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Exploring the three dimensions of sustainability related to clay cups

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Abstract

Since long before the use of disposable foil, plastic and paper cups, clay cups have been widely used in India as single-use containers for a variety of beverages and foods. This is now changing. The cost, convenience and transportability of non-earthen containers has resulted in their replacing clay containers. This paper discusses the gains and losses from this substitution along the three dimensions of sustainability economic, environmental and social, and shows that the replacement analyses for even such a simple product are complex with tradeoffs in the three dimensions impacting the wellbeing of the producers and users. The paper also presents the life cycle assessment of clay cups in terms of endpoint and midpoint categories using ReCiPe method, and also find the environmental hotspots.

Keywords: Disposable Cups; LCE; Sustainability; Social Impact

1. Introduction

Long before the use of disposable foil, plastic and paper cups, clay has been widely used in India for making single and multiple use containers for a variety of beverages and foods. India's clay cup for tea is iconic [1]. Clay pots have also been used for yogurt, sweets, cereal storage, and for potable water. This is now changing. The cost, convenience and transportability of paper, foil and plastic containers have resulted in their replacing clay cups and pots in most markets [2].

In recent years, attempts have been made to revive the use of clay containers [3]. These efforts were the result of top-down political decisions, and among the justifications cited for the retention of clay cups were the preservation of the jobs linked to the production of clay pots, the littering caused by plastic and paper cups and, traditions. For a country with a population exceeding 1.2 billion people, simple products such as clay cups support the livelihood of more than 3,000,000 potters [3].
Paper, plastic and polystyrene cups are used for drinks ubiquitously in developed countries, and increasingly so in developing countries. However, the environmental consequences associated with their increased use are attracting notice [4–6]. Estimates of the number of disposable containers used per year, along with their sources are in table below:

Table 1 Use of disposable cups

Container Type	Annual Consumption	Estimate Year	Source
Plastic Cups	500 billion - global	2016	[4]
Paper Cups	16 billion - global	2017	[7]
Polystyrene Cups	25 billion -USA	2017	[7]

Plastic, paper and polystyrene containers are easy to produce using automated machines, and the cost of the ingredients materials for their manufacture is low. However, this mode of production is economical only in large volumes. When population densities are high, as is the case in cities and towns, the distribution costs of such products can be low. But

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in the case of rural populations, the added expense of procuring these disposable items recurrently can take away from slim profit margins. An evaluation of the life cycle costs of disposable containers has found that the principal cost of these containers relates to their transportation to the end users, and from the disposal of these containers after use [6].

The earliest disposable containers used for food and drinks were made of clay. Clay containers include stoneware, glazed ceramics, terracotta and low-fired clay containers. Low-fired clay containers are baked in pit-fires, bonfires or kilns, to a temperature less than 600◦C. In this paper, attention is limited to the use of low-fired clay containers which are still used in India for tea and for other food items such as yogurt, sweets and drinking water. The manufacturing energy can also be saved by not fully baking the clay cup in the kiln as shown in Fig. 1. This under baking does not decrease the functionality of the cup but the disposal at the end of life becomes faster.

Fig. 1 A conventional unfinished clay cup

The goal of this paper is to discuss the financial, environmental and social impacts of locally produced clay containers, and those of mass-produced disposable beverage containers. In the following sections we explore the impacts related to the production and use of disposable clay cups. This is followed by an examination of the trade-offs and comparisons with alternate solutions.

2. Assessment Methodology and Results

It is widely accepted that the three dimensions of sustainability are economic, environmental and social. Methods for evaluation of economic sustainability are well known. Neoclassical economics posits that market forces are the ultimate arbiters of economic viability. Most evaluations of economic sustainability are single dimensional i.e. in monetary units. The evaluation of environmental viability is more recent. There are many subcategories related to environmental impacts. One metric that is widely used nowadays is the CO2 impact which measures the CO2 equivalent of Greenhouse Gases (GHG) produced over the life cycle of a product. Because of the plurality of environmental impact indicators, a comparison of the sustainability of products is not easy. The appraisal of social sustainability is even more complicated. Methodologies for Social LCA have been proposed [8] but this field is nascent and accepted quantitative or comparative approaches are under development.

To conduct an assessment in all three sustainability dimensions, the following production process is considered: The process for making clay cups begins with the retrieval of clay from local sources. Clay is a widely available material, and sources include quarries and river banks. Clay has been used as a primary material for thousands of years [9] but is naturally renewed by erosion, chemical weathering of rocks etc. Fig. 2 shows the various steps involved in the transformation of clay into cups. After extraction, clay is air dried, crushed and sieved to remove larger rocks and impurities. The sieved material is mixed with water, and hand molded into clay cups. These are first sun-dried, and then fired in batches in kilns. The fuel for firing is location dependent, but a typical mixture includes different proportions of Bajra Husks, cow dung cakes, and wood shavings or dust. A batch usually consists of cups and pots of different sizes packed together. Unlike artisan pottery, firing of clay cups is at a much lower temperature (⩽ 600◦C), and the kilns used for firing are rudimentary. In some cases, cups are placed on the combustible material directly, and the sun-dried cups are arranged so that smaller cups take up the interstitial spaces, blocking heat flow out of the pot pile, and becoming surface hardened in the process.

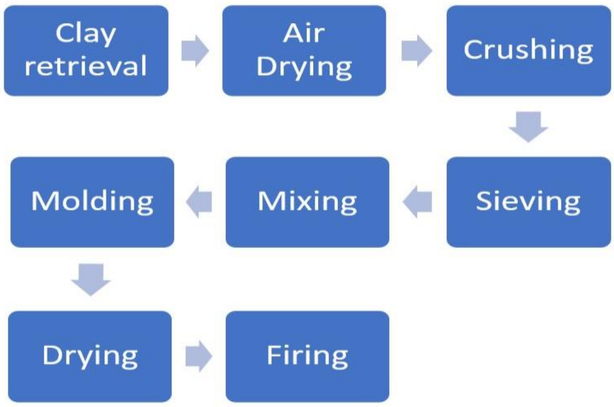

Fig. 2 Manufacturing process for clay cups

2.1. Economic Assessment

The selling price that paid by the end user - of a clay cup used for tea is INR 3 about 0.4 ¢(US), while the cost of a polystyrene cup locally is about INR 2 (0.3 ¢US), and that of an equivalent paper cup is about INR 0.5 (0.02 ¢US). However, wax lined paper cups can cost as much as INR 38. Later in the paper, the cost of clay cups is cited to be INR 0.75 and that of a paper cup INR 0.1. However, international comparisons reveal much higher costs for the disposable cups internationally - of the order of INR 7 - 10 for a paper cup for hot drinks. The common practice for disposal of clay cups is to discard after use without any systematic material recovery effort. It is conceivable that a local collection effort could lead to litter-free disposal of the waste from end-of-life clay cups, with clay recovery. The loop for returning and reusing paper and plastic cups is certainly longer and more expensive. Any tally of

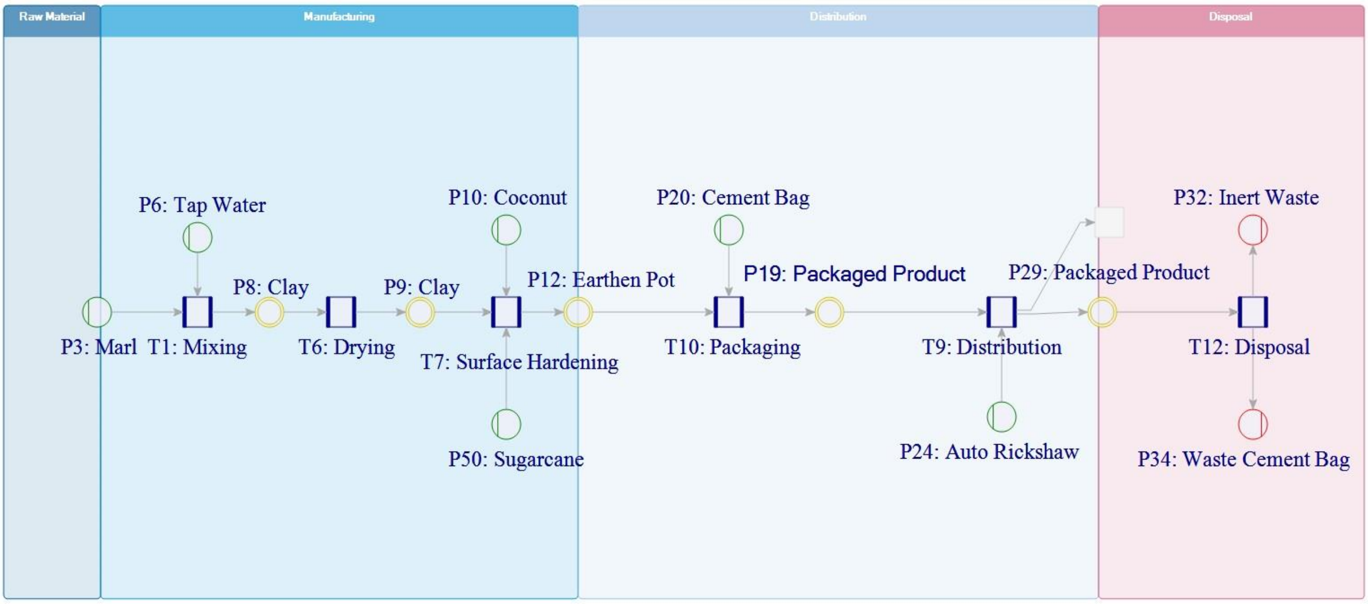

Fig. 3 Umberto model representation of LCA phases for clay cups

economic costs should therefore include these reverse loop costs for a meaningful comparison, and based on the international costs of disposable cups, clay cups appear to be cheaper. However, an in-depth evaluation is currently ongoing by the authors.

2.2. Environmental Assessment

The guidelines of ISO 14040 standards have been followed for the LCA of the clay cups. The four stages of the assessment are: goal and scope definition, inventory analysis, impact assessment, and interpretation of results.

2.2.1. Goals and Scope

The goal of the study is to conduct a Life Cycle Analysis of clay cups used for beverages, and to identify the phases that result in the most environmental impact. The study identifies the environmental impact of earthen cup material-wise, i.e. which material is responsible the most for degradation of the environment and phase-wise, i.e. which phase is responsible for most environmental impact. The analysis is also done from the material perspective, i.e. to find the material hotspots during the life cycle of the clay cups.

The scope of this study is cradle-to-grave, i.e. all relevant processes from raw materials to disposal have been included within the system boundaries. The four phases considered are 1) raw material extraction, 2) manufacturing of clay cups, 3) distribution to nearby areas and 4) disposal of packaging and used clay cup waste. This is the system boundary. An Umberto NXT LCA and the basic structure of the foreground system is Figure 2. Data has been recorded at three manufacturing sites, which were selected only because of their proximity to Pilani, India. These sites are representative of rural potteries, but the exact mix of materials used varies considerably by locality. The sizes of the cups differed at the sites observed, and the functional unit is therefore one kg of unfired clay cups.

Table 2 Fuel used for a batch of cups

Fuel	Site 1	Site 2	Site 3
Bajra Stalks	30Kg	60Kg	30Kg
(Husk Coconut)	(0.052 Kg/unit)	(0.116 Kg/unit)	(0.199 Kg/unit)
Cow dung cake	60Kg	75Kg	25Kg
(Sugar Cane)	(0.105 Kg/input)	(0.144 Kg/input)	(0.166 Kg/unit)
Wood Chips	160Kg	130Kg	
	(0.281 Kg/unit)	(0.25 Kg/unit)	-

2.2.2. Life cycle inventory and assumptions:

The primary data for the processes in the foreground system were collected from three sites at Pilani, India. The fuel for burning (cow dung, Bajra stalks, wood chips, and husk) were observed on-site and the following assumptions have been made:

- The fuel is completely combusted during the firing of a batch.
- The potter’s wheel is not included in the analysis - wheels have a lifetime of decades, and at the sites visited, each of the wheels was over 15 years old and not in need of replacement.
- The clay cups have been assumed to be delivered to buyers within a radius of 10 Km.

Information about the firing of the clay cups is shown in Table 3.

Table 3 Batch firing data from the three sites

	Site 1	Site 2	Site 3
Raw mass/cup	200gm	150gm	200gm
Fired mass/cup	170gm	120gm	180gm
cup/firing	2845	3457	753
Total Mass input	569 Kg	518.6 Kg	150.6 Kg
Cow dung cake	60 Kg	75 Kg	25 Kg
Wood Chips	160 Kg	130 Kg	NA
Bajra Stalks	30 Kg	60 Kg	NA Husk
NA	NA	30 Kg	
Cup Transportation	Auto Rickshaw	Auto Rickshaw	Auto Rickshaw
Distance	10Km	10Km	10Km
Packing Bag for cups (200 gm)	Plastic waste bag, not recycled		

Based on the numbers in Tables 2, 3 and 4, the energy expended for firing one unit (1 Kg of clay) at sites 1, 2 and 3 is 1198KJ, 1071 KJ and 1094 KJ respectively. The Ecoinvent 3.0 database was used as a secondary data source for processes in the background system. As datasets for cow dung cakes and Bajra stalks and husks were not available, they have been approximated by datasets for sugarcane and coconut husks since they have similar properties.

Table 4 Kg fuel used per kg of clay input

Fuel	Site 1 (*t*)	Site 2	Site 3	Calorific Value
	Kg fuel used per kg of clay input			KCal/Kg
Bajra Stalks	0.052 1	0.116	.199	3950
Cow Dung	0.105	0.144	0.166	4300
Sugarcane				3800
Wood Chips	0.281	0.25	-	3175

2.2.3. Life Cycle Impact Assessment

ReCiPe endpoint and ReCiPe midpoint assessment methodologies have been used to assess the environmental impacts to provides the results at both midpoint and endpoint levels. ReCiPe is chosen mainly for harmonizing the exiting midpoint and endpoint assessment methods [10]. Ecosystem quality has been measured by the climate change (CC) potential. Two subcategories of the human health which were found significant in this study are – human toxicity (HT) and particulate matter formation (PMF). Fossil depletion (FD) and metal depletion (MD) have been considered for the resources category. Midpoint assessment has been done for eight different environmental impact categories of climate change, fossil depletion, freshwater ecotoxicity, human toxicity, ozone depletion, particulate matter formation, terrestrial acidification, and water depletion.

2.2.4. Results and Discussion

Fig. 4 shows the mid-point assessment results for selected midpoint indicators for the materials used in the clay cups. The level of impact as well as the contribution of individual life cycle phases depend on the production location. The production process at site 1 has the lowest impact in the climate change, fossil depletion, human toxicity and water depletion, followed by site 2 and 3. For the remaining analyses, the differences in the assessment results are too small for establishing a rank order. It can be seen that the major impact in midpoint category comes from the fuel used for the firing of kiln and the disposal of the cup. The midpoint results are not in the absolute term but percentage of contribution in each category. The fuel for the kiln firing is waste material to be disposed off. However, to make the study future ready for mechanized kiln firing, its impact is recorded. The second high impact category material is inert waste at the end of life. There is a continued trend to bake the cup less so that the disposal is

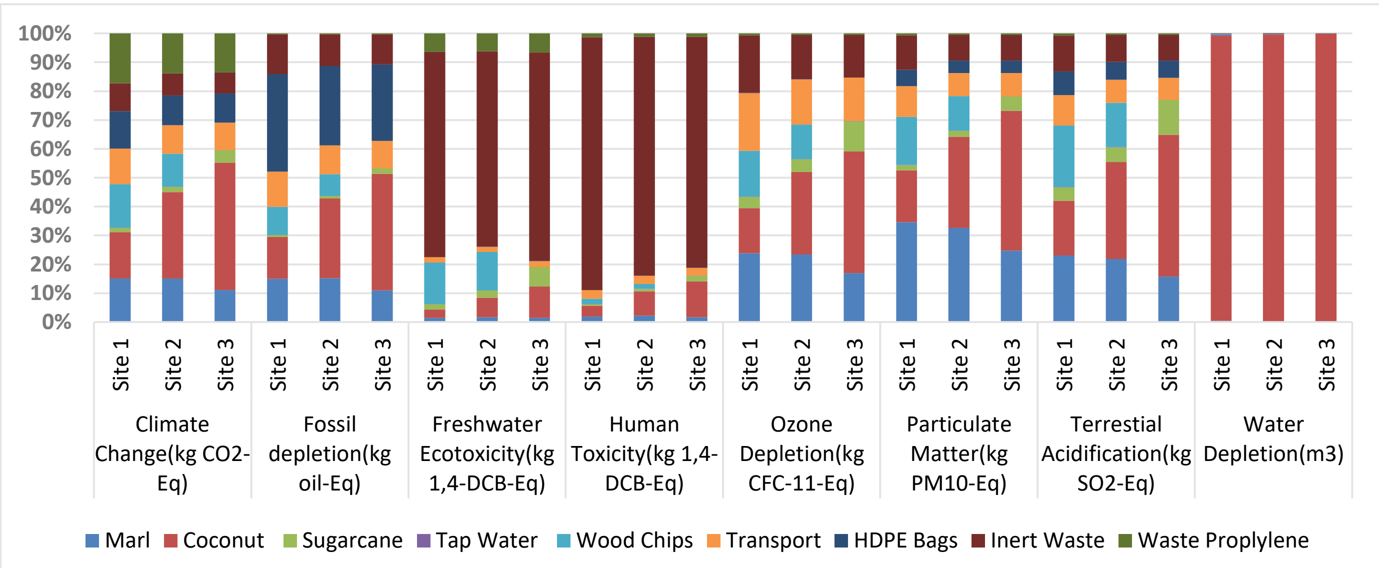

Fig. 4 Material wise midpoint results for clay cups LCA

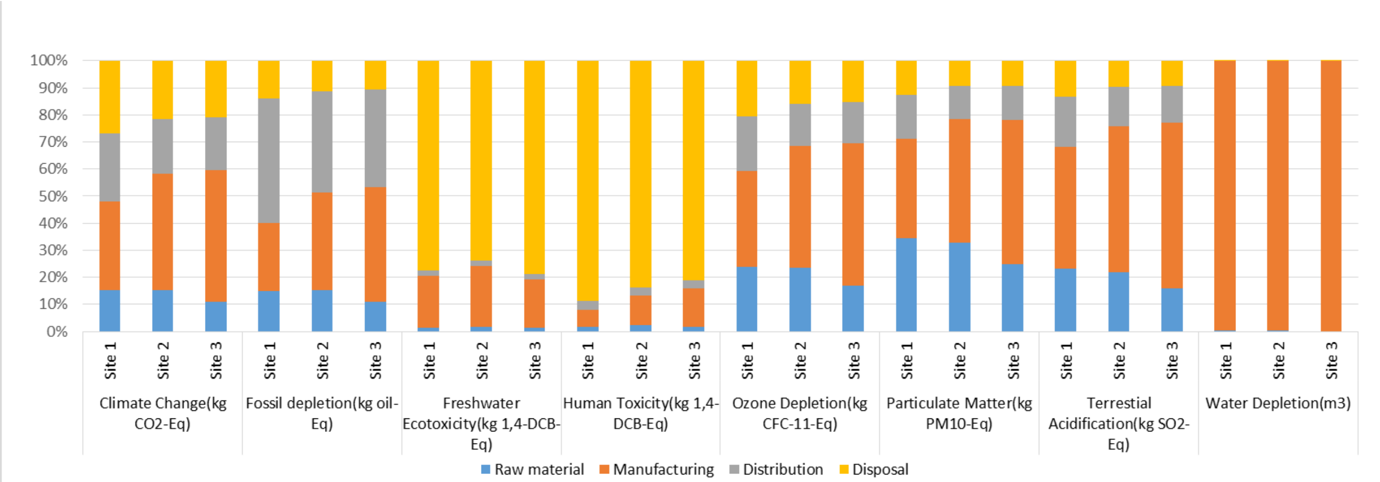

Fig. 5 Life cycle phase wise midpoint results for clay cups LCA

easier as well as the energy required for the baking will also be less.

Fig. 5 shows the midpoint impact in eight categories throughout the life cycle phases of the clay cups. With regard to climate change, all life cycle phases have a significant share on the total impact. The impact on fossil depletion is mainly driven by manufacturing as well as the distribution phase. Toxicity impacts are dominated by the disposal phase, and water depletion impacts are dominated by the manufacturing phase.

In Fig. 6 the assessment results are expressed on an endpoint level for different materials. ReCiPe endpoint, which lets environmental effect in a single score, is designed around three major damage categories of ecosystem quality, human health and resources. In this analysis, the contribution of the different materials that are used for making the cup are compared. Several hotspots can be observed. With regard to ecosystem quality, the fuel used for firing of kiln (coconut husk) is the major contributor. For human health, the inert waste is one of the key drivers, and with regard to resources, the largest contributors depend very much on the selected location. The resources used for the clay cups have little environmental impact.

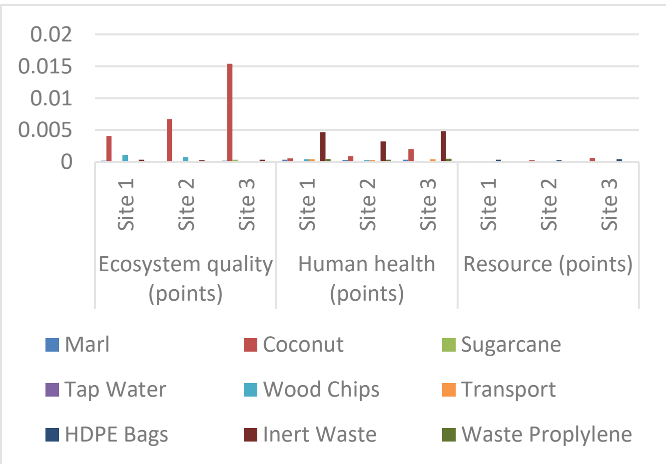

Fig. 6 Endpoint results for clay cups LCA (material wise)

Fig. 7 shows the end point category results for the different life cycle phases of a clay cup. It also shows that the environmental impacts are mainly due to the manufacturing and disposal phases. Fuel used in the kiln is responsible for the environmental impacts in manufacturing phase.

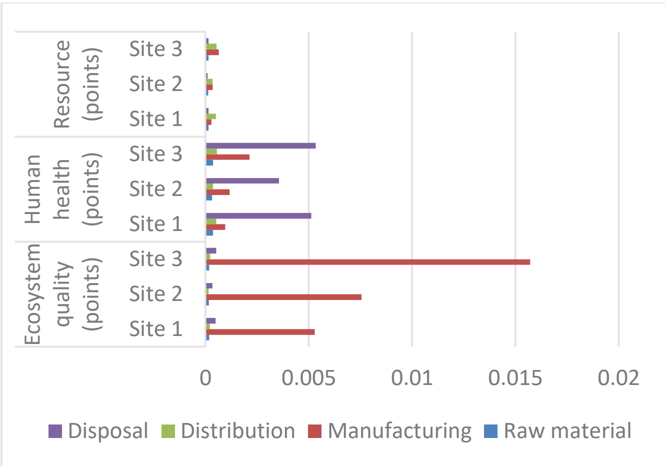

Fig. 7 Endpoint results for clay cups LCA (phase wise)

2.3. Social Impact

The assessment of social impacts is focused on the jobs in the pottery sector. In India clay cups are made mostly by rural potters. Communities of potters can be found in different locations throughout the country, and the work of making cups and pots is a communal effort. The material cost is low, and the fuel used for firing is mostly agricultural or industrial waste. Some estimates of the population of rural potters are more than 3 million [3]. In 2004, the Minister for Railways in India decreed that all tea and coffee served to passengers traveling on Indian Railways would be in clay cups [3]. The justification for this directive was that this would reduce the litter and waste caused by plastic cups, and it would preserve employment opportunities for a large rural population. Critics of this policy noted that paper cups were much cheaper than clay cups (INR 0.2/cup compared to INR 0.5 for the clay cups for railway bulk purchases), and that clay cups were usually disposed at the train station, generating litter. However, as noted in [2], fragments from clay cups quickly disintegrate under the sun and rain, returning to the soil as ”a perfect ecological model”, and paper cups, if not collected properly, can also result in aesthetically and environmentally harmful debris.

Estimates for production times of cups vary widely. The time for the molding of each cup is noted to be ten seconds, and the output of a potter is observed to be exceed thousands of small clay cups per day [2]. These estimates are not based on systematic studies, and the ten seconds is only for molding each cup by “throwing off the hump” - a technique for molding where many small cups are swiftly formed from a large lump of clay rotating on the potter’s wheel. As noted above, there is considerable additional effort including the retrieval of clay, the gathering of fuel, setting up of a kiln, dismantling of the fired batch and packing and distribution of the cups. Production measurements made as part of this study noted that a batch of clay cups and pots, composed of 100 big pots, 200 small pots and 500 small clay cups with a finished weight of 2700 grams, 800 grams and 100 grams respectively takes over 150 man-hours to complete. Given the large number of cups required for serving the tea drinking population in India and the availability of low-cost labor, the employment opportunities involved in the production of clay cups are substantial. Furthermore, alternate employment opportunities for potters are not readily available. Some potters’ communities have been in existence for several hundred years and the evaluation of social sustainability must take the viability of these communities into consideration.

The discussion above is largely anecdotal but is the starting point for an analysis of the social sustainability impacts related to the production and use of clay cups.

3. Conclusions

Disposable clay cups have been used for beverages in India for millennia. In recent times, they are being replaced by non-earthen containers. This paper explores the economic, environmental and social impacts associated with the use of clay cups, and presents some preliminary results related to the environmental assessment of the life cycle of this product. The discussion on social impacts is not quantitative, but issues that should be addressed are identified and further work on developing related measures is ongoing. Discussions on the use of clay cups have been elevated by political intervention in favor of their continued usage - and critics have disparaged this effort without offering a reasoned counterargument. This paper starts the systematic analysis which will lead to an objective tally of the three dimensions of sustainability related to the use of clay cups. The life cycle assessment of the clay cups shows that the manufacturing phase and the fuel used for the firing of kiln in the manufacturing phase are the environmental hot spots. The current research is based on the traditional potteries used by the artisans in rural India for producing these clay cups. Future studies can be carried out on the mechanization of the process.

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References

[1] Kolkata’s age old tradition of bhar chai, Published Oct 26, 2016, url=https://www.aljazeera.com/

[2] India’s passion for traditional tea in a clay cup, Updated Feb. 3, 2011, url=http://news.bbc.co.uk/2/hi/programmes

[3] Pots of Money for Tea in pot:Laloo’s experiment with earthen cups comes at high price, Published June 13, 2004, url=https://www.telegraphindia.com

[4] Potting, Jose and van der Harst, Eugenie. Facility arrangements and the environmental performance of disposable and reusable cups. The International Journal of Life Cycle Assessment 2015; 20,8,1143–1154,

[5] Van der Harst, Eugenie and Potting, Jose and Kroeze, Carolien,. Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups. Science of the Total Environment 2014; 494:129– 143.

[6] Vercalsteren, A., Spirinckx, C. & Geerken, T. Life cycle assessment and eco-efficiency analysis of drinking cups used at public events. Int J Life Cycle Assess 2010; 15: 221–230.

[7] Factsheet: How much disposable plastic we use,Accessed October 15, 2018, url=http://www.earthday.org/2018/04/18

[8] Dreyer, Louise Camilla and Hauschild, Michael Z and Schierbeck, Jens. Characterisation of social impacts in LCA. Int J Life Cycle Assess 2010; 15(3): 247–259.

[9] Righi D., Meunier A. Origin of Clays by Rock Weathering and Soil Formation. In: Velde B. (eds) Origin and Mineralogy of Clays. Springer, Berlin, Heidelberg 1995; 978-3-642-08195-8.

[10] Sangwan K. S., Choudhary K. Benchmarking environmental performance of electric insulator supply chain in India using life cycle assessment. Int J Life Cycle Assess 2019; 24 (3): 518–529