

Assessing the Financial and Environmental Sustainability in Raw Rubber Processing; a Case Study with Ribbed Smoked Sheet Manufacture in Sri Lanka

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Abstract

Sri Lanka has been renowned for its top quality natural rubber products. Among the locally manufactured raw rubber types, ribbed smoked sheets (RSS) hold a significant position as it entails ca. 50% of total natural rubber production in island. With no sufficient information on effectiveness in the use of materials and finance and then environmental impacts of RSS manufacture, this study aimed at assessing RSS manufacturing process adopting Material flow analysis, Material flow cost accounting and environmental Life cycle assessment in three factories in view of providing effective suggestions for making the system to be more cost efficient and environmentally friendly. Results indicated that manufacture cost, financial loss and GHG emissions generated by processing 1 MT of RSS were LKR 104,004 ± 6,336, LKR 1,007 ± 44 and 38.0 ± 2.1 kg CO₂e, respectively (mean ± standard error). As an improvement option, installing single-day smoke dryers was proposed. This option could reduce firewood consumption per 1 MT of RSS by ca. 30% resulting in 0.1% and 14% of reductions in manufacture cost and GHG emissions, respectively. Implications of these findings are also discussed.

Keywords: Ribbed smoked sheets (RSS); Material flow analysis (MFA); Material flow cost accounting (MFCA); Life cycle assessment (LCA); Sri Lanka

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1. INTRODUCTION

Sri Lanka is the eighth largest natural rubber producer in the world and accounts for ca.1.2% of natural rubber produced worldwide^[1]. Being the second largest crop-based industry in island, natural rubber industry has been a key contributor to Sri Lankan economy in terms of foreign exchange earnings and employment generation. For instance, 88.57 MT of natural rubber had been produced in 2015 and 10.37 MT of which had been exported with a value of USD 22.13 million^[2]. Moreover, over 300,000 of employment opportunities have been recorded to have generated by this sector to Sri Lankans across various professions and walks of life^[3]. Natural rubber is used to produce value added rubber products like tyres, tubes, footwear, condoms, surgical gloves, etc. which are indispensable for humans. Ribbed smoked sheet/s (RSS) is a type of natural rubber which dominates the natural rubber manufacture in Sri Lanka and elsewhere. More than 50% of natural rubber produced in Sri Lanka is in the form of RSS^[4]. RSS is used as a raw material for tires, tubes, hoses and footwear at value addition. RSS manufacture in Sri Lanka is mostly done in small scale within the farmland.

RSS manufacture is a labor-, energy-, and material-intensive process; requires substantial amounts of thermal energy, fresh water, and chemicals at different stages of manufacture^[5]. Therefore, RSS manufacture would have been confronted with high cost of production, low cost efficiency and various environmental impacts (e.g., water pollution, greenhouse gas (GHG) emissions, etc)^{[1], [6], [7], [8]}.

Several studies have been conducted to scrutinize above issues. Peiris^[6] and Fagbemi^[9] outlined number of cleaner production measures to uplift the profitability and productivity with lesser environmental load in RSS manufacture. Rathnayake^[10] reviewed an energy efficient smokehouse to smoke-dry RSS in a day to save cost of firewood and labor. In view of quantifying GHG emissions associated with RSS manufacture in Thailand, a life cycle assessment has been performed by Jawjit^[11]. Observing that firewood use as a key determinant affecting GHG emissions, Jawjit^[11] proposed various measures to uplift the efficiency of smokehouses to use less firewood. The same method has been followed by Wijaya^[12] to quantify GHG emissions associated with RSS manufacture in Indonesia. Meanwhile, Musikavong^[13] attempted to quantify water scarcity footprint of RSS manufacture in Thailand. A device called electrostatic precipitator

has been introduced in Tekasakul^[14] and Tekasakul^[7] to minimize smoke particles inside RSS factories.

No previous studies have ever considered economic and environmental aspects of entire RSS manufacturing process as a whole. Instead, they have been confined to several partial analyses scrutinizing an issue or a set of issues belonging to economic or environmental aspect of RSS manufacture. Therefore, identification of real issues or hotspots in RSS manufacture would have been failed. None of the studies foresee the benefits of improvement options in quantifiable terms. Hence, this study aims at addressing such lacunas in view of developing RSS manufacture to be more cost-efficient and environmentally friendly.

2. METHODS

2.1. RSS manufacture

RSS manufacture in Sri Lanka is mostly done by smallholders who own less than five acres of rubber. RSS factories in this scale can process up to 40 kg of rubber per day^[5]. As shown in Fig. 1, rubber trees are tapped and man-handled to the factories. As soon as latex reaches the factory, latex is coagulated by adding water and formic acid after putting it across several flat pans. Once the coagulum formed, it is taken for milling. Two hand operated rollers, i.e. smooth and grooved rollers, are used for this purpose. Coagulum is passed two to three times through smooth roller before sending it once through grooved roller. Milled sheets are then rinsed and draped in a shade for dripping prior to smoke-drying. Smoke-drying is done by hanging sheets at a smokehouse and keeping them there for three to five days. The dried sheets are finally weighted and transported to regional retailing centers.

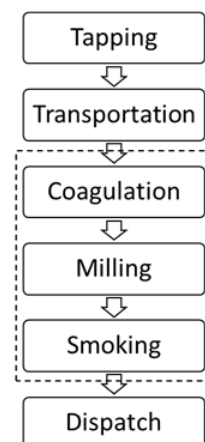


Fig. 1. Ribbed smoked sheet manufacturing process in Sri Lanka. Perforated line depicts the system boundary of the study.

2.2. Goal definition

A three-stepped method has been deployed as follows: step-1) quantification of material flows and waste, monetary loss, and GHG emissions using material flow analysis (MFA), material flow cost accounting (MFCA) and life cycle assessment (LCA) respectively, step-2) Identification of key drivers of monetary loss and GHG emissions and developing improvement options using What-if analysis, field interviews and literature; and step-3) Benefit validation via repetition of step-1.

2.3. Step-1

2.3.1. System definition

This study entails all activities carried out in small scale RSS factories in Sri Lanka (please refer to Fig. 1). External activity such as formic acid production has also been considered for LCA herein.

2.3.2. Functional unit

Production of 1 MT of RSS was considered as the functional unit of the study.

2.3.3. Data collection

Data was collected by investigating three RSS factories (factory A, B, and C) belonging to rubber smallholders in Sri Lanka. They were scattered across three major rubber producing districts of Kegalle, Kurunegala and Gampaha, and could process ca. 30 kg of rubber per day. All factories were visited in person to collect required data. Dry rubber contents of field latex and throughputs, quantities of acid and water were measured on-site. Rubberwood required as firewood for smoke-drying was known by interviewing workers and owners. Lab experiment at Rubber Research Institute of Sri Lanka was carried out for knowing ash content of rubber. Required emission factors for LCA were extracted referring to literature.

2.3.4. Material flow analysis

MFA is a systematic assessment of the flows and stocks of material within a system defined in a space and time^[15]. MFA is used herein to visualize all material inflows, throughputs and outflows in RSS manufacture and to achieve an input-output balance.

Material flow for each factory was prepared using STAN 2.5 software^[16] and finally combined to get a common material flow representing RSS manufacture in Sri Lanka. Values in material flow were indicated using mean $\pm$ standard error (SE). For the sake of clarity, material flow diagram herein was created using e!sankey software^[17].

2.3.5. Material flow cost accounting

MFCA is tool of having both environmental management accounting and cost reduction abilities,

which surpasses traditional management accounting^[18]. It allocates material, system, and energy costs into positive and negative product costs based on material flows at each quantity center (QC), i.e., unit process. However, waste management costs are solely allocated to negative product costs. Here, positive and negative product costs are the costs that are allocated to product and wastes, respectively^[19]. Moreover, MFCA considers three types of materials^[20]: raw, auxiliary and operating materials. Raw materials are materials that create final product. Auxiliary materials are the materials that end up in final product. Operating materials are essential for producing final product but always end up as non-product outputs, i.e., waste or emissions.

MFCA model of each factory was designed on excel spreadsheets. Then all models were combined to get a common MFCA model which signifies RSS manufacture in Sri Lanka. Values in this model were indicated using mean $\pm$ SE. Sri Lankan rupees (LKR) was used as the unit for MFCA; LKR 1 = USD 0.0062. For clarity, e! Sankey software^[17] was used to create common MFCA model in Fig. 3.

2.3.6. Life cycle assessment

LCA is a tool which measures environmental impacts of a product's life cycle, i.e., from raw material extraction to disposal or recycling^[21]. However, conducting an in-plant assessment has been the focus of LCA herein. Due to lack of data on emission factors, LCA herein has been confined to measuring global warming potential (GWP) impact incurred by GHGs. GWP impact model mentioned in Jawjit^[11] was used in this regard. In some cases where an emission factor was found in kg CO₂e per unit, that was multiplied by level of activity to calculate GWP. Required emission factors were extracted from literature and are as follows: firewood use^[11]; CO₂:110 kg/TJ, CH₄: 30 kg/TJ, N₂O: 4 kg/TJ; and formic acid^[22]; 2.51 kgCO₂e/kg. Since firewood came from the rubber trees which had been replanted, CO₂ emissions from firewood burning were not included in GWP impact. GWP impact per activity and total GWP were calculated for each factory and then combined to get common GWP impact values in mean $\pm$ SE representing RSS manufacture in Sri Lanka.

2.4. Step-2

Step-2 has two objectives: 1) Identifying key drivers of GWP impacts; and 2) Proposing applicable improvement options. For the first objective, What-if analysis^[23] was deployed to assess the impact that one parameter in a model would incur on that model when it changes. Only one parameter was changed at each iteration while the changes were recorded and ultimately presented as a tornado plot (see Fig.5). The

longer the bar, the greater the impact that a parameter had on the model.

The second objective was achieved by interviewing factory owners and referring to literature.

2.5. Step-3

The objective of this step is to evaluate financial and environmental benefits of the proposed options. MFA, MFCA and LCA were re-executed in this regard. In order to compare the performances of options against that of current situation, changes in five Organisation for Economic Co-operation and Development's sustainable manufacturing indicators (SMIs)^[24] ((SMIs; water intensity (O1), energy intensity (O2), renewable proportion of energy (O3), GHG intensity (O4), and residual intensity (O5)) were examined.

3. RESULTS AND DISCUSSION

3.1. Results of Step-1

As shown in Fig. 2, manufacture of 1 MT RSS requires $2,764 \pm 210$ kg of field latex, 449 ± 46 kg of formic solution and $4,490 \pm 1,532$ kg of water. Not following industrial standards seems to have caused high uncertainties in the use of operating materials, i.e., formic acid and water. Firewood had been the only energy source for RSS manufacture and was used to generate heat for smoke-drying process. Average use of firewood was recorded as 767 kg per 1 MT of rubber input with a SE of 83. This amount provides $12,330 \pm 1,334$ MJ of thermal energy on the basis of 16.1 MJ per kg of firewood^[25]. No wastewater treatment plants were installed at factories; hence, no treatment was given to wastewater prior to discharging.

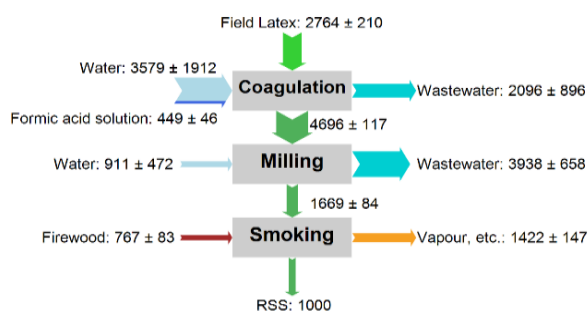


Fig. 2. Material flow analysis of ribbed smoked sheet manufacture (RSS) per 1 MT of RSS. All values are denoted as mean $\pm$ standard error in kg per 1 MT of RSS.

MFCA of RSS manufacture is illustrated in Fig. 3 where all QCs incur negative material costs. This happens because formic acid acts as an operating material, in other words, it streams out at each QC whereas, no rubber losses were identified; hence, no negative electricity and system costs were evident. Total negative product cost of the system was recorded as LKR 1007 ± 42 ,

reflecting ca. 1% of total input cost. This affirms that monetary loss of RSS manufacture is very less hence in a state which can be neglected.

As per LCA, GWP impact of RSS manufacture was found to be as low as 38.0 ± 2.1 kg CO₂e. As shown in Fig. 4, there were only two activities contributing to GWP impact in RSS processing; firewood and formic acid use. Of them, firewood use is the largest contributor to GWP impact accounting for ca. 63% of total GWP. In addition, formic acid use notably adds 14.0 ± 0.6 kg CO₂e to total GWP impact in processing of 1 MT of rubber.

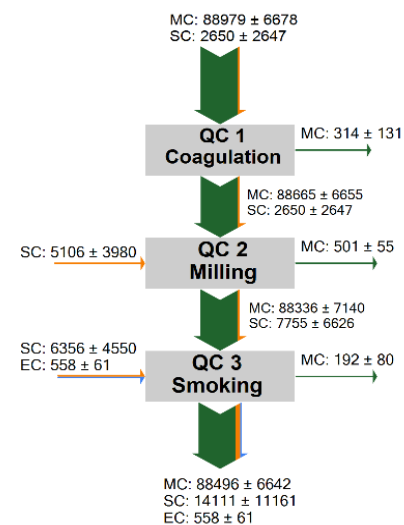


Fig. 3. Material flow cost accounting of ribbed smoked sheet manufacture (RSS) per 1 MT of RSS. Codes QC, MC, SC and EC refer to quantity center, material cost (in green), system cost (in orange), and energy cost (in light blue), respectively. All values are denoted as mean $\pm$ standard error in kg per 1 MT of RSS.

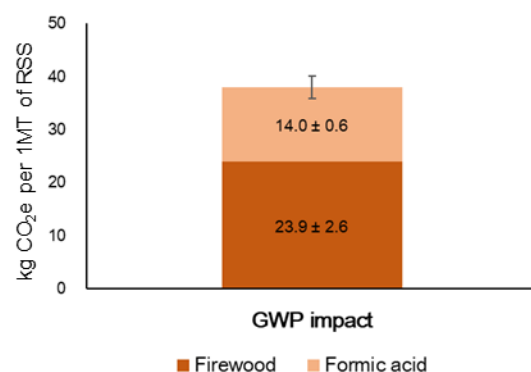


Fig. 4. Global warming potential (GWP) of ribbed smoked sheet manufacture (RSS) per 1 MT of RSS. All values are denoted as mean $\pm$ standard error in kg CO₂e per 1 MT of RSS.

3.2. Results of Step-2

As per results of step-1, it appeared that monetary loss in RSS manufacture was negligible. Therefore, identifying key drivers affecting GWP impact was focused. What-if analyses performed on factory A, B and C highlighted that firewood use had been the most

influential on GWP impact (Please refer to Fig. 5 for tornado plot of factory B). As mentioned in section 3.2.6, GWP herein excludes CO₂ emissions as firewood becomes a regenerated material.

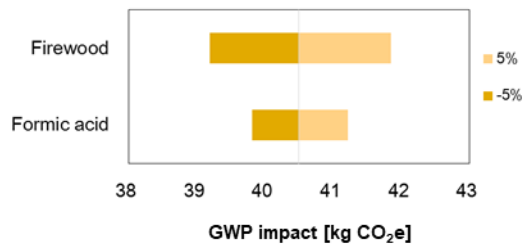


Fig. 5. Tornado plot of What-if analysis in factory B. GWP refers to global warming potential.

Factory A used an efficient smokehouse that could complete smoke-drying in a day. This smokehouse was called single-day smoke (SS) dryer^[10]; hence, factory A consumed far less amount of firewood than that the other two factories did. Therefore, we propose factory B and C to install this SS dryer as an improvement option to reduce GWP impact.

3.3. Results of Step-3

The main concern over applying SS dryer had been reducing GWP impact. As per results, GWP attributed to firewood combustion had reduced to 18.7 kg CO₂e from 23.9 ± 2.6 kg CO₂e per 1 MT of RSS; hence, total GWP per 1 MT of RSS had decreased to 32.7 ± 0.6 kg CO₂e from 38.0 ± 2.1 kg CO₂e. Though no change could be observed in negative product cost, overall manufacturing cost had slightly been reduced by 0.1% per 1 MT of RSS (from LKR 104004 $\pm$ 6336 to LKR 103883 $\pm$ 6386).

Among the potential changes in SMIs after installing SS dryer to factory B and C, the largest variation can be observed in O4 (GHG intensity) due to the reduced GWP impact (Fig. 6). Application of SS dryer has reduced firewood use in manufacture by 30%; hence, O2 (energy intensity) has also decreased. However, the rest of the indicators showed no significant changes.

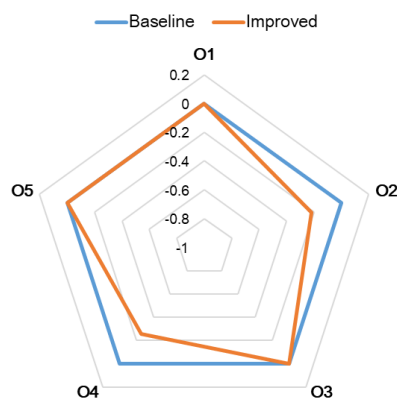


Fig. 6. Average change in sustainable manufacturing indicators for current situation (baseline) and improved situation of ribbed smoked sheet manufacture (RSS) per 1 MT of RSS. O1, O2, O3, O4 and O5 refer to water intensity, energy intensity, and renewable proportion of energy, GHG intensity, and residual intensity.

Overall, SS dryer had been a useful option for reducing not only GWP impact but also cost of manufacture. Moreover, additional benefits such as consuming low space in factory, and low health risks are foreseeable^[10]. During the field visits, we observed that workers in factory B and C were excessively exposed to wood smoke as they entered smokehouses for firing and removing dried RSS. This is health-threatening^[7]. Since SS dryer can be operated from outside, health risks are minimal.

Virtually, no studies on financial aspects in RSS manufacture are found; however, several studies have reported on GWP impact of RSS manufacture. GWP impact of Thai RSS manufacture had been recorded 40 kg CO₂e^[11] whereas that in Indonesia was 139 kg CO₂e^[12]. Both GWP impacts remain larger than GWP impact (i.e., 38 kg CO₂e) recorded in this study for Sri Lanka. Scale of manufacture can be a major factor for this difference as both Thai and Indonesian GWP impacts were based on small and medium-sized factories. These factories used both electricity and firewood for their manufacture. GWP impact incurred by transportation has also been regarded in calculating above GWP impacts.

The method used herein had been very useful in identifying monetary loss, GWP impact and degree of improvement. If repeated after applying improvement options, this method may reveal a new set of issues at each repetition. Owners may try to address such issues when required to gain profits and environmental benefits. Progress made overtime can be analyzed using tools such as SMIs and illustration techniques introduced herein.

Apart from SS dryer, solar based dryers^[26] may eliminate firewood consumption resulting in less GWP impact for RSS manufacture. Proper adoption of industrial standards can reduce formic acid consumption resulting in less monetary losses and GWP impact. This would also reduce the toxicity in wastewater. Moreover, mini scale biogas plants can be introduced to small scale RSS manufacturers to generate their own power and heat from wastewater. Whilst providing a renewable energy source to save money, this measure would lower wastewater pollution.

However, barriers to sustainability of RSS manufacture still exist; limited expertise in sustainable manufacturing or cleaner production tools and techniques, prioritizing profits and higher capital costs are some of them. Therefore, regular workshops on sustainable manufacturing and government subsidies

provided for one who tries to initialize cleaner production are pivotal in addressing the said barriers.

Not assessing social impacts of RSS manufacture is a major lacuna in the method herein. Therefore, inclusion of a tool such as social life cycle assessment may be considered by future research. Evaluation of financial feasibility of SS dryer or any other improvement options is another component of importance. Adoption of discounted cash flow analyses with prominent financial indices such as net present value, internal rate of return and discounted payback period can be considered in this regard.

4. CONCLUSIONS

Current RSS manufacture in Sri Lanka incurs LKR 1007 ± 42 of monetary losses and 38.0 ± 2.1 kg CO₂e of GWP impact per 1 MT of RSS. Identifying key monetary loss factors was skipped as monetary losses remained ca. 1% of total manufacturing cost. Firewood use was observed as a key factor affecting GWP impact. Therefore, SS dryer in factory A was proposed for factory B and C, as an improvement option for reducing GWP impact. SS dryer could reduce firewood use by 30%, resulting 0.1% and 14% reductions in cost of manufacture and GWP impact, respectively. This study has taken an initial step to improve RSS manufacture and stressed the importance of combining process analysis and decision-making techniques and tools. Therefore, future research may develop the method herein for further improvements in RSS manufacture.

ACKNOWLEDGEMENT

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Reviewer's Comment	Response	Location of Response in Revised Manuscript
REVIEWER COMMENTS		
1. Its better this part move to METHODS	We have moved Section "RSS MANUFACTURE" to "METHODS" as advised.	Section: Methods Sub-section: RSS manufacture
2. How much the capacity of each RSS factory	We have mentioned average capacity of small-scale RSS factories in Sri Lanka in "METHODS" section. Capacity of the audited factories was also mentioned in the same section.	Section: Methods Sub-sections: RSS manufacture; Data collection
3. Built?	We have changed the word "built" to "designed" for clarity.	Section: Methods Sub-section: Material flow cost accounting
4. 1 MT = 1000 kg?	Yes. 1 MT denotes a metric ton which equals to 1000 kg. Functional unit for MFA, MFCA and LCA of this study has been 1 MT of RSS, in other words, 1000 kg of RSS.	N/A