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Evaluation of the environmental and economic performances of three selected textile factories in Biyagama Export Processing Zone Sri Lanka

Shyamika Shiwanthi[a,*], Erandathie Lokupitiya[a], Sena Peiris[b]

[a] *Department of Zoology and Environmental Sciences, Faculty of Science, University of Colombo, Colombo 03, Sri Lanka*
[b] *Faculty of Graduate Studies, University of Sri Jayewardenapura, Sri Lanka*

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ABSTRACT

The textile industry plays a critical role in the Sri Lankan economy. It is also a major consumer of energy and water and it is the fifth largest contributor to CO_2 emissions in the world. With the increasing popularity of the concept of sustainability and the effect of the external and internal drivers, the textile industry of Sri Lanka has adopted more environmentally friendly production processes and uses sustainability as a marketing tool. This study was undertaken to evaluate the environmental and economic performances of three selected textile processing factories in the Biyagama Export Processing Zone, Sri Lanka. Eco-efficiency analyses were performed for each factory using the formula suggested by the World Business Council for Sustainable Development (WBCSD). Total production for the factories for five- year period (2011–2015) was considered as an indicator of product value. Indicators of environmental influence were selected by considering inputs (energy, material and water) and outputs (wastewater and greenhouse gas emission) associated with the production process. Sustainability measures undertaken by the factories within the study period were evaluated using the eco-efficiency change over time. The sustainability measures taken by each factory had a positive impact on their eco-efficiency. A correlation analysis considering eco-efficiency of different environmental factors and the revenue of the factories was performed. The study revealed that eco-efficiency influenced the production cost. The study also revealed a positive significant correlation between eco-efficiency and the factory level revenue.

1. Introduction

The textile industry plays a critical role in the Sri Lankan economy due to its contribution to industrial production, employment and exports. The textile industry accounts for 16% of Gross Domestic Product (GDP) of the country. It recorded a substantial growth of 8.5% in 2014 compared to 7.8% in 2013. It is the highest foreign exchange earner in the industrial sector amounting to 40% of total exports and 52% of industrial exports. It is the largest employer in the industrial sector providing more than 300,000 employment opportunities to the local community (Embuldeniya, 2015). Despite the positive effects on the economy, the sectors on the environment is negative as it causes resource depletion, greenhouse gas emission and pollution. Mostly the water pollution is due to the high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the effluents produced. Greenhouse gas (GHG) emissions associated with the textile industry include CO_2 (the majority) and N_2O. In addition, NO_X, SO_X, dust, etc., contribute to air

* Corresponding author.
E-mail address: shyamika22@gmail.com (S. Shiwanthi).

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pollution.

The textile processing industry requires a large volume of water for various unit operations especially the wet process. The production of approximately 1 kg of cotton through wet processing requires 60–360 L of water. The specific energy requirement for natural fibre processing has been recorded as 10–20 $MJkg^{-1}$ and that for chemical fibre processing is 5–50 $MJkg^{-1}$ (Chavan, 2001). Due to the popularization of the sustainability concept and identification of the environmental impacts of the industry, strategic drivers, internal drivers and external drivers have led the textile factories to initiate sustainability practices (Amadi et al., 2014). Internal drivers such as managerial attitudes, safety of employees, company culture, concern about environmental impacts and the state of the environment, protection of land, social responsibilities also have a positive effect on practising sustainability (Amadi et al., 2014). Most powerful drivers are categorized as “external drivers”, which include the pressure from government and other stakeholders (public, competitors, investors, etc.), customers’ demand, compliances with regulations, etc. (Amadi et al., 2014). Industries use sustainability principles as a marketing strategy, particularly to achieve competitive advantage, differentiation, marketing benefits, public image and reputation. Sustainable measures are also taken as a cost saving strategy and to improve the quality of the products (Amadi et al., 2014).

Three textile factories located within Biyagama Export Processing Zone (EPZ) were selected for this study. All three companies have used their sustainability practices as a marketing tool and published their sustainable nature on their own websites. All three companies have signed agreements with their customers (e.g. Nike, Adidas, etc.) to maintain the environmentally friendly nature of the factories. They have obtained Environmental Protection Licences (EPLs) for emission and disposal of waste and signed agreements to comply with the Board of Investment (BOI) standards, etc. The names of the factories are not revealed due to ethical concerns. Therefore, the factories were labelled as A, B and C. These factories have practised sustainability over several years and used their sustainability practices for marketing purposes. In this study, we analysed their performance for a period of five years (2011–2015).

1.1. *Eco-efficiency*

Different organizations provide different methods for calculating eco-efficiency. The World Business Council for Sustainable Development (WBCSD) has published guidelines to report company performance and Badische Anilin und Soda Fabric (BASF) has also developed a unique method to calculate eco-efficiency. With the aim of providing a common methodological framework for eco-efficiency assessment, the International Standards Organization published ISO 14045 (Environmental management- Eco-efficiency assessment of product systems- Principles, requirements and guidelines) in 2012, but in this study we followed the guidelines given by the WBCSD, as it is freely available and can be followed by people from the industry sector with moderate knowledge of environmental management.

The WBCSD introduced the eco-efficiency concept in 1992. According to the WBCSD, “Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth’s estimated carrying capacity” (Bidwell and Verfaillie, 2000). Eco-efficiency combines basic economic and environmental components. It encourages a company to achieve more value with lower inputs and emissions. It stimulates environmental improvement and economic development simultaneously. Therefore eco- efficiency in simple terms means producing more with less environmental impact (Bidwell and Verfaillie, 2000), including the impact on climate change.

The WBCSD introduced seven success factors to achieve and increase eco-efficiency in the business sector: 1) Reduction of material intensity, 2) Reduction of energy intensity, 3) Reduction of toxic dispersion, 4) Enhancement of material recyclability, 5) Maximum sustainable use of renewable resources, 6) Extension of product durability, and 7) Maximum service intensity of products (Bidwell and Verfaillie, 2000).

The eco-efficiency concept incorporates the main environmental performance indicators e.g. cleaner production, pollution prevention and waste minimization (Salem et al., 2011). According to Salem et al. (2011), the eco-efficiency concept has advantages over other environmental performance measures because it can give a real indication of environmental performance of a business despite differences between different businesses entities.

The eco-efficiency framework is flexible enough to be used by integrating with other concepts such as environmental indices, life cycle analysis, etc. and it can also be easily interpreted across the business spectrum (Bidwell and Verfaillie, 2000). Therefore this concept has been used in the literature for different purposes. For example, the eco-efficiency concept has been used as a tool to analyse sustainability of factories, identify the impact of economic activities on the environment,to find out the effect of corporate environmental performance on financial performance, to identify most environmentally friendly and economically beneficial production process to meet international standards and create possible linkage between environmental consumption and sustainability (Amadi et al., 2014; Burchart-korol et al., 2012; ESCAP, 2009; Tegstedt, 2011; UNIDO, 2002).

Laso et al. (2018) have integrated Life Cycle Assessment and Life Cycle Costing to propose a two-step eco-efficiency methodology assessment for the fish canning industry, which can be used by decision makers in the anchovy canning sector and industrial sector.

An eco-efficiency analysis based in Kenya has shown potential gain in the profitability of a firm by improving eco-efficiency in resource use (Kamande and Lokina, 2013). According to the latter study, proactive firms (whose Environment Management System (EMS) meets requirement of regulatory authorities and incorporate some voluntary actions such as Cleaner Production Initiatives or ISO certification) were found to perform better than reactive firms (whose EMS merely meets requirements of regulatory authorities) in terms of profitability and eco-efficiency. Moreover, the firms that combine both proactive and reactive EMS perform even better, which shows the benefit of adopting commitment based approaches with the compliance based approaches to environmental management.

Although some authors (Kamande and Lokina, 2013) have proved direct relationship between environmental and financial performances, another set of authors (Lucato et al., 2017) claim that it is not possible to establish a direct relationship between the environmental and financial performance of companies.

A study by Sklyarova et al. (2011) evaluated the state of environmental friendliness of a well-known furniture and textile retailer (IKEA) of Russia, which has gained publicity for it's environmentally friendly measures during manufacturing processes and operations.

In this study we selected three well-known textile factories in Biyagama EPZ, which have a good reputation for their sustainable practices and eco-friendly nature. The major objectives of this study are to compare and evaluate the environmental performance of each factory over the years to identify their level of eco-efficiency, identify the effect of sustainable practices on eco-efficiency and identify if there is a relationship between a factory's revenue and its eco-efficiency.

2. Methodology

All three factories use knitting technology to produce fabric by using imported yarn. Yarn is knitted by the machines, produce fabric. Then the fabric goes through wet processing which includes pre-treatment, dyeing, printing and finishing. In the pre-treatment step fabric undergoes desizing, scouring, bleaching and mercerizing which requires a large amount of water for washing, rinsing and steam generation. Each and every step uses pure water. Different kinds of chemicals are required for this process. Steam generating boilers consume a large amount of energy. All three factories use two types of boilers. One type operates by using biomass (sawdust, wood logs, wood chips) and the other one uses heavy fuel oil (HFO).

The dyeing process uses different amounts and types of textile reactive dyes, dye bath chemicals and auxiliaries to obtain the required colour and colour strength on the fabric. This process also requires a large amount of water in different temperatures (hot/cold) which requires energy. This process uses a high material to liquor ratio, which results in a large volume of effluents.

If it is necessary to print a pattern on the fabric, a pigment paste which includes various types of chemicals as thickening agent, binder and, other auxiliaries such as fixing agents, plasticizers, defoamers, etc., are applied to the fabric according to a pre-determined pattern and then the fabric is dyed and the pattern in fixed by using steam. Therefore, this step also requires energy for steam generation, machines, etc. and it adds a large amount of chemicals to the effluents.

Depending on the quality required for the fabric, different types of mechanical methods such as relax dryers, stenters, compactors, etc., and chemical methods like elastomeric finish, softening, anti-pilling finish etc., are used in the finishing process. Mechanical methods require different types of energy (heat, pressure and kinetic energy) while chemical methods use a number of chemicals to add different qualities to the fabric. This step also produces a large volume of effluents with high BOD and COD values.

All three factories produce fabric by using the above production processes. The amount of water, energy, yarn and chemical required and waste generated differ according to the amount and the type of the fabric each factory produces and technology used.

2.1. Input and output indicators

The indicators were selected based on the eco-efficiency formula which brings the economic and ecological dimensions together to relate product value to environmental influence. Eco-efficiency is calculated using the Eq. (1).

$$\text{Eco} - \text{efficiency} = \frac{\text{Product or service value}}{\text{Environmental influence}} \tag{1}$$

The product or service value indicators (economic variables) represent the productive outputs of the business. This can be expressed either in monetary terms (sales, value added) or in physical terms (quantity of production) (Boffa Miskell Limited, 2009). In this study; economic variables are expressed by using the quantity of products over the five-year study period. As factories were not willing to share the monetary values, the product value is expressed in physical terms (i.e. fabric production per annum).

Indicators for environmental influence (Physical indicators) represent those that are related to mass, and energy flow through the business process. According to WBCSD, physical indicators can be defined as core indicators or generally applicable indicators and sector specific or supplementary indicators (Bidwell and Verfaillie, 2000). The core indicators represent overall resource use and waste production of the organization over time (Boffa Miskell Limited, 2009). Five generally applicable indicators of environmental influence have been selected for this study; those are energy, water, material, solid waste and greenhouse gas emission. The calculations are based on the resource use and waste generated within the physical boundaries of the factories due to the production process. Thus it incorporated a gate to gate analysis where upstream or downstream impacts of the life cycle were not considered, for which the data were also not available.

All the data were collected from the respective divisions and the year book (2011–2015) of each factory.

2.2. Data analysis

Annual eco-efficiency ratios were calculated for each parameter for a five year period (2011–2015). The analyses were performed using statistical analysis software Minitab version 17.0. The significance of variation in eco-efficiency among factories over the study period was tested using general Multivariate Analysis Of Variance (MANOVA) test and the Post-Hoc tukey's test at 95% confidence intervals. Pearson correlation analysis was performed in order to test possible correlations between eco-efficiency and revenue of the factories.

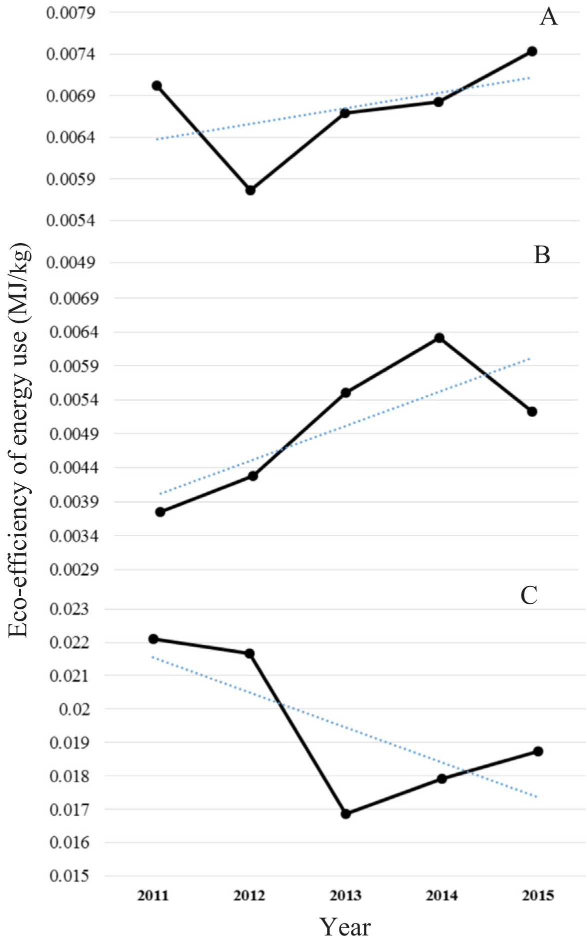

Fig. 1. Eco-efficiency of energy use - factory A (top), factory B (middle), and factory C (bottom).

As all three companies had shifted to sustainable practices within 2011–2012 period, the change over time was calculated considering 2011 as the baseline using Eq. (2) (UNIDO and UNEP, 2010). If the use of a particular source had not been initiated in 2011, the year of initiation was taken as the baseline.

$$\text{Change}(C) = \frac{(A\text{–}B)}{B} \ {}^{*}100 \tag{2}$$

Where, A = Follow up value B = Baseline C = Change from the baseline

3. Results

Electricity, Diesel, HFO, Liquid Petroleum Gas (LPG) and biomass (sawdust and wood) are the main sources of energy which are used to generate electrical, thermal and kinetic energy for boilers, processers, motors, compressor, lighting and air conditioning.

3.1. Eco-efficiency of energy use

Factory A had continuously increased its eco-efficiency of energy use after 2012 and factory B has managed to increase the eco-efficiency until 2014 but it was dropped in 2015. Energy efficiency of factory C had dropped continuously up to 2013 compared to 2011 and it increased thereafter. Although Factory A had increased energy consumption by 37% by the end of the study period, it has managed to increase eco-efficiency by 6%; factory B reached 57% increment in eco-efficiency with 23% increase in energy use. Factory C had not been able to increase its eco-efficiency compared to 2011 as their energy consumption had increased by 54%. Energy efficiency of factories had changed within the study period as illustrated in Fig. 1 and percent change of eco-efficiency by each year compared to 2011 is given in the Table 1.

Moreover, factories were able to reduce cost of energy and cost of production after replacing HFO with biomass, which also led to an increment in eco-efficiency. Fig. 2 illustrates this relationship over time.

Table 1
Percent eco-efficiency change of energy use compared to 2011.

Year	Factory A	Factory B	Factory C
2012	− 18	27	− 2
2013	− 5	66	− 24
2014	− 2	92	− 19
2015	6	57	− 15

(- indicates percent reduction).

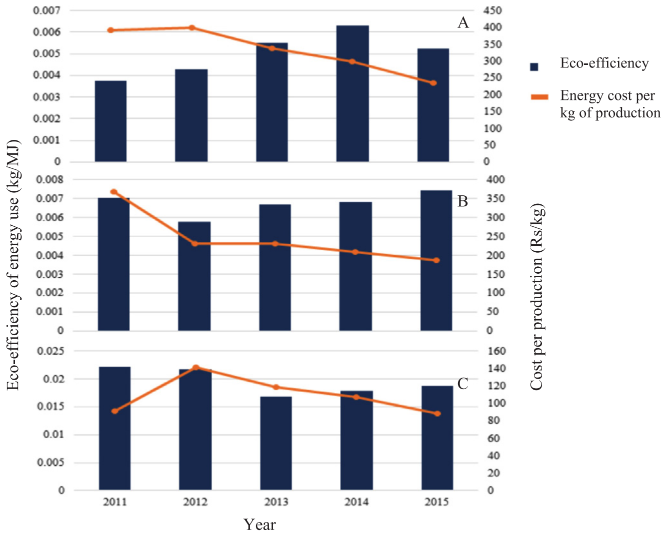

Fig. 2. Change in the eco-efficiency and energy cost per unit production of factory A (top), factory B (middle), and factory C (bottom) over time.

3.2. Eco-efficiency of water use

Eco-efficiency of water use for each factory has increased over the study period. Further, factory A had reduced 6% of water consumption to reach 54% increase in eco-efficiency while Factory B had gained 135% increment in eco-efficiency by reducing water use by 27%. Factory C had reduced water consumption by 0.1% over the five five-year study period, but was able to gain 31% increase in eco-efficiency. The eco-efficiency had increased over the five-year period as illustrated in Fig. 3 and percent change of eco-efficiency compared to 2011 is given in Table 2.

When eco-efficiency of water is increased, water cost borne by the factory to produce a 1 kg of product is decreased. The effect of eco-efficiency on cost of production is illustrated in Fig. 4.

3.3. Eco-efficiency of material use

The eco-efficiency of materials used has considerably changed after 2012 in all three factories. Factory A has increased its material consumption year by year and decreased the eco-efficiency of material use continuously after 2012. Factory B had increased the eco-efficiency by decreasing material consumption. Although factory C had increased its material consumption compared to 2011 except in 2014, it had managed to increase its eco-efficiency by proportionally increasing production of the factory. Fluctuation of eco-efficiency in material use from 2011 to 2015 is illustrated in Fig. 5. Percent change of eco-efficiency in each year compared to 2011 is given in Table 3.

3.4. Eco-efficiency in terms of GHG emission

The quantity of production per unit of CO_2 equivalent (CO_2e) is indicated in the eco-efficiency of greenhouse gas emission. All three factories had increased eco-efficiency by 2015 and showed a similar pattern in the change in eco-efficiency. All three factories had increased eco-efficiency after 2012, dropped in 2014 and again increased in 2015, as illustrated in Fig. 6. Table 4 gives the percent change of eco-efficiency compared to 2011.

3.5. Statistical comparison of the eco-efficiency among the factories at the confidence level 95%

Significant variation of eco-efficiency among factories over the study period has been detected by the findings of MANOVA. There

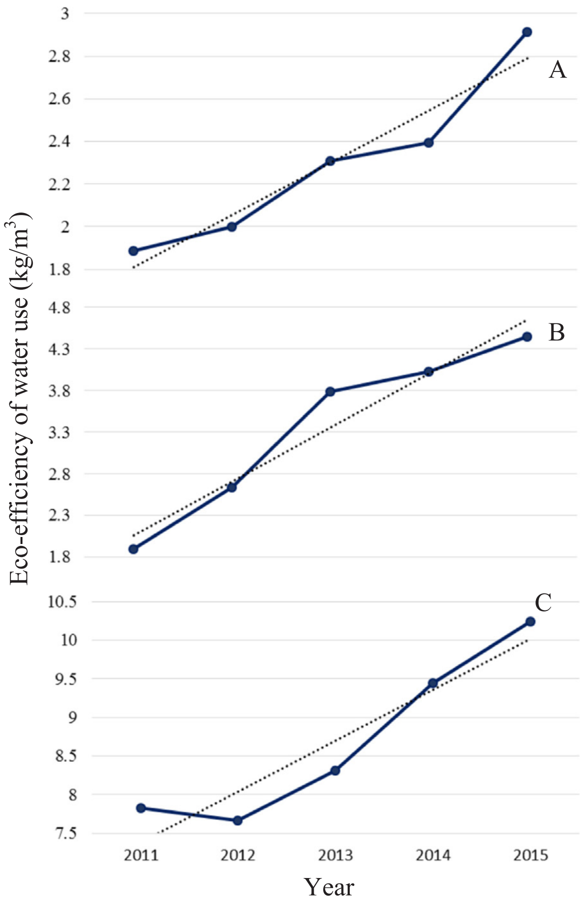

Fig. 3. Eco-efficiency of water use - factory A (top), factory B (middle), and factory C (bottom).

Table 2
Percent eco-efficiency change of water use compared to 2011.

Year	Factory A	Factory B	Factory C
2012	6	39	− 2
2013	22	100	6
2014	27	113	21
2015	54	135	31

(- indicates percent reduction).

is a significant difference of eco-efficiency among companies (general MANOVA; F= 85.687, P = 0.000) and among the years (general MANOVA; F=4.313, P = 0.041).

Further, according to MANOVA, the eco-efficiency of energy is significantly different among the factories (F=127.17, P = 0.000).

Post Hoc tukey's test at 95% confidence level also gave evidence for differences among factories in eco-efficiency of energy use: factory A (1) and factory C (3), and factory C and factory B (2) are significantly different in eco-efficiency of energy use but factory B and A do not indicate a significant difference as depicted in Fig. 7(i.e. If an interval does not contain 0.00 within it, the corresponding means are significantly different)

Eco-efficiency of water use is also significantly different among the factories (F=34.26, P = 0.000). Moreover, A, C and C, B pairs are significantly different but B and A factories are not significantly different as illustrated in Fig. 8.

The material efficiency among factories are significantly different (F=94.19, P = 0.000). A, B and B, C pairs shows a significant difference in eco-efficiency of material use but factory B and A are not significantly different as illustrated in Fig. 9.

Eco-efficiency of greenhouse gas emission indicates a significant difference among the factories (F=4.64, P = 0.035). A significant difference was shown only between the factory B and C. A and B, A and C pairs are not significantly different as illustrated in Fig. 10.

The Pearson correlation analysis revealed a positive significant correlation of eco-efficiency with the revenue of the factories as shown in Table 5.

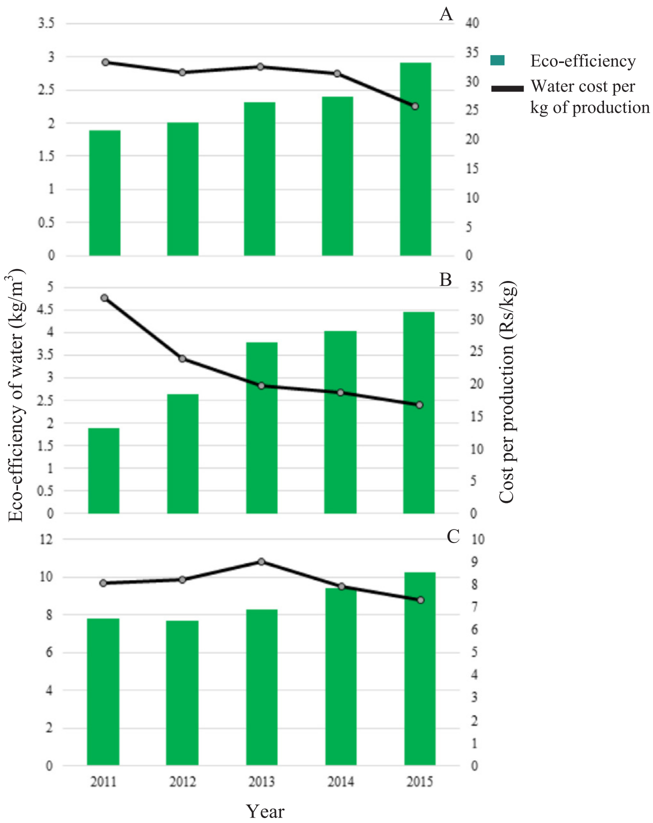

Fig. 4. Effect of eco-efficiency on water cost per production of factory A (top), factory B (middle), and factory C (bottom).

4. Discussion

4.1. Eco-efficiency of energy consumption and CO_2 emission

The results of the current study indicates that total energy consumption of the factories had increased year by year with the production. Higher energy requirement during the second half of the year indicated the winter consumption which supports the other studies on energy consumption patterns of the textile industry (Agha and Jenkins, 2014).

Even with higher energy consumption, eco-efficiency of factory A has increased after 2012, factory B has displayed an increase in eco-efficiency since 2011, while factory C has illustrated a trend of increase in energy efficiency only after 2013. This trend of eco-efficiency is clearly related to the measures the factories have taken to use energy in a more sustainable way.

Factory A has started its first sustainability project on energy in January 2012 by introducing efficient motors. Since then several projects have been carried out and some are ongoing to improve efficiency of electricity use by using more sustainable lighting systems, motors, heating, chilling systems and also steps have been taken to improve fuel use by selecting more environmentally friendly fuels (i.e. Biomass, Solar) and selecting more efficient and environmentally friendly boilers (i.e. biomass boilers). Further improvements have been done on steam use by reducing the leakages and installing steam accumulators, etc.

Factory B has started its energy saving projects at the end of 2010 by introducing skylights to the dye house and finishing areas and more projects have been carried out since then.

Factory C has moved forward with a more sustainable energy consumption pattern in November 2012 by installing wood chip fired boilers to replace furnace oil fired boilers.

Most of these projects that have been carried out by factories for increasing eco-efficiency come under operations, maintenance and engineering.

Our findings suggest that sustainability measures have caused an increase in eco-efficiency in the energy use of the factories. Therefore eco-efficiency can be used as a tool for evaluating the sustainability in energy use (Lucato et al., 2017; Zhang et al., 2008).

Sustainability measures indicated a positive effect on the eco-efficiency in energy use of the factories and illustrated a year- by-year increase in eco-efficiency since the initial year of the practices. However, factory A and C have shown a reduction in eco-efficiency compared to 2011, which means that they need to develop more management strategies and innovations to increase energy efficiency of the factories.

Factories could have increased their energy efficiency further by adopting energy management standard ISO 50001, which provides a strong organizational framework for energy management and to gain the highest possible advantage over sustainability

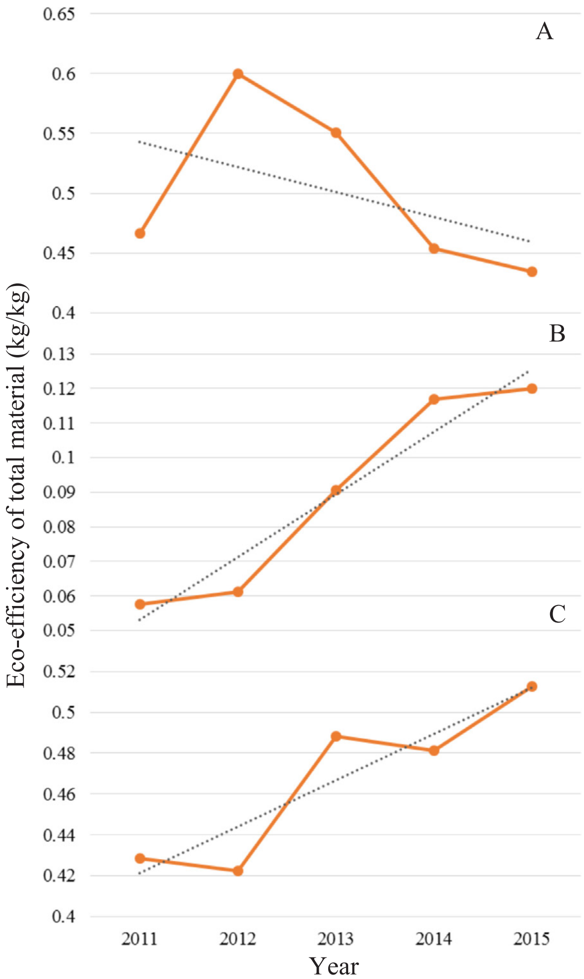

Fig. 5. Eco-efficiency of material use - factory A (top), factory B (middle), and factory C (bottom).

Table 3
Percent eco-efficiency change of material use compared to 2011.

Year	Factory A	Factory B	Factory C
2012	29	6	− 1.4
2013	18	57	14
2014	− 3	103	12
2015	− 7	108	20

(- indicates percent reduction).

measures. More energy saving strategies that can be used by the factories and technical guidelines for textile industries are given by Agha and Jenkins (2014), Hasanbeigi (2010), UNIDO (1992, 2002), and UNIDO and UNEP (2010).

Increased eco-efficiency in energy had clearly led to a reduction of the energy cost of the product. Cost reduction has a positive effect on profitability (Avenir, 2009). Moreover, Pearson correlation analysis revealed that eco-efficiency of energy has a positive significant correlation ($r = 0.933$; $p < 0.05$) with the revenue of the factories. These results support studies that have claimed that improving eco-efficiency in resource use leads to a potential gain in profitability (Nishitani et al., 2017).

Within the study period, year by year eco-efficiency of CO_2 emission (i.e. mass of the product sold per CO_2 emission) has increased with fluctuations in between. Moreover, all three factories indicated a similar pattern in eco-efficiency change of CO_2 emission over time. These variations are mostly due to the changes in the thermal and hydroelectricity fraction changes of the grid electricity and changes of fuel types used within the factories.

In 2015, factory A has increased its production by 45% compared to 2011 and its energy consumption has increased by 27%. But it was able to reduce its CO_2 emission by 74% through the reduction of HFO consumption by 88%. Its energy requirement was mostly fulfilled through biomass and grid electricity.

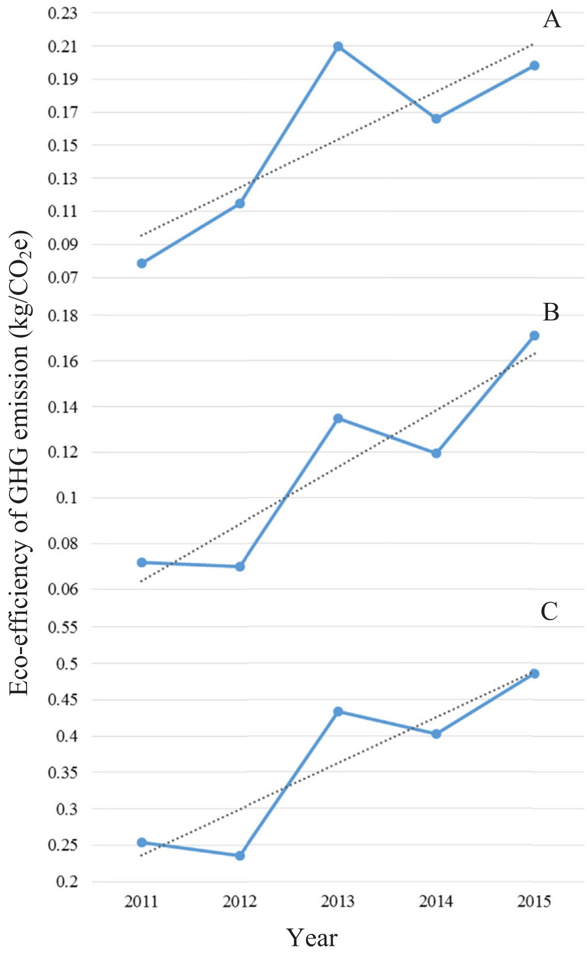

Fig. 6. Eco-efficiency of greenhouse gas emission – factory A (top), factory B (middle), and factory C (bottom).

Table 4
Percent eco-efficiency change of greenhouse gas emission compared to 2011.

Year	Factory A	Factory B	Factory C
2012	46	− 2	− 7
2013	167	88	71
2014	111	67	58
2015	152	139	91

(- indicates percent reduction).

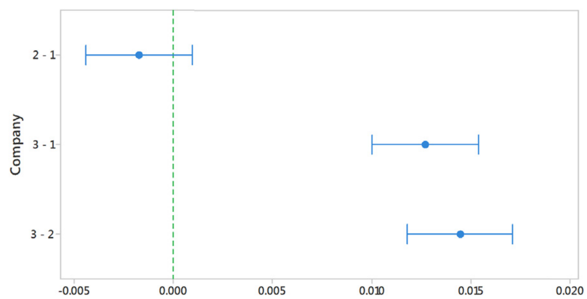

Fig. 7. Differences of eco-efficiency in energy use (1 = factory A, 2 = factory B, 3 = factory C).

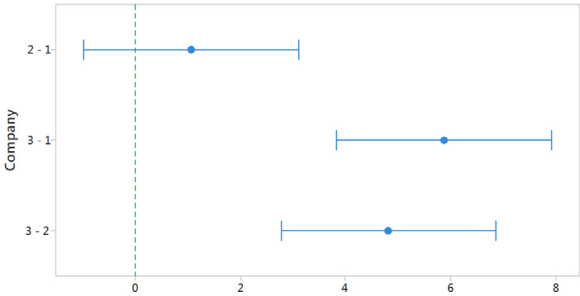

Fig. 8. Differences of eco-efficiency in water use (1 = factory A, 2 = factory B, 3 = factory C).

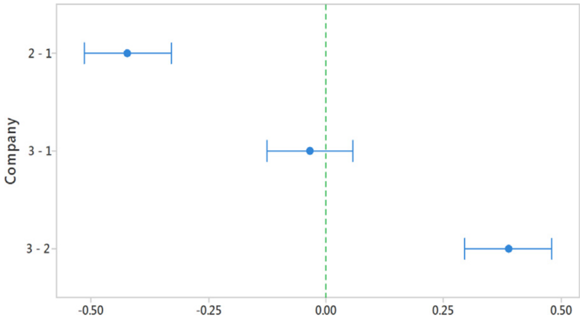

Fig. 9. Differences of eco-efficiency in material use (1 = factory A, 2 = factory B, 3 = factory C).

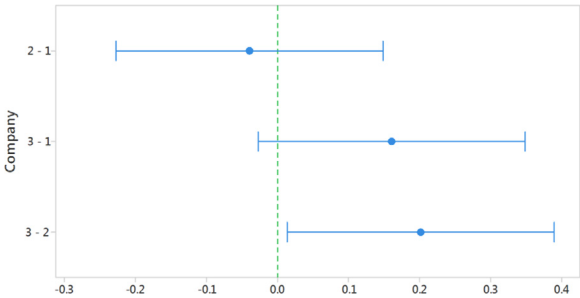

Fig. 10. Differences of eco-efficiency in greenhouse gas emission (1 = factory A, 2 = factory B, 3 = factory C).

Table 5
Correlation of eco-efficiency with revenue.

Correlation of revenue with eco-efficiency under different environmental factors	r value	p value
Energy use	0.933	0.000
Material use	0.481	0.069
Water use	0.950	0.000
Greenhouse gas emission	0.911	0.000
Wastewater generation	0.937	0.000

(r-correlation coefficient).

Factory B has increased its production by 71% by end of the period only through increasing total energy consumption by 23%. It was also able to reduce its CO2 emission by 40% as it reduced its HFO consumption by 118% within the 5 year study period (2011–2015).

Total production of factory C increased by 31% in 2015 compared to 2011. It achieved this target through increasing its energy consumption by 54% but it was able to reduce its CO_2 emission by 46% as it has reduced its HFO consumption by 70%.

Further, Hydroelectricity fraction of the grid electricity varied between 28% and 58% within the study period (2011–2015) and thermal fraction varied between 40% and 71% (Ceylon Electricity Board, 2015, 2014, 2013, 2012). These changes also affected our results. Moreover, reduction of diesel consumption and grid electricity consumption through sustainable measures such as using more efficient and modern machines, training staff, automation, using full load of the machines, etc., also have positively contributed to the above results.

Replacing HFO with biomass has caused a reduction in the cost of fuel and greenhouse gas emission, but it might have led to other environmental problems such as deforestation. The firewood supplied by the villagers around the factory has become a way of income, but sometimes-uncontrolled logging may cause severe environmental problems. Therefore alternatives such as sawdust, wood chips, agro residues including rice husks, straw, bagasse, sugarcane tops (barbajo), cotton stalk, coconut residues, etc. can be used (Netherlands Organization for Applied Scientific Research, 2010). According to Karunasena and Kannangara (2012), even dewatered sludge can be used as a fuel for the boilers with advanced technology.

After identifying the potential problem of uncontrolled logging, all three factories have reduced wood log consumption compared to the initial year and have increased the sawdust consumption instead. Factory A has reduced wood log consumption by 10% and increased sawdust use by 82% while factory C had indicated a 46% reduction in log burning and 67% increment in sawdust utility by the end of the study period. Although factory B had increased log consumption by 35%, it had introduced sawdust in 2015. Sustainability of the supply chain can be managed by only buying sustainably harvested wood. Factory C has initiated it by only buying rubber logs. These steps are environmentally sound and economically beneficial especially as the cost of sawdust is less than the wood logs.

4.2. Eco-efficiency of water consumption and wastewater generation

Water consumption of all three factories was decreased by 2015. Energy consumption changed parallel to the water consumption. This indicated that reduction of water consumption led to reduction of energy use (Agha and Jenkins, 2014).

Eco-efficiency in water use significantly changed over the study period and the sustainability measures factories have taken had some effect on this result. Factory A and C had introduced low liquor ratio dye machines in 2012, after which the factories started to indicate a significant increment in eco-efficiency. After that many interventions such as rapid dyeing projects, dye bath analyzer, etc. have been introduced. Further, all three factories have followed cleaner production techniques such as training staff, maintaining equipment, using right amount of water, running full load of the machines, good housekeeping etc., to reduce the wastage of water.

Due to the above strategies, factories were able to reduce water cost per production from 2011–2015, even when the cost of a water unit (i.e cubic meter) had increased from 63 rupees to 75 rupees. The reduction of cost led to increased profit. The Pearson correlation analysis yielded a positive significant correlation ($r = 0.950$; $p < 0.05$) between eco-efficiency of water use and the revenue of the factories.

Further, pure water consumption could have been reduced by using recycled water for the production process and other activities of the factory. Even though none of the three factories use recycled water for the process, literature related to textile industry has given many operational methods by illustrating the ability to reuse water in the process (New cloth market, 2015; Ströhle et al., 2008).

On average, about 75–80% of water is discharged as wastewater. The wastewater generated through the production process is primarily treated at the factory site and then released into central water treatment a center of the zone. The authorities have given standards for parameters of the wastewater such as maximum BOD and COD levels, pH, metal concentration, colour, etc. Therefore, factories maintain the parameters of wastewater within the standard range but norms are not given for the sludge; therefore to maintain these values different concentration and volumes of treating chemicals are added which could cause an increase in the sludge volume.

If the ratio between BOD and COD is greater than 0.5 water is considered to be easily treatable by biological means; the value in the range 0.4–0.5 mgL^{-1} is considered as averagely biodegradable and 0.2–0.4 mgL^{-1} is considered as the slowly biodegradable and if the ratio is below 0.2 mgL^{-1}, waste may have some toxic components and not biodegradable (Samudro and Mangkoedihardjo, 2010). The BOD: COD ratio of factory A is 0.18 and that of C is 0.5, which means effluents of factory C are more biodegradable than factory A.

The sewage sludge is produced during sewage treatment. Each factory produces a large amount of sludge per year and all of them are transported to Holcim Geocycle Company for incineration. This is a huge waste of resources. Even though the sludge is considered toxic as it contains heavy metals and other impurities, it also contains large amount of nutrients especially the minerals that can be used as fertilisers. A number of research studies can be found in nuclear science literature which have indicated successful results by using irradiated sewage sludge in agriculture as an alternative fertilizer (El-Motaium, 2006; Kumarasinghe and Lapidot, 1994).

A reduction of water consumption leads to reduced energy consumption, wastewater generation and reduced energy and chemicals required to treat the wastewater (UNIDO and UNEP, 2010).

4.3. Eco-efficiency of material consumption and solid waste generation

The chemicals, yarn, dye ratio, etc., vary according to the colour, pattern and even factory wise as their technology differ. The Selection of chemicals for the production process within the factories proceeds under the supervision of environmental management of the BOI zone (Board of Investment Sri Lanka, 2011). It encourages factories to select more environmentally sound chemicals but environment norms of the BOI zone do not address the quality of dyes that can be used in the process.

Both factory A and C had increased material consumption over the study period. Factory C indicated a higher average material consumption rate (414,634 kg per year) than factory A (347,527 kg per year); but factory C had managed to increase its eco-efficiency of material consumption, while factory A had dropped the eco-efficiency over years. This transformation is mainly affected by the measures taken by the factory C in the second half of the 2013, which introduced 21 new low liquor ratio dyeing machines; by 2014 factory C had replaced inefficient older large machines with small, efficient machines. This caused an increase in eco-efficiency of material by reducing dye use and chemical wastage. It further increased energy efficiency, water efficiency, and reduced the lead time. Reduction of the eco-efficiency of material use in factory A was mainly affected by the increased yarn consumption of the factory after 2012. According to the sustainable unit of the factory, this is due to the experiments that were started in 2012 to develop new designs and product types. Moreover, they had managed to reduce this impact on energy and water consumption by using more efficient machines with advanced technology.

Factory B had reduced material consumption by an average rate of 338,988 kg per year and increased production at a rate of 64,428 kg per year. Therefore eco-efficiency of material had increased over time. Reductions of wastage through introducing automated machines, new reactive dyestuff which provide very good level of fastness, etc., had caused a reduction in the material consumption.

These new strategies had reduced per kilogram cost of production and increased production capacity and efficiency in both factories B and C.

According to the Pearson correlation test, eco-efficiency of material use was also positively correlated with the revenue of the factories ($r = 0.481$; $p < 0.05$) but this relationship was weak compared to the correlation of revenue with water and energy.

According to the Karunasena and Kannangara (2012), most of free trade zones of Sri Lanka and factories within them do not keep records of waste generation properly. Current study also revealed the lack of data recorded on waste generation and lack of attention on waste management.

Further, according to the BOI Sri Lanka, sewage treatment plants are the only proper industrial waste management systems maintained in free trade zones (Karunasena and Kannangara, 2012). An open dump yard is maintained by the zone management to dispose all the other waste types. All three factories have been contracted with Holcim Geocycle to transport and incinerate hazardous waste, as it is the only licence holder for hazardous waste transportation and processing. The Central Environmental Authority has vested power to control waste management within free trade zone to BOI. Environmental Protection Licence (Appendix B) only emphasizes wastewater management (Karunasena and Kannangara, 2012). This isolation of existing waste management regulations has created some environmental issues such as soil pollution and water pollution.

According to Karunasena and Kannangara (2012), the separation of waste within factory premises is useless since disposal is directed towards an open dump yard. Therefore factory A, B and C do waste separation at the factory site and allow third parties who use waste as raw material for other production processes to collect waste from the factory site. This is an environmentally sound step that factories have taken to reduce the landfill. According to the factory officers, factory A and B give away waste free of charge while factory C charges a small amount of money.

All three factories encourage recycling and reuse of some waste types: waste food is sent for the piggeries, cardboard and polythene are recycled and boiler ash is used as a fertilizer. But as the factories do not maintain proper records and do not identify the sources of non- hazardous waste generation, it is impossible to reduce waste generation. Further, most of these recycling methods are down-cycling (i.e. reusing a product at a lower quality level; McDonough and Braungart, 2002).

Therefore, both factories A and B have started a programme to identify waste sources while factory C is looking for the methods that can up-cycle the waste.

Waste problem of the zone can be addressed by introducing integrated waste management systems into the zones (McDougall et al., 2001). Another method that can be used is Pay As You Throw (PAYT). In this strategy factories are charged based on the amount of waste that a particular factory releases to the common dump yard of the industrial zone (Elia et al., 2015). This study was based on the basic equation suggested by the WBCSD. It can be improved into a more accurate decision making and policy making tool by integrating Life Cycle Assessment and Life Cycle Costing into the basic equation (Bengtsson, 2004).

5. Conclusion

Results revealed that eco-efficiency of water, greenhouse gas emission, and material use had increased (except factory A) over the considered study period. Factory B had increased eco-efficiency in energy use throughout the study period while factory A indicated a pattern of increment after 2012. Factory C had reduced the eco-efficiency of energy after 2011 but it had indicated a trend of increase in eco-efficiency after 2013. These patterns of increments in eco-efficiency values are parallel to the sustainability measures that factories have implemented within respective period. It indicates the clear effect of sustainability measures on eco-efficiency ratios. Further, eco-efficiency has a significant effect on cost reduction of the production and it has a strong correlation with the revenue of the factories. It was revealed that being environment-friendly (sustainable) is economically beneficial for all three factories. Additionally, eco-efficiency proves to be a good tool for use in sustainability analysis; however, as it only covers environmental and economic dimensions, more indicators should be included to cover the social responsibilities.

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