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Financial and environmental sustainability in manufacturing of crepe rubber in terms of material flow analysis, material flow cost accounting and life cycle assessment

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ABSTRACT

The natural rubber (NR) processing industry plays a critical role in the economies of many developing countries, particularly in Asia. Among the different types of NR, crepe rubber holds a significant position, as it is used to produce pharmaceutical and surgical rubber items, and also articles that are in contact with foods. At present, the crepe rubber manufacturing has been challenged by low productivity, rising cost of production, and environmental issues. Therefore, this study was aimed to assess the feasibility in the adoption of sustainable manufacturing practices in the crepe rubber production as a case study in Sri Lanka. This study consisted of three steps: 1) quantification of material and economic losses and global warming potential (GWP) via material flow analysis (MFA), material flow cost accounting (MFCA), and life cycle assessment (LCA) on a gate-to-gate basis, 2) developing proposals of improvement options with the help of Pareto and What-if analyses, field interviews, and the existing literature; and 3) validation of suggested improvement options through the re-execution of MFA, MFCA, and LCA. For 1 MT of rubber input, the underlying economic losses and GWP impact in the current manufacturing process were identified as LKR 19,585 and 279.3 kg CO2e with the values of 7% and 13% for Relative Standard Deviation, respectively. As improvement options, reduction options of water, chemicals, electricity, milling duration were proposed. It revealed that adoption of these reduction options could mainly reduce 32,064 kg of water and 30.1 kWh of electricity resulting in 5.3% of cost savings and a 4.3% of GWP impact reduction. Other implications associated with improvement options and their limitations are also discussed.

1. Introduction

The natural rubber (NR) industry plays a critical role in the economies of many developing countries, particularly in Asia where 92% of world's NR produced (Markit, 2017). NR industry in Sri Lanka is the third largest export earner of the country (Sri Lanka Export Development Board (EDB), 2015). In 2014, NR exports contributed LKR 122,074 million (USD 824 million) to Sri Lanka's foreign exchange revenue (The Ministry of Plantation Industries, 2015) accounting for about 8% of the total annual export value (Sri Lanka Export Development Board, 2016). Furthermore, the NR sector has provided over 300,000 direct and indirect employments to Sri Lankans across various walks of life (Herath, 1984).

In NR production, rubber trees are tapped to collect fresh latex which is then processed into primary rubber products named as raw rubber [e.g., crepe rubber, concentrated latex, ribbed smoked sheets (RSSs)]. Subsequently, these raw rubber types are reprocessed into secondary rubber products (value-added rubber products) such as tires, tubes, gloves and condoms (Jawjit et al., 2010). Of the raw rubber types, crepe rubber is considered to be the purest form of natural rubber available in the market (Rubber Research Institute of Sri Lanka, 2003). Sri Lanka is the world's leading crepe rubber producer for the international market with a production of about 46,502 MT per year, which is about 31% of the overall rubber production in the country (Rubber Research Institute of Sri Lanka, 2008). Crepe rubber acts as a foundation of many pharmaceutical and surgical items which are in contact with human body (Rubber Research Institute of Sri Lanka, 2003).

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Being a long-term tree crop, rubber cultivation is considered as an environmental friendly process with low tech involved. A rubber tree fixes about 1 MT of CO_2 in its 30 year economic lifespan and even resource poor farmers could cultivate rubber in tropical climates (Munasinghe et al., 2014). In Sri Lanka and elsewhere, processing of latex to RSS is mostly done in small scale within the farmland. Crepe rubber manufacturing in Sri Lanka is done in factories built over 50 years ago, hence considered as a labor-, energy-, and material-intensive process in present day context. Compared to other categories of raw rubber, a considerable extent of skilled labor is involved in the processing of crepe rubber (Rubber Research Institute of Sri Lanka, 2003). A large amount of electricity is needed to run the heavy-duty machinery used for milling, water pumping, wastewater treatment, and factory lighting. Furthermore, heat energy generated from firewood is used to dry crepe laces in drying towers. Fresh water is one of the key material inputs in crepe rubber manufacturing. It is mainly used to dilute the latex and chemicals, to wash crepe sheets during milling, to avoid heat building up in machinery and for their cleaning. In different stages of crepe rubber manufacturing, chemicals are used as preservatives, bleaching agents, and coagulants (Rubber Research Institute of Sri Lanka, 2003; Cecil and Mitchell, 2005).

On this background, crepe rubber processing suffers from low level of labor productivity, lack of cost effectiveness and rising cost of manufacture (Peiris, 1997; Unescap, 2011; Tillekeratne, 2017; Edirisinghe, 2013). Obviously, these issues are connected with low level of efficiencies in material, labor and energy use, high degree of waste and losses and rise in cost of all inputs. Furthermore, high level of water use and effluent discharge in crepe rubber manufacturing would create environmental issues, if not addressed properly. Discharge of untreated rubber factory effluent to the environment may lead to water pollution, malodor and crop damage whilst high level of water consumption would results in intensified depletion of adjacent water resources (Massoudinejad et al., 2015). Other environmental issues related to crepe rubber production include emissions that occur from heavy electricity and firewood use (Tekasakul and Tekasakul, 2006; Kumara et al., 2016). Nevertheless, crepe rubber production in the country should continue to meet the international demand and to maintain the in-country economy. Therefore, it has become vital to develop and implement sustainable production strategies in crepe rubber production for its long-term existence.

For providing a cost-efficient solution to high firewood consumption, Siriwardena and Fuller (1997) investigated four solar powered drying tower systems for the crepe rubber drying process and concluded that a roof integrated solar air heater-storage system is effective in this regard. Also, Tillekeratne (1999) highlighted the steps taken by the Rubber Research Institute of Sri Lanka (RRISL) to minimize the cost involved in Sri Lankan crepe rubber manufacturing. Production of unfractionated and unbleached crepe rubber has been identified as an effective means in this regard due to avoidance of cost for the bleaching agent and saving on extra labor associated with the removal of the yellow fraction. Furthermore, RRISL has introduced a low-cost biological wastewater treatment system for rubber factory effluent and this has already been installed in many Sri Lankan crepe rubber factories (Rubber Research Institute of Sri Lanka (RRISL), 1999). Applying Covered Activated Ditch type reactors, Kudaligama et al. (2007) tried to minimize the cost associated with a biological wastewater treatment system. Also, Kudaligama et al. (2010) had investigated how nitrogen and other chemicals in the effluent affect the efficiency of wastewater treatment plants installed in crepe rubber factories. Based on a water sample analysis, Gamaralalage et al. (2016) assessed the effectiveness of available wastewater treatment plants in Sri Lankan NR sector. Identifying that the wastewater discharged from crepe rubber factories still contains harmful nitrate-nitrogen concentrations though being treated, the necessity of cost effective and efficient de-nitrification process in order to convert nitrate-nitrogen into nitrogen gas was stressed. Nevertheless, strict guidelines and standards have already been imposed by the central governmental authority of Sri Lanka to reduce the pollution level associated with the wastewater of crepe rubber factories (Central Environmental Authority, 1992). Meanwhile, Peiris (1997) reported some steps taken by a crepe rubber factory to reduce cost of production and to improve the quality of product, i.e., crepe rubber. Training on factory upkeep and the 5S concept had been effective in motivating the employees to reduce wastewater and keep the workplace clean while enhancing profits. In an attempt to quantify GHG emissions associated with crepe rubber manufacturing, Kumara et al. (2016) identified the electricity consumed by machinery as a prominent factor and noted that replacing such energy requirements with the electricity from renewable energy sources could be a sensible move toward curbing GHG emissions. However, no studies on process analysis of crepe rubber manufacture have been reported.

Though have not so far been used in the raw rubber manufacturing, various process analysis techniques have been developed and deployed to assess the performance efficiencies under different segments in the sustainability. In particular, Material Flow Analyses (MFA) and Material Flow Cost Accounting (MFCA) deal with the economic aspects whilst Life Cycle Analyses (LCA) extend the above two analyses to cover the environmental aspects of the sustainability. For instance, MFA and MFCA have been applied for Cassava processing (Jakrawatana et al., 2016), meat processing (Chaiwan et al., 2015), textile production (Kasemset et al., 2015) and wood products manufacturing in Thailand (Chompu-inwai et al., 2015), micro-brewery (Bamidele Fakoya and van der Poll, 2012) and paper manufacturing in South Africa (Doorasamy, 2015), and small medium scaled enterprises (SMEs) in Malaysia (Sulong et al., 2015). In all these studies, reduction in wastes and improvement in cost efficiency have been focused pinpointing the deficiencies in respective processes and ultimately enhancing profits. Nevertheless, the combine useof MFA, MFCA, and LCA have been limited to few studies. Ulhasanah and Goto (2012) used this combination to evaluate the environmental and economic performances in cement production of Indonesia. As a result, a new design for economically viable and less polluting cement production system was proposed. Nakano and Hirao (2011) developed a supply chain collaboration model for enhancing improvement activity of product environmental performance of which the above-mentioned tools were in its process analysis stage. Further, Schaltegger et al. (2012) used MFA, MFCA, and LCA to identify the process deficiencies in a beer brewing facility in Vietnam against an equivalent facility in Germany. Overall, the use of the said tools had confined to appraising the current environmental and economic situation of the respective processes in all these studies; however, there are some lacunas in assessing the financial worthiness of proposed changes in the systems.

Techniques like cost-benefit analyses are used to determine the worthiness of an investment against the financial returns (Kokubu and Tachikawa, 2013). For instance, Doorasamy (2015) integrated cost-benefit analyses with MFCA to identify the payback period of the boiler-related modifications proposed for a paper manufacturing company in South Africa. Also, a technique like Pareto analysis can be used to distinguish the key tasks having significant impact on the ultimate effect (Chompu-inwai et al., 2015). For instance, it has been used with MFCA to select the key loss cost factors in a meat processing factory (Chaiwan et al., 2015), a textile factory (Kasemset et al., 2015), and a wood products manufacturing company (Chompu-inwai et al., 2015) in Thailand.