of alternative ways of achieving the goal. The main advantage is the pricing of our products that could match other alternatives to cutlery and crockery. Moreover, they will represent products almost carbon neutral, eco-friendly, and that consider fair trade. Once our products convince the early majority the company would move ahead in getting certifications such as fair trade and ISO 14000, to better convince the next market segments. In this phase, the communications focus is on reducing the fundamental competitive claim to a two-sentence formula in every piece of company communication always be sure to reinforce the second sentence of this claim, the one that identifies your primary competition and how you are differentiated from it [39]. This will demonstrate the validity of your competitive claim (to conclude you are) the indisputable leader.
- *Launch the invasion:* distribution and pricing. The direct sales force is optimized for creating demand. At its center is the consultative salesperson who works with the client in needs analysis and then, supported by a team of specialists, develops and proposes solutions, which, after additional interaction with the customer, and a competitive procurement, turn into purchase orders. There would be a team of designers who would be working with our corporate clients to deliver solutions and another part where the customer/employee and stakeholder feedbacks would be considered and changes made accordingly [39].

One could conclude that the technology adoption life cycle could be applied to almost all the new and innovative products that are launched in the market. A perfect example would

be post it notes on how they crossed the chasm, they had found a niche market in the early majority- Offices and corporations and familiarized their niche through free samples. Once this was done they moved through the other niches of the early majority that caught on with the bulk of the market chain later because of customers referring to other people from niche markets.

6.4. Operations and maintaining success

There are several ways to bring a new product to market. It is here that most of the companies make mistakes and choose the wrong method, even if the product is exceptional and if the parent company has a sizeable chunk of the market share. One can classify them broadly in three ways: integrator, orchestrator and a licensor as shown in Figure 36 and as discussed by Andrew, J.R., Sirkin, H.L. in Harvard business review [40].

Since our business is based on suppliers, the model that would best suit us would be the orchestration model initially. Once the brand name is established and sufficient profits and funds are raised, the manufacturing communities could be imbibed inside the organization to produce under the organization's name later moving to an integrator. Since the market is yet to be tested the safest bet to start would be as an orchestrator [40].

Diversification of the product is necessary for maintaining success, yet this represents a huge dilemma amongst innovator's and companies that are already established. In particular, they must chose on move on and sell more sophisticated products for top tier loyal customers of the brand and intermediate supporters, or if they would diversify the company product portfolio to seek out the customers that still not use the company products Several successful and unsuccessful cases were studied upon and the base refection that would best suit our product is to initially to launch a simple base product that would be priced lower than our competition for initially capturing the niche [41]. For seeking out the unendowed, reusable coconut shell cutlery and crockery priced higher could be sold under a different name.



Figure 36 - Illustration of the methods of operation when launching a product, by Andrew, J.R. and Sirkin, H.L. in the Harvard Business Review, from the September 2003 edition.

For entering the home industry, party grade disposable items with a lower thickness and processing could be sold under a lower price based on coco fiber sponges and ropes. The party grade items could be sold directly to customers or to party organizing sponsors (eg. Superbock, MEO, etc). The bottom of the consumer pyramid, as described by Figure 37, is essentially captured by the products that we offer, that are simple and inexpensive compared to plastics under the party grade brand. Corporate products would focus more on the top of the pyramid, where products will be modeled to their desire would be sold. The top of the pyramid products would also be available to the public in stores and online, but they will have aesthetic design, reusability and would be marked more on the price when compared to our party grade brand.

Disrupting the Pyramid

In the past, major waves of growth have been created by innovations that have had an impact only on the bottom of developed markets. Disruptive innovations at the base of the pyramid — home to billions of the aspiring poor — have much greater potential than those that begin and end in developed markets.

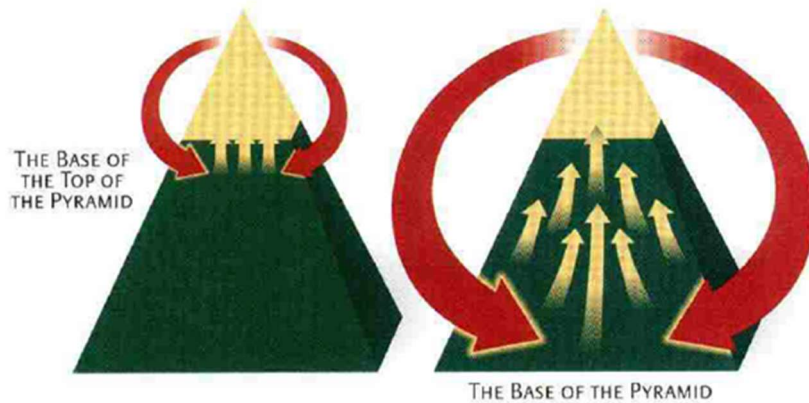


Figure 37 - The impact of the bottom level disruption in the consumer pyramid as described by Christiansen in *The Great Leap: Driving Innovation from the Base of the Pyramid*. MIT Sloan Management Review 2002

Usage of several names (Brands) under the same brand would effectively stop cannibalization and capture a wider group of customers that are still not using, or even aware of the product. This would help us capture a sizable portion of the market. The bottom of the consumer pyramid is essentially captured by the products that we offer, that are simple and inexpensive, compared to plastics under the party grade brand [41].

6.4.1. Price comparisons per functional unit (One ton)

The wholesale price of the existing product was obtained from several rural self-help groups working on similar products. Shipping, transport and distribution costs were also obtained from several shipping and supply chain companies from Tamil Nadu. The price of the suggested products is lower than the existing market products as in Table 3. The prices of the existing products were taken from the products available in the Portuguese super markets like Pingo doce, continente and Mini preco. The tabulations for the calculations are in annex 2. If marketing and operation costs were included, there would be a marginal rise in the cost of each unit but would be still cheaper compared to existing products.

Table 3 - Cost of manufacturing and the retail price of existing market

Product	Wholesale price for the functional unit (Eur)	Shipping (Eur)	Transport (Eur)	Distribution (Eur)	Final cost (Eur)	Cost for 25 pieces (Eur)	Existing product – Price 25 pieces (Eur)
Palm boxes	833.4	73.21	10	20	936.61	1.40	2.5
palm plates	781.25	73.21	10	20	884.46	0.90	1.20
Palm bowls	781.25	73.21	10	20	884.46	0.35	1.0
Sal wraps	711.11	73.21	10	20	814.54	0.30	Not available
Coco shell cups	900.2	73.21	10	20	1003.41	0.50 (×5pieces)	1
Coir sponges	455.3	73.21	10	20	558.51	0.11 (×5 pieces)	0.70 (×5 pieces)

6.5. Conclusion of the business study

With the staggering number of disposable cutlery and crockery used if we could occupy just 1% of the market share in the launching months (Total Sales of about 30 million individual pieces), at an average price of 5 cents per piece, a turnover of 1.5 Million euros could be expected. To have 1% of the market share the above steps must be considered carefully and 1% of the market is a huge chunk for a start-up. A minimal investment must be made just to get the supply chain established, including warehousing.

For the initial phase of the project as just being an orchestrator, a warehouse and a transport network must be established, deals should also be negotiated with supermarket and fast food chains, the initial investment would be around 8000 euros and upward for a micro scale establishment. Once the company starts to get sales more money from turnover would be pumped into the business to make it better.

Before jumping into production, marketing and selling, an opinion poll would be considered, free samples will be distributed among potential customers and several test runs would be carried out. The products would be launched slowly in a step by step manner to ensure maximum market penetration. From sales analysis and customer reactions, the production and distribution /sales would be carried out. Over procurement could be avoided in this method. Rigorous quality testing standards must also be established in the process

The cost of operation, marketing would result in the price of our product costing the same or marginally less than the conventional products in the market.

7. Conclusions

It is clear from the above environmental impact calculations and business plan analysis that shipping the product from India to Portugal most of the environmental impact is lower when compared to conventional disposable materials. The business plan provides further support and adds to the claims to the results provided by the environmental impact analysis, supporting the idea that producing and selling product described and studied in this work would be a good idea. If marketed and launched properly, as the product can compete with existing paper and plastic disposable cutlery and crockery. This work also establishes results and calculates the life cycle analysis for the products discussed in the above sections. Table 2 verifies the same as most of the impacts are low compared to the conventional products. One such example is the comparison of cardboard boxes and palm areca boxes, the results indicated show a marked 40 percent reduced impact in most categories. The differences can also be highlighted by the values obtained in the results between plastic plates and palm areca plates, values for abiotic depletion and acidification are 2.134844475 and 0.40978921 versus the 2.81E-04 and 2.78E-04 respectively. This shows the in effectiveness of our suggested alternatives, all the impacts could not be studied in detail and in-depth due to the unavailability of compatible and complete LCA studies. Nevertheless, the results are obvious and is clear indication that our alternatives fares better. This study might be of considerable importance and impact as this is the first endeavour to carry out a life cycle analysis for such products.

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Annex A. Eco Invent Data

This section contains the emission factors used in the calculation of the environmental impact calculations, including energy generation. They were obtained using life cycle inventory data obtained using the Eco Invent V2.1 database, available in the LCA software Simapro™, and using the environmental impact assessment methodology CML 2000. The information presented in each graphic is the following:

- Figure 38 gives the impact factor for 1 kg of wrapping plastic
- Figure 39 gives the impact factor for 1 kWh of electricity produced by nuclear power.
- Figure 40 gives the impact factor for 1 kWh of electricity produced by wind power.
- Figure 41 gives the impact factor for 1 kWh of electricity produced by lignite.
- Figure 42 gives the impact factor for 1 kWh of electricity produced using biomass.
- Figure 43 gives the impact factor for 1 kWh of electricity produced using hydroelectric power plants.
- Figure 44 gives the impact factor for 1 kWh of electricity produced using natural gas.
- Figure 45 gives the impact factor for 1 kWh of electricity produced using landfill gas.
- Figure 46 gives the impact factor for 1 kWh of electricity produced photovoltaic systems.
- Figure 47 gives the impact factor for 1 kg of waste incinerated.
- Figure 48 gives the impact factor for transportation using a van, expressed in tkm, tonnes per km.
- Figure 49 gives the impact factor for transportation by seaship, expressed in tkm, tonnes per km.

Sel	Impact category /	Unit	Total	Extrusion, plastic film/RER S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.00358	0.00358
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.00207	0.00207
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.00127	0.00127
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.522	0.522
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	2.64E-8	2.64E-8
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.3	0.3
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.235	0.235
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	472	472
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.00224	0.00224
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	9.3E-5	9.3E-5

Figure 38 – Impact factor for 1 kg plastic wrapping,

Sel	Impact category /	Unit	Total	Electricity, nuclear, at power plant/UCTE S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	5.39E-5	5.39E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	5.5E-5	5.5E-5
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	1.9E-5	1.9E-5
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.00779	0.00779
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	1.72E-8	1.72E-8
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.111	0.111
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.0212	0.0212
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	39	39
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.00039	0.00039
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	2.51E-6	2.51E-6

Figure 39 – Impact factor for 1 kWh of electricity using nuclear power.

Sel	Impact category /	Unit	Total	Electricity, at wind power plant/RER S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	8.22E-5	8.22E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	5.16E-5	5.16E-5
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	2.74E-5	2.74E-5
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.0113	0.0113
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	6.12E-10	6.12E-10
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.0623	0.0623
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.0147	0.0147
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	19.9	19.9
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.000159	0.000159
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	3.63E-6	3.63E-6

Figure 40 – Impact factor for 1 kWh of electricity using wind power.

Sel	Impact category /	Unit	Total	Electricity, lignite, at power plant/UCTE S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.00924	0.00924
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.00906	0.00906
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.01	0.01
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	1.23	1.23
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	1.94E-9	1.94E-9
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.923	0.923
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	1.6	1.6
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	3.32E3	3.32E3
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.0021	0.0021
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	0.000346	0.000346

Figure 41 – Impact factor for 1 kWh of electricity using lignite.

Sel	Impact category /	Unit	Electricity, biomass, at power plant/US
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	1.52E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000754
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.000103
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.0459
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	8.36E-14
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.00282
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.000705
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	2.58
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	9.69E-8
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	0.0231

Figure 42 – Impact factor for 1 kWh of electricity using biomass.

Sel	Impact category /	Unit	Total	Electricity, hydropower, at reservoir power plant, non alpine regions/RER S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	2.52E-5	2.52E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	1.7E-5	1.7E-5
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	6.48E-6	6.48E-6
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.0111	0.0111
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	3.1E-10	3.1E-10
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.00913	0.00913
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.0022	0.0022
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	2.9	2.9
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	2.91E-5	2.91E-5
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	2.59E-6	2.59E-6

Figure 43 – Impact factor for 1 kWh of electricity using hydroelectric power plants.

Sel	Impact category /	Unit	Total	Electricity, natural gas, at power plant/UCTE S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.00546	0.00546
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000609	0.000609
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.000102	0.000102
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.64	0.64
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	7.84E-8	7.84E-8
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.0706	0.0706
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.00363	0.00363
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	34.6	34.6
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.000105	0.000105
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	4.89E-5	4.89E-5

Figure 44 – Impact factor for 1 kWh of electricity using natural gas.

Sel	Impact category /	Unit	Total	MSW deposition, landfill incl. landfill gas utilisation and leachate treatment, ES,GR,PT mix EU-27	Dummy Electricity from landfill gas utilisation, AC, production mix, at landfill site, < 1kV
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.000278	0.000278	0
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000204	0.000204	0
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.00317	0.00317	0
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.849	0.849	0
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	1.39E-9	1.39E-9	0
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.00129	0.00129	0
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	8.88E-5	8.88E-5	0
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	0.369	0.369	0
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	3.19E-5	3.19E-5	0
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	0.000233	0.000233	0

Figure 45 – Impact factor for 1 kWh of electricity using landfill gas.

Sel	Impact category /	Unit	Total	Electricity, production mix photovoltaic, at plant/PT S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.000361	0.000361
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000246	0.000246
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.000157	0.000157
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.0509	0.0509
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	9.6E-9	9.6E-9
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.117	0.117
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.037	0.037
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	81.5	81.5
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.00037	0.00037
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	1.54E-5	1.54E-5

Figure 46 – Impact factor for 1 kWh of electricity using photovoltaic systems.

Sel	Impact category /	Unit	Total	Waste incineration of municipal solid waste (MSW), EU-27
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	-1.29E-5	-1.29E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000153	0.000153
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	6.67E-5	6.67E-5
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.33	0.33
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	1.69E-9	1.69E-9
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	-0.00115	-0.00115
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	-0.000171	-0.000171
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	-1.17	-1.17
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.000532	0.000532
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	-1.44E-5	-1.44E-5

Figure 47 – Impact factor for 1 kg of waste incinerated.

Sel	Impact category /	Unit	Total	Transport, van <3.5t/RER S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	0.0131	0.0131
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.00722	0.00722
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	0.0024	0.0024
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	1.91	1.91
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	2.68E-7	2.68E-7
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.923	0.923
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.348	0.348
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	731	731
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	0.00632	0.00632
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	0.00071	0.00071

Figure 48 – Impact factor for transportation using a van, expressed in tkm, tones per km.

Sel	Impact category /	Unit	Total	Transport, transoceanic freight ship/OCE S
<input checked="" type="checkbox"/>	Abiotic depletion	kg Sb eq	7.14E-5	7.14E-5
<input checked="" type="checkbox"/>	Acidification	kg SO2 eq	0.000236	0.000236
<input checked="" type="checkbox"/>	Eutrophication	kg PO4--- eq	2.57E-5	2.57E-5
<input checked="" type="checkbox"/>	Global warming (GWP100)	kg CO2 eq	0.0107	0.0107
<input checked="" type="checkbox"/>	Ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-9	1.21E-9
<input checked="" type="checkbox"/>	Human toxicity	kg 1,4-DB eq	0.00736	0.00736
<input checked="" type="checkbox"/>	Fresh water aquatic ecotox.	kg 1,4-DB eq	0.0012	0.0012
<input checked="" type="checkbox"/>	Marine aquatic ecotoxicity	kg 1,4-DB eq	3.09	3.09
<input checked="" type="checkbox"/>	Terrestrial ecotoxicity	kg 1,4-DB eq	2.51E-5	2.51E-5
<input checked="" type="checkbox"/>	Photochemical oxidation	kg C2H4 eq	7.5E-6	7.5E-6

Figure 49 – Impact factor for transportation, expressed in tkm, tones per km.

Annex B. Calculations and Results

The impact of electricity is calculated by taking the percentage of the different mixes in the electricity and averaged. The impacts were multiplied with the percentage and the total impact was summed. The impact of electricity in total is multiplied with the number of kWh. Similarly, data is multiplied with the number of kilometers transported and shipped. The same according to the number of boxes, ropes and plastic film required.

The impact of boxes was considered and the impact from boxes of different dimensions were extrapolated accordingly. Table 4 and 5 show the calculation of the impact of electricity per kW

Table 4 – Calculations for the impact of electricity per kW

Electricity Impact calculations per kW												
Impact category	Unit	Coal	%	Product	Gas	%	Product	Nuclear	%	Product	Hydro	%
Abiotic Depletion	kg Sb eq	0.00904	0.442941	0.004004187	5.46E-03	0.021085	1.15E-04	5.39E-05	4.58E-02	2.47E-06	2.52E-05	9.43E-02
Acidification	kg SO ₂ eq	0.00906	0.442941	0.004013045	6.09E-04	0.021085	1.28E-05	5.50E-05	4.58E-02	2.52E-06	1.70E-05	9.43E-02
Eutrophication	kg PO ₄ eq	0.01	0.442941	0.00442941	1.02E-04	0.021085	2.15E-06	1.90E-05	4.58E-02	8.70E-07	6.48E-06	9.43E-02
GWP 100	kg CO ₂ eq	1.23	0.442941	0.54481743	6.40E-01	0.021085	1.35E-02	7.79E-03	4.58E-02	3.57E-04	1.11E-02	9.43E-02
Ozone layer depletion	kg CFC-11 eq	1.94E-09	0.442941	8.59306E-10	7.84E-08	0.021085	1.65E-09	1.72E-08	4.58E-02	7.88E-10	3.10E-10	9.43E-02

Electricity Impact calculations per kW												
Impact category	Unit	Coal	%	Product	Gas	%	Product	Nuclear	%	Product	Hydro	%
Human Toxicity	kg 1,4-DB eq	0.923	0.442941	0.408834543	7.06E-02	0.021085	1.49E-03	1.11E-01	4.58E-02	5.08E-03	9.13E-03	9.43E-02
Fresh water aquatic ecotox	kg 1,4-DB eq	1.6	0.442941	0.7087056	3.63E-03	0.021085	7.65E-05	2.12E-02	4.58E-02	9.71E-04	2.20E-03	9.43E-02
Marine aquatic ecotox	kg 1,4-DB eq	3.20E+03	0.442941	1417.4112	3.46E+01	0.021085	7.30E-01	3.90E+01	4.58E-02	1.79E+00	2.90E+00	9.43E-02
Terrestrial ecotox	kg 1,4-DB eq	0.0021	0.442941	0.000930176	1.05E-04	0.021085	2.21E-06	3.90E-04	4.58E-02	1.79E-05	2.91E-05	9.43E-02
Photochemical oxidation	kg C ₂ H ₄ eq	0.000346	0.442941	0.000153258	4.89E-05	0.021085	1.03E-06	2.51E-06	4.58E-02	1.15E-07	2.59E-06	9.43E-02

Table 5 – Continuation of the calculation of the impact of electricity per kW

Electricity Impact calculations per kW												
Impact	Unit	Wind	%	Product	Solar	%	Product	Biomass	%	Product	Final Impact	
Abiotic Depletion	kg Sb eq	8.22E-05	3.12E-01	2.57E-05	3.61E-04	4.72E-02	1.70E-05	1.52E-05	3.63E-02	5.52E-07	4.17E-03	
Acidification	kg SO ₂ eq	5.16E-05	3.12E-01	1.61E-05	2.46E-04	4.72E-02	1.16E-05	7.54E-04	3.63E-02	2.74E-05	4.09E-03	
Eutrophication	kg PO ₄ eq	2.47E-05	3.12E-01	7.71E-06	1.57E-04	4.72E-02	7.41E-06	1.03E-04	3.63E-02	3.74E-06	4.45E-03	
GWP 100	kg CO ₂ eq	1.13E-02	3.12E-01	3.53E-03	5.09E-02	4.72E-02	2.40E-03	4.59E-02	3.63E-02	1.67E-03	5.67E-01	
Ozone layer depletion	kg CFC-11 eq	6.12E-10	3.12E-01	1.91E-10	9.60E-09	4.72E-02	4.53E-10	8.36E-14	3.63E-02	3.04E-15	3.97E-09	
Human Toxicity	kg 1,4-DB eq	6.23E-02	3.12E-01	1.95E-02	1.17E-01	4.72E-02	5.52E-03	2.82E-03	3.63E-02	1.02E-04	4.41E-01	
Fresh water aquatic ecotox	kg 1,4-DB eq	1.47E-02	3.12E-01	4.59E-03	3.70E-02	4.72E-02	1.75E-03	7.05E-04	3.63E-02	2.56E-05	7.16E-01	

Electricity Impact calculations per kW											
Impact	Unit	Wind	%	Product	Solar	%	Product	Biomass	%	Product	Final Impact
Marine aquatic ecotox	kg 1,4-DB eq	1.99E+01	3.12E-01	6.21E+00	8.15E+01	4.72E-02	3.85E+00	2.58E+00	3.63E-02	9.38E-02	1.43E+03
Terrestrial ecotox	kg 1,4-DB eq	1.59E-04	3.12E-01	4.97E-05	3.70E-04	4.72E-02	1.75E-05	9.69E-08	3.63E-02	3.52E-09	1.02E-03
Photochemical oxidation	kg C ₂ H ₄ eq	3.63E-06	3.12E-01	1.13E-06	1.54E-05	4.72E-02	7.27E-07	2.31E-02	3.63E-02	8.40E-04	9.96E-04

Table 6 represents the number of pieces that are required to make up one ton of material, calculated from the weight of a single. This information was obtained from the companies that produce similar products. The box dimensions were taken from the references for the box impact calculations.

Table 6 – Number of boxes

To manufacture one ton of material	No of pieces/ton	Box dimensions (cm)	Weight (kg)	Number of boxes
Double box: 60 g	16667	60*40*24	0.823	29
plate (25cm): 40g	25000	51*51*26	1	27
Small bowl (6 cm)/cup (180 ml): 16g	66667	60*40*24	0.823	17
One open box: 30 g	33334	60*40*24	0.823	29
Coconut shells (400 ml)	10000	60*40*24	0.823	39
Coir sponges	25000	60*40*24	0.823	15
Coir ropes	-	-	-	-
Sal leaf wraps	66667	60*40*24	0.823	47
Banana paper	22222	60*40*24	0.823	5

The complete simplified data on the number of km that travels, to the energy required for processing and disposal is mentioned below in Table 7.

Table 7 – Complied primary data for the product

Materials	Product	Extraction	Transport (km)		Processing (kWh)		Cardboard boxes (0.823 g)	Transport (km)			Disposal
			Collection	Distribution	Preprocessing	Processing		Local Transport	Shipping	Intl. transport	
Palm areca	Boxes	Manual- No energy	50	50	0	293	29	200	12320	100	20%Incineration & 80% landfills
	Plates	Manual- No energy	50	50	0	220	27(1kg)	200	12320	100	20%Incineration & 80% landfills
	Cups	Manual- No energy	50	50	0	196.4	16	200	12320	100	20%Incineration & 80% landfills
Coconut	Ropes	Manual- No energy	0	150	7.46	59.67	0	200	12320	100	20%Incineration & 80% landfills
	Shells	Manual- No energy	0	150	7.46	15	39	200	12320	100	20%Incineration & 80% landfills
	Sponges	Manual- No energy	0	150	7.46	37	15	200	12320	100	20%Incineration & 80% landfills
Sal leaves	Plates/ wraps	Manual- No energy	0	0	0	0	47	300	12320	100	20%Incineration & 80% landfills
Banana fibers	Paper	Manual- No energy	10	60	0	13.5	5	200	12320	100	20%Incineration & 80% landfills

Table 8 shows the values of prices obtained from the companies, they are multiplied according to their functional units and the total price is then calculated accordingly in Table 3 the prices are in euros converted through the formula converted into euros by = Functional unit *price of a single product/75. The costs of banana sheath could not be obtained due to the unavailability of data.

Table 8 – Price calculation for the products

Product Base	Price of the raw material	Price of the finished product (one unit -wholesale) -approx.	Functional unit	Total price(INR)
Areca Palm boxes	INR 1 per sheath	INR 3.75	16667	62501.25
Areca palm plates	INR 1 per sheath	INR 2.34	25000	58600
Areca plam bowls /cups	INR 1 per sheath	INR 0.93	62500	58600
Sal leaf wraps , plates and bowls	-	INR 0.80	66667	53334
Coconut shells cups /bowls	INR 1 per shell- semi polished	INR 6.75	10000	67500
Coconut coir sponges	INR 3 per kilo	INR 1.34	25000	34150

Table 9 represents the amount of capital required to establish a small business as an orchestrator, with only a warehouse and a few other people who work in the business. The supply network is operated through third party owners. Garage rent information was taken from casasapo.pt , procuring materials is the sum of the cost of the materials listed above . Work force pay is the amount that would be paid to two interns or the owners who work for marketing and negotiation. Marketing cost was considering establishing a website, advertising on paper and social media, using our warehouse to sell our products on amazon Spain and ebay. Repacking and Misc. costs include us boxing our products into new containers

and other office expenses.

Table 9 – Investment cost to set up the company

Expenditures	Euros (approx)
Garage to rent and electricity	800
Procuring 1 ton (All products) and distribution	4500
Marketing – Initial , small sacle on newspapers and social media	500
Work force (2 people -Misc)	1200
Repacking and other misc. office expenditures	500
Establishing and registering	500
Total	8000