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Evaluation of *Areca* palm renewable options to replace disposable plastic containers using life cycle assessment methodology

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Abstract

In spite of raising awareness of the environmental impacts associated to the production and utilization of plastics, in many situations, the use of plastics is advantageous, and options are still unavailable or under development, representing an opportunity to develop more sustainable options, such as less energy intensive solutions. In this work, the LCA methodology is used to evaluate the environmental impacts of boxes, bowls and plates produced using *Areca* palm (*Areca catechu*) sheath, a waste material common in southern India. The inventory is a combination of primary data from a company in India, complemented with secondary data from the Ecoinvent v2.1 (Simapro V7.3). Results show that the main contributors to the potential environmental impact categories and the most energy intensive life cycle steps, are transportation, shipping and electricity generation. Carbon footprints of 1180, 1033 and 1090 kg CO_2eq/ton were obtained for *Areca* boxes, plates and bowls, respectively. Plates made from *Areca* palm sheath have lower environmental impacts than plastic plates, except in the ozone layer depletion and terrestrial toxicity impact categories.

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Keywords: *Areca* palm sheath; Life cycle assessment; Plastic containers; Renewable; Waste materials

1. Introduction

Plastic materials are used extensively in most of the products and/or activities of modern societies. Although in many applications plastic materials are adequate, cheaper, and perform better when compared with other materials for the same applications [1], as for example wood, glass or metal, the last years have witnessed an exponential awareness of the environmental negative impacts resulting from its production and widespread utilization. As most plastics are not biodegradable, they accumulate in the environment, leading to potential negative impacts

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in various areas, as for example in the food supply, where plastics may contaminate fish or animals used for human consumption [2]. Moreover, plastics are mainly produced from non-renewable resources, in particular oil and non-renewable energy, and are normally hard or even impossible to recycle. Thus, recently laws and policies were proposed and are starting to be implemented at the international, national and regional levels to reduce the consumption of non-biodegradable materials or to promote the development of more sustainable alternatives [3]. Since plastics are used in a multitude of products for countless applications, a plethora of various solutions are required, and currently this is a very active area of research [4]. As many solutions are still under development and far from the market, there is a window of opportunity to develop the most sustainable options by applying the principles of life cycle thinking to product design and/or selection [5–7], allowing for example the reduction of non-renewable resources in particular energy.

An important part of the plastic waste corresponds to the disposable cutlery and crockery, such as: plates, cups, forks, knifes, among others, used in many life situations such as at parties or at work. Those items are normally not recycled/reused, and if not properly disposed of, they will contribute to the increase of environmental problems [6,7]. A potentially good option involves the use of organic residues, particularly from agricultural practices or from food waste [8,9]. Besides contributing to the valorization of low value residues, it also contributes to a more circular and sustainable economy, as those residues have a renewable nature and are biodegradable [10,11]. Moreover, this option also contributes to reduce the energy consumption needed to obtain the products, as no chemical feedstocks and intermediate products are needed. Hence, this work studies the utilization of agricultural and forestry residues, originated in central and southern India, in particular *Areca* palm sheath, to obtain disposable items to be used as crockery or cutlery [12]. These will be studied using the life cycle analysis (LCA) methodology [13], in order to quantify their potential environmental impacts and identify their hotspots, and to compare with products with the same functions made from non-renewable raw materials and/or energy.

2. Materials and methods

2.1. Study goal

The goal of this study is to determine the main potential environmental impacts of boxes, plates and bowls made from *Areca* Palm (*Areca catechu*) sheath (Fig. 1). The study follows the LCA methodology based on the framework defined in ISO 14040 [13] standard [14,15].

2.2. Functional unit

It is considered as functional unit one tone of *Areca*'s boxes, plates or bowls shipped from India to Portugal.

2.3. Study scope and main assumptions

The life cycle stages considered are material collection and transportation to the processing facilities, processing to the final production, transportation from Southern India to Europe/Portugal, and final disposal (Fig. 2). The LCA study has an attributive nature and considers the product systems and technological conditions found in Southern India.

The materials are extracted and processed in India, especially in the state of Tamil Nadu. The raw materials, *Areca* sheaths, are generally harvested by hand, collected and stored. 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 were not considered. People use their own transportation methods, as they live generally near the plantations. They walk to the site or use bicycles as a means of transport. The impact of these transportation means is minimal and was not accounted for.

The extracted materials are bundled and tied together. Usually minivans are used for transportation within the state or district. It is assumed that a ton of the material is transported in each trip for an average distance of 100 kilometers for *Areca* palm products.

Ground water drawn from wells is used to soak the materials, if needed, or they are retted in tanks of salt water, or in backwater, 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

Fig. 1. (a) *Areca* palm plantation in Kerala India (photo above in the left); *Areca* sheath bundles near a plantation (photo above in the right); *Areca* sheaths being processed (photo below in the left); finished plates and containers (photo below in the right).

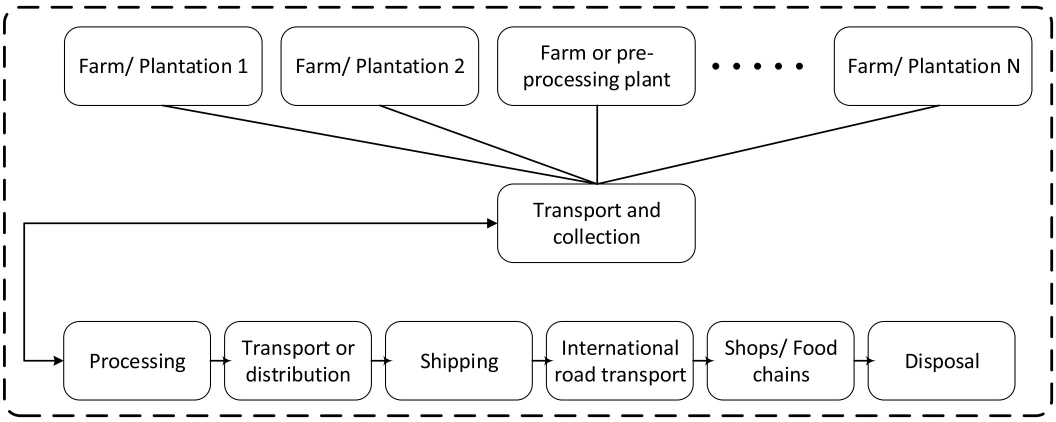

Fig. 2. System boundary definition for the study.

reused 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 this information, we can assume that the impact regarding water consumption is low. The next step, processing, involves pressing/ spinning /stitching and cutting. If heated, presses used may reach between 60 and 80 degrees Celsius.

The *Areca* palm products are pressed and cut using machines operated using medium voltage (5.5 kW) electricity from the electricity distribution network. The energy mix of the Indian State of Tamil Nadu was considered in the estimation of the environmental impacts of the electricity consumed by the machines in the processing facilities.

The processed materials are then packed and bundled by hundreds, tied down using coir ropes, packed in boxes and then, transported across the country using open minivans. Some agencies export them abroad, usually by ship. The minivans travel an average of 200 kilometers. *Areca* palm plates are shipped in cardboard boxes weighing 1 kg.

Transportation from the waste collection to the processing plant was assumed to be by truck, and from India to Portugal by boat. For international shipping, 12320 kilometers was considered for shipping to Portugal (Lisbon). Once in Lisbon they should be shipped throughout Portugal, assuming an average distribution distance of 100 km since most of the population is near the coastal regions.

At the end of their life, the products are biodegradable and they can be collected to grow mushrooms or used for gardening. In practice, they are collected to be incinerated or disposed of in landfills. A disposal scenario of 20% incineration and 80% landfilling was assumed. Transportation from trash collection to points of incineration and landfills was also considered.

Excluded processes and materials include: materials and inks used in labels; impacts from storage; transportation from the retail shop to the consumer's house; and the impacts generated by building construction, machines and vehicles/ships manufacture.

2.4. Inventory analysis

For the inventory data, was used a combination of primary data, mainly from the processing plant, and secondary data obtained from the Ecoinvent v2.1 life cycle inventory (LCI) database available in SimaproTM version 7.3. The primary data regarding the process was obtained from the self-help groups and cottage industries who work with these kinds of materials.

2.5. Impact assessment

The potential environmental impacts were estimated using the CML 2000 method, and the calculations were performed using the Simapro 7.3 software. The following environmental impact categories were selected in this work, and the set include most of the indicators used in practice in LCA studies of products or services [11,16–18].

- Global warming potential: The Global warming potential, GWP, is a measure of total greenhouse gas emissions (for example, CO_2, methane, nitrous oxide). GWP is measured in terms of CO_2 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 non-living (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 NOx 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 life forms. Nitrogen and phosphorus are the two nutrients most implicated in eutrophication. Eutrophication is measured in terms of phosphate (PO_4^{3-}) 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 SO_2, NOx, HCL and NH_3. Acidification is measured in terms of SO_2 equivalents;
- Toxicity: Toxicity is the degree to which something can produce illness or damage to an exposed organism. Four different types of toxicity were considered in this work: human toxicity, terrestrial ecotoxicity, marine aquatic ecotoxicity and fresh water aquatic ecotoxicity. Toxicity is measured in terms of dichlorobenzene equivalents.

3. Results and discussion

In Figs. 3 to 5 the relative importance of environmental category for each of the *Areca* sheath products: boxes, plates and bowls, is given. It can be seen that transportation (local) and electricity generation are the life cycle stages that mostly contribute to the overall potential environmental impact. They correspond to more than 50% in each environmental impact category varying their relative importance on the life cycle step. Shipping contribution to the potential environmental impacts is below 15%, with the exception of Acidification to which shipping contributes about 40%. The relative importance of the remaining life cycle stages is very small, with the exception of cardboard production in the Global Warming impact category, but always below 10%.

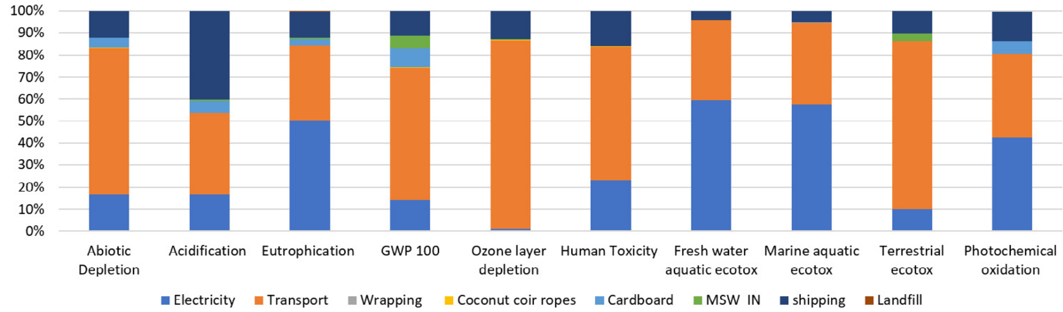

Fig. 3. Environmental Impacts for each life cycle stage for *Areca* palm boxes.

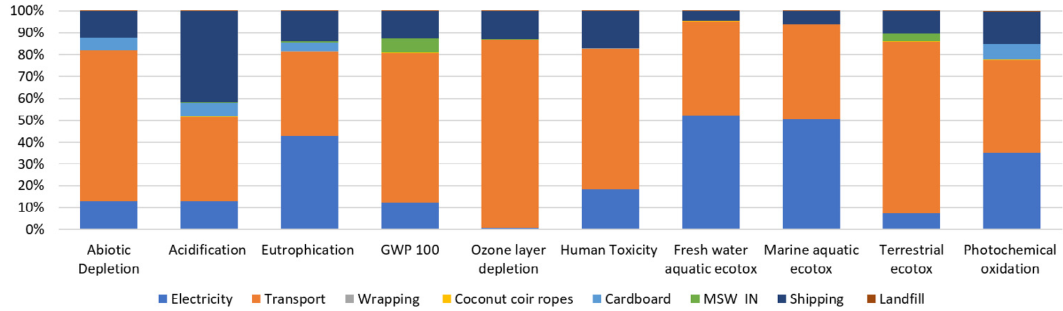

Fig. 4. Environmental Impacts for each life cycle stage for *Areca* palm plates.

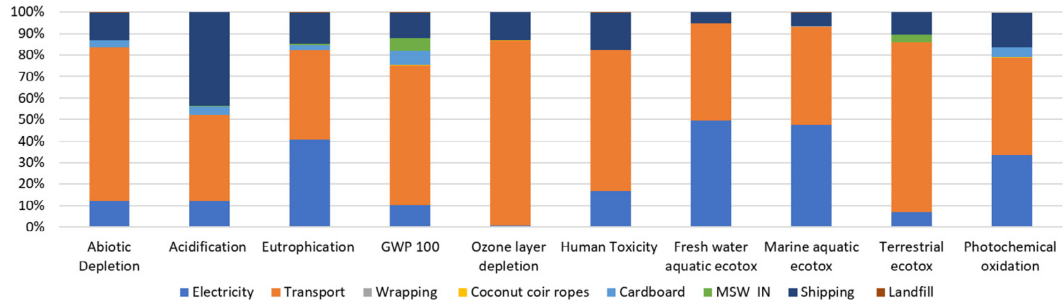

Fig. 5. Environmental impacts for each life cycle stage for *Areca* palm bowls.

Moreover, the products have very similar environmental profiles, as the dominant life cycle stages are alike between the three products. In particular, carbon footprints (GW100) of 1180, 1033 and 1090 kg CO_2eq/ ton of shipped materials were obtained for respectively *Areca* boxes, plates and bowls (Figs. 3 to 5). The differences can be attributed mostly to small variations in the production system taking into account the variations in forms and quantity of raw materials needed to obtain a unit of each product. Therefore, similar values were obtained for each product in each environmental impact category. These values are considerably lower than those found by Ingrao et al. [19] for trays made of expanded polylactic acid (EPLA) and expanded polystyrene (EPS) of respectively 4826 and 5110 kg CO_2eq/ ton of trays, showing that the products made from residual biomass have a better environmental performance.

Transportation and electricity production are the main contributors to all the potential environmental impact categories. Thus, reducing the energy consumption by being more energy efficient, or using renewable energy will lower the environmental impacts [20]. Yet, the different modes of transportation used and the local conditions must be taken into account as they may limit the applicability of proposals to reduce the environmental impacts of energy utilization and thus, the products overall environmental impact. For transportation, that is mostly local, the utilization of renewable fuels, such as biogas obtained by the anaerobic digestion of agricultural residues and/or the production of biofuels from biomass [8,21] and/or biological residues such as fatty materials [22,23] may be good options in a region where the agricultural sector is still very important. Also, the increasing of renewable energy in the local electricity mix [6,7], in particular produced locally or even onsite at the processing facility, may reduce the environmental impact due to electricity production and utilization, as for example renewable electricity using photovoltaic systems [24].

Plastic plates are also compared with *Areca* palm plates (Fig. 6). GWP was not considered, as the study used in the comparison report GWP20 and not GWP100 [4]. The comparison with plastic plates shows that *Areca* palm sheaths plates have much lower potential environmental impacts in most environmental impact categories, with the exception of ozone layer depletion and terrestrial toxicity [4], further supporting the conclusion that plates made from this waste material are adequate to partially replace currently used disposable plastic products. The production of this type of products, made with renewable materials, also represents an additional income for the local inhabitants in Southern India.

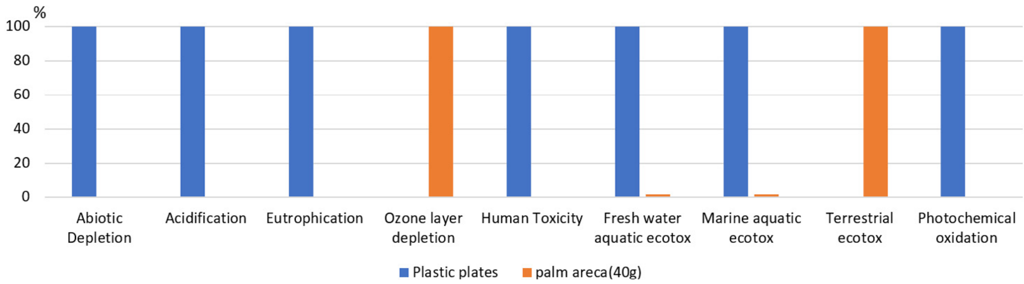

Fig. 6. Comparison between *Areca* palm plates and plastic plates.

4. Conclusions

In this work, a LCA study of the production of boxes, plates and bowls produced using waste materials obtained from the processing of agricultural products *Areca* palm sheaths was performed, using whenever possible primary data combined with data from LCI databases. 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. The results show that the transportation and electricity production are the life cycle stages responsible for most of the environmental impact categories. For example, carbon footprints of 1180, 1033 and 1090 kg CO_2eq/ ton of shipped materials were obtained for respectively *Areca* boxes, plates and bowls, which are lower than literature values reported for expanded EPLA and EPS of respectively 4826 and 5110 kg CO_2eq/ ton of trays. Also, the comparison between *Areca* palm plates and plastic plates show the plates made from *Areca* sheath are significant better in most environmental impact categories. Improvements in the life cycle should focus on the increase use of renewable energy, as for example biofuels in transportation or the local or onsite renewable electricity generation, for example by using photovoltaic systems.

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