Fibers and Polymers 2015, Vol.16, No.4, 926-933
DOI 10.1007/s12221-015-0926-8

ISSN 1229-9197 (print version)
ISSN 1875-0052 (electronic version)

Post-consumer Energy Consumption of Textile Products During 'Use' Phase of the Lifecycle

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(Received March 14, 2014; Revised December 25, 2014; Accepted December 31, 2014)

Abstract: The purpose of this research is to propose a rating model that measures the post-consumer energy consumption, specifically during the washing, drying, and ironing processes of textile products. Prior to designing the rating model, the methodology of sustainability assessment is overviewed, with discussions on textile sector's efforts in developing the sustainability index as an assessment tool for textile products or their manufacturers. Despite the significant environmental impacts made by the 'maintenance' or 'use' phase of the textile lifecycle, the assessment of 'use' phase is not thoroughly evaluated. In this study, a rating model was built to measure or estimate the amount of energy use during the product maintenance. The maintenance during 'use' phase, defined as washing, drying and ironing processes, is categorized for its maintenance options; washer type, wash temperature, dryer type, filling load, and ironing. The selection of maintenance options generates the score for the impact on energy use. Scenario analysis for different maintenance conditions with different textile products presents the applicability of the proposed rating model as a simple yet effective measurement tool.

Keywords: Sustainability, Textile products, Lifecycle, Use phase, Energy

Introduction

Sustainability and sustainable development can be described in various terms depending on the purpose of the defining subject, but the concept defined by the World Commission on Environment and Development (WCED) has been the widely accepted one: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]". Sustainability assessment is generally conducted for 3-bottomlines that include economic, social, and environmental dimensions [2], measuring the long-term economic success capability, social efforts for human rights, and environmental responsibility. Among the three dimensions of sustainability, the environmental aspect is closely associated with the ecological sustainability, often referred to 'green' or 'eco' claims. Since WCED exclaimed the importance of sustainable development, sustainability has become the most crucial motto for institutions and individuals [3]. The textile industry also moves towards 'greener' business with this trend, as being one of the most significant contributors to social and environmental sustainability.

In this context, researches on sustainable textiles have been widely conducted. Since textiles industry is a complex network of businesses and technologies operating across the world [4] and their intertwined impact on sustainability spans throughout its lifecycle, it is desirable that sustainability be assessed throughout the comprehensive life cycle phases of textile products. However, most researches were focused on the specific phase of textile life cycle, for instance, garment manufacturing [5] or fiber production [6,7]. Herva *et al*. [5] evaluated the ecological footprint during the apparel tailoring process in terms of energy, resources and waste. In this study, the principal environmental contribution by the apparel tailoring manufacturer was analyzed as 'resources'. Chen and Burns [6] overviewed the potential environmental impacts of the fibers throughout their lifecycle in terms of renewable resource use, pollution generation, and disposal/recycle. The study claimed that cleaning and maintenance phase of fibrous products was the most overlooked phase in the lifecycle assessment (LCA). Muthu *et al*. [7] proposed the ecological indicator to quantify the environmental impact of textile fibers in the initial stage of lifecycle, from the growth of natural fibers or synthesis of polymeric materials to the stage ready to be spun into a yarn. The rating methodology developed was simple and practical to be applied in the later-phase assessments.

Regardless of the efforts in analyzing the environmental impacts made by textile products, the environmental assessment of the post-consumer phase of the textile products still lacks. The purpose of this study is to present the methodology to assess the energy consumption made by the maintenance options during the washing, drying and ironing processes. To this end, sustainability studies available for textile products were reviewed to find the gap in the assessment of textile products. The environmental impact made by energy consumption during the 'use' phase was attempted to be measured via the proposed rating scheme, and the scenarios with different maintenance options were comparatively analyzed by the developed rating methodology. Finally, the energy impacts made during the production phase and use phase were compared with the probable maintenance scenarios for different textile materials.

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Review of Sustainability Assessment

Sustainability Indices for Corporations

In recent years, measurement of sustainability is getting growing attention not only by the organization's decision makers [8] but also by investors, non-governmental organizations (NGOs), regulatory offices. The combination of the public's demand of knowing about the companies' long-term success and the companies' need of keeping up the reputation made the sustainability reporting more and more recognized. The sustainability reporting is often made by the third party to give the comparative rating or ranking of the selected companies. The assessment framework may differ from raters, but the general assessment framework involves 1) rating input elements for economic, social, environmental aspects, such as organization's performance, management strategy, transparency, environmental impact and reputation, 2) weighting the initial rating by the pre-determined model, resulting in the final rating. The examples of comparative sustainability reporting are presented in Table 1, with descriptions of assessment structures and weighting schemes. As can be observed, the sustainability reporting is often made organization-centric, measuring the organization's performance.

Lifecycle Sustainability Assessment of Textile Products

Along with the sustainability assessment of the company, assessing the product sustainability throughout its lifecycle would also give a critical insight especially to consumers in making environmental-conscious choices. Particularly, the post-consumer phase of textile products' lifecycle is highly dependent of consumers' behavior on their maintenance choice and habits, thus the maintenance options and decisions on this phase greatly influence the eco-efficiency of textile products. The assessment of post-consumer environmental impact and its implication could be utilized as an informative reference to share with the public to promote the environmentally responsible consumer behavior.

The concept of lifecycle assessment (LCA) as defined by the International Organization for Standardization (ISO 14040:2006 [14] & ISO 14044:2006 [15]) differs from sustainability in that LCA is often product-centric [16]. The limitation of LCA is that it measures mainly the environmental impacts of products by counting the inputs and environmental releases. Klöpffer [17] and United Nations Environment Programme [18] mentioned that the lifecycle sustainability assessment (LCSA) rather than LCA would be more relevant to count the whole aspects of the product's sustainability throughout the lifetime. The report [18] guides that the

Table 1. Comparative corporations' sustainability reporting examples [9-13]

Reporting title	Data provider	Data collection	Assessment structure	Weighting
Dow Jones Sustainability Indices [9,10]	RobecoSAM, Dow Jones S&P	- Company's self-report to survey questionnaire - Media and stakeholder analysis	- 3 dimension: economic, environmental, social aspects that consist of multiple criteria and questions - Industry-specific survey questions	- Sector-specific weights - For 'clothing, accessories, and footwear sector', economic (36 %), environmental (24 %), social (40 %)
Interbrand: Best Global Green Brand [11]	Interbrand, Deloitte	- Performance data from publicly open resources - Perception assessed by consumer survey	- Performance 6 pillars (governance, operations, transportation and logistics, stakeholder engagement, products and services, supply chain) - Perception 6 pillars (authenticity, differentiation, relevance, consistency, understanding, presence)	- Standardization by country GDP - Gap score counted: reputation vs. reality = [Performance - Perception] - Previous year's rating considered
CR's 100 Best Corporate Citizens [12]	CR Magazine & Corporate Responsibility Officers Association (CROA)	- Through the committee consists of practitioners, academics, NGOs, investment firms, relevant communities	- 7 Categories (weight): environment (19.5 %), climate change (16.5 %), human rights (16 %), employee relations (19.5 %), corporate governance (7 %), philanthropy (9 %), financial (12.5 %)	- Different weights for different categories - Same weights for all sub-categories/elements - Same weighting system for all companies
Newsweek Green Rankings [13]	Newsweek, Trucost, Sustainalytics	- Publicly disclosed data	- Environmental impact (45 %): greenhouse gas, air pollutants, water, land and water pollutants, waste, natural resource usage - Management (45 %): company operations, contractor and suppliers, products and services - Disclosure-transparency (10 %)	- Impact 45 %, Management 45 %, Disclosure 10 % - Impact is calculated as a cost to society of resulting environmental damage - No sector-specific consideration

economic and social dimensions can be measured by the lifecycle costing (LCC) [19] and the social-LCA (S-LCA) [20] respectively, and all of which can be measured consistently based on ISO 14040 [14] framework.

In the textile sector, Sustainable Apparel Coalition (SAC) is making significant efforts in developing a metric called 'Higg Index' [21] to measure the sustainability performance for the apparel and footwear companies, focusing on environmental and social sustainability indicators. The Higg Index [21] is a self-assessment tool that enables the company to assess the textile products' lifecycle sustainability from raw materials to end-of-life, through the survey questionnaire that would be rated for the environmental and social aspects of suppliers, packaging components, materials, brands, and products. In evaluating the materials assessment, the index employed the materials sustainability index (MSI) that was originally developed by Nike (Nike and SAC, Inc.) to rate the environmental aspects of the material components in terms of chemistry, energy and greenhouse gas (GHG) intensity, water and land use intensity, and physical waste. It is noteworthy that the Higg Index was developed with the collaborated efforts, employing the readily available database such as MSI. However, the rating for 'product care & repair service' section seemed very simplified. If the rating scheme can be elaborated for the maintenance process during the 'use' phase of lifecycle, it is expected to better represent the textile sustainability as a practical self-check.

The lack of studies in assessing the environmental impact made by the product cleaning and maintenance is not new, and was previously recognized by Chen and Burns [6]. The environmental impact during the product use is not insignificant; on the contrary, the dominant environmental impact can be made in the washing process of clothes [22]. From the investigation by Allwood *et al.* [4], the dominant portion of energy profile for a conventional cotton T-shirt was taken by the 'use' phase (65 %) among the evaluated phases of 'material', 'use', 'production', transportation' and 'disposal'. Regarding the toxicity profile of the organic cotton T-shirt, 'use' phase took 34 % of lifecycle toxicity. Also, when the washing scenarios with different washing temperature and tumble or air dry condition were analyzed, the resulting environmental impact was differed, giving the implications that consumers' maintenance behavior would make great impacts on overall textile products sustainability [4,23,24]. With such insight, the rating methodology to measure the environmental impacts made by the energy consumption during the textile maintenance was designed. The scope of this study is to examine the existing data from the earlier studies in order to develop a general rating model that would apply for different maintenance options. By utilizing the data available from various sources, it was possible to overcome the lack of laboratory capability in developing a rating model that includes the options of different washers and dryers.

Methodology for Designing the Rating Model

Assumptions

Environmental impacts during washing clothes mainly consist of two aspects: 1) energy consumption due to mechanical actions and thermal elevation within the washing machine, and 2) emission of pollutant such as excessive detergents. When extra detergents were discharged from the washing machine, the wastewater can result in environmental problems regarding biodegradability, toxicity and eutrophication [25]. Such environmental issues caused by detergents emission have been extensively studied [25,26], but the environmental impact by energy consumption during textile products use phase has been little discussed. As the first step to discuss the sustainability assessment during the textile product maintenance, environmental impacts made by the energy consumption for the washing, drying and ironing processes were investigated. So as to simplify the design of sustainability assessment model, at this stage of the study, only the energy consumption was considered, and all other impacts such as toxicity, GHG, or water use were not considered yet. Nor were economic/social impacts considered.

In this study, we assumed textile use phase consist of three sub-phases: washing; drying; and ironing. For those phases, we assumed five maintenance conditions or options that can be differed depending on the textile material type and the consumer maintenance behavior, which are: 1) washer type, 2) wash temperature, 3) dryer type, 4) filling load, and 5) ironing. Those maintenance conditions could be different for different textile materials, greatly influencing the electricity consumption during maintenance, thus those maintenance conditions were carefully chosen as probable maintenance options for different materials and included in our rating model.

For all estimated quantification of total energy consumption, we assumed that 250 g of clothing is washed and dried for 25 cycles [4].

Development of Rating Model for Post-consumer Energy Impact

Energy Consumption Data Collection

The quantitative data for energy consumption during washing and drying processes were surveyed from the literature and presented in Table 2. The surveyed raw data were presented as the energy consumption per washing or drying cycle of 1 kg of clothing, and those values were converted to our assumed maintenance cycles of 25 times for 250 g clothing.

The energy used during ironing was measured in the laboratory via a digital power meter (model Yokogawa 2533, Yokogawa Electric Corporation, Japan). The ironing process was conducted using an iron, Novita SI-903SW (Samsung Electronics, Korea). In pressing the wrinkles on a cotton shirt of about 250 g, it took 10 min. with the energy

Table 2. Scoring scheme to rate the energy impact during textile products maintenance [23,24,27]

Wash, dry, ironing condition		Energy consumption per cycle per 1 kg clothing (kWh/cycle/kg)	Sources	Total energy consumption: 25 cycles, 250 g clothing (kWh)	Normalized score : (max-respective points)/max
Washer type (E_{washer})	Drum	0.033	Yamaguchi *et al.* [27]	0.209	C^{norm}: $(C^{max}-C)/C^{max}$ C^{max}: maximum possible value of C, which is 58.179. Calculated by the energy consumed (25 cycles, 250 g clothing) for the drum type washer, 60 °C wash temperature, use of condenser type dryer, 10 % filling load, ironing.
	Pulsator	0.023		0.142	
Wash temp. ($E_{temp.}$)	60 °C	0.256	Laitala *et al.* [23]	1.389	
	40 °C	0.150		0.730	
	30 °C	0.103		0.452	
	Cold	0.000	Yamaguchi *et al.* [27]	0.000	
Dryer type (E_{dryer})	Condenser	1.075	Yamaguchi *et al.* [27]	6.719	
	Heat pump	0.485		3.029	
	Hang dry	0.000		0.000	
				A: SUM of above from each condition	
Filling load (α_{load})	10 %	×686 %	Laitala *et al.* [23] Josephy *et al.* [24]	B: A×weight % per filling load	
	50 %	×188 %			
	100 %	×100 %			
Ironing (E_{iron})	Ironing	0.180	From the lab. test	1.125	
	No ironing	0.000		0.000	
				C: B + energy for ironing	

consumption of 45 Wh.

Estimation for the Amount of Energy Use

Table 2 presents the scoring scheme of the energy consumption during maintenance. First, the amount of energy use for the respective washer type, wash temperature, and dryer type were quantified for 250 g of clothing during 25 cycles with full capacity of washing machine. According to Yamaguchi *et al*. [27] and Park *et al*. [28], drum washers consume more electricity than pulsator washers do. The energy data from Yamaguchi *et al.* [27]'s work was adopted in our study to estimate the amount of electrical energy consumed by different type of washers.

Washing machine consumes energy mainly by two operations; mechanical operation and temperature elevation of water. Lataila *et al*. [23] revealed that different level of energy is consumed when the wash temperature was varied. Once the energy use for different washer types were estimated at the first step of rating, the energy used for water temperature elevation was considered at the second step of the rating process. For this step of estimation, the energy consumption at cold water [27] was assumed zero, and the energy consumption at 30, 40, 60 °C were referenced from the study by Laitala *et al.* [23] (Table 2).

The total energy consumed for washing machine operation, temperature elevation and drying process is calculated as in equation (1). For all the calculations, the assumption of 250 g of clothing and 25 cycles of washing was consistently applied.

$$A = \Sigma(E_{washer} + E_{temp} + E_{dryer}) \tag{1}$$

A: total energy consumed for washing machine operation, temperature elevation, and drying process

E_{washer} : energy consumed at cold water wash for different washer types

E_{temp} : energy consumed for temperature elevation (30, 40, 60 °C) of water

E_{dryer} : energy consumed for dryer operation for different dryer types

The sum of energy consumption so far (A in Table 2) was weighted by its filling load (B in Table 2), as was studied by Laitala *et al*. [23] such that laundry with 50 % or 10 % of full capacity load leads to 188 % or 686 % energy use of 100 % full capacity, respectively. Washing machines generally have the fuzzy system which detect the load capacity and automatically change the washing program, thus half load theoretically would lead to a reduction of water use and the resulting energy saving for water temperature elevation. However, the electricity consumed for mechanical operation would remain similarly regardless of the reduced load, thus the total energy use for washing machine operation for less than 100 % filling load would be generally much greater, considering more number of washing operations.

For example, if we had total 40 number of 250 g shirts and we used a washer of which capacity is 10 kg, one time washing with all 40 shirts would make the full capacity operation. If we assume that this full capacity operation consumed the energy X (kWh), the average energy consumption for one 250 g shirt would be X/40 (kWh). If we used 50 % filling load, two times of washing operation would be needed to wash all 40 shirts; and if all washing conditions remained the same, now the average energy consumption for one 250 g shirt would be 2X/40 (kWh). For 50 % filling load, Laitala *et al.* [23] gave 188 % weight, which is a little less than twice the energy consumption that would be used for two times of washing operations. This may be due to the control of water and electricity by the load sensor, though it may not always accurately function [23,24]. Likewise, the weight for 10 % filling load was given as 686 %, which is less than ten times of washing operations. Calculation of B in Table 2 is shown as follows:

$$B = \alpha_{load} \cdot A \tag{2}$$

B: weighted value of total energy consumption for different washer types, wash temperatures, dryer types, and filling loads

α_{load}: weighting factor for filling load

Finally the energy use during ironing process was added (C in Table 2). The amount of energy consumed by ironing process can be differed as the wrinkled condition of textiles after washing, but in this rating model, the ironing process was simplified for one same condition for the sake of facile estimation. With the consistent assumption of 250 g of clothing and 25 cycles maintenance operations, calculation of C in Table 2 can be described as in equation (4).

$$C = B + E_{iron} \tag{3}$$

C: total energy consumption during washing, drying, and ironing processes for varied maintenance conditions.

B: weighted value of total energy consumption for different washer types, wash temperatures, dryer types, and filling loads

E_{iron}: energy consumed during ironing process

The energy score obtained as C in Table 2 was then normalized to fit in the scale of 0 to 1 for the convenience of comparison with other indices in different scales:

$$C^{norm} = \frac{C^{\max} - C}{C^{\max}} \tag{4}$$

C: the very value of C when respective washer type, wash temperature, dryer type, filling load, ironing conditions are chosen, calculated by (4)

$C^{\max}$: the maximum possible value of C, which is 58.179. Calculated by the energy consumed (25 cycles, 250 g clothing) for the drum type washer, 60 °C wash temperature, use of condenser type dryer, 10 % filling load, ironing.

C^{norm} : normalized score of C

The maximum value of total energy possible from the suggested rating model was quantified as 58.179 for the condition of drum type washer, 60 °C wash, condenser type dryer, 10 % filling load, ironing. The energy consumption points were normalized to fit in the scale of 0-1 and to give higher score for less energy use. Thus, for the energy consumption values, the greater value presents the higher amount of energy consumption representing environmentally less favored options. On the contrary, for the normalized score, the greater value represents more environmentally favored maintenance option.

Comparative Scenario Analysis

The scenario analysis was conducted to test the relevancy of the developed rating model in assessing different maintenance conditions and adequately representing the environmental impacts that can be led by the consumers' maintenance behavior. The scenario comparison in Table 3 shows how the energy impact can be improved during use phase by choosing an energy-savvy maintenance condition or by choosing a material that can be maintained under such conditions as washing at lower temperature and hang-drying.

With the implications that the post-consumer maintenance behavior could make a difference on the environmental impacts, the scenarios with different textile materials, which generally lead to different cleaning and care behaviors, were

Table 3. Scenario analysis with different maintenance conditions

Scenario	Energy from washer (kWh)	Energy from temp. (kWh)	Energy from dryer (kWh)	Energy from filling load (%)	Ironing	Energy total (kWh)	Normalized score (points, 0-1)
Case 1: Pulsator type; cold water wash; hang dry; filling load 100 %; no ironing	0.142	0	0	100	0	0.142	0.998
Case 2: Drum type; 40 °C wash; heat pump dryer; filling load 50 %; no iorning	0.209	0.730	3.029	188	0	7.460	0.872
Case 3: Drum type; 60 °C wash; condenser dryer; filling load 10 %; ironing	0.209	1.389	6.719	686	1.125	58.178	0.000

*Note: the energy consumption (kWh) indicated all above except "energy from filling load (%)" is based on 250 g clothing, 25 cycles of washing operation.

analyzed in Table 4. The maintenance assumptions for cotton, wrinkle-free cotton, viscose rayon, wrinkle-free finished viscose rayon, nylon 6, and polyester shirts were made based on the probable maintenance options.

The advantage of normalized score is that it makes a convenient comparison with other indices. The material production score for the textile material that was determined by the Higg Index 1.0 [21] was normalized to fit in the scale of 0-1 as shown in the calculation in Table 4, in order to compare with the maintenance score (also normalized) in the similar scale. When scoring the environmental impacts for production phase, the Higg Index 1.0 [21] employed Nike's MSI base material rating, where energy/greenhouse gas intensity, chemistry, water/land use intensity, and physical waste were all counted. The Higg index also considered the negative environmental impact made by the coating/finishing process, and a subtraction of 4 points is attributed to this coating/finishing process.

Though the Higg Index [21] can serve as efficient assessment tool to measure the social and environmental sustainability of textile products, rating for the use/maintenance phase of lifecycle was not detailed for the convenience of assessment. Therefore it was thought that the rating for use phase considering different maintenance options would be helpful in assessing the whole impact throughout the lifecycle of textile products.

For the material from the production phase (by the Higg Index), the greater points represents more environmentally favored choice. In order to compare the impact during 'production' and 'use' phases in the similar scale, the ratings obtained by the Higg Index was normalized by the following equation:

Normalized production score by the Higg Index =

$$\frac{\text{material points} + \text{finish points}}{\text{maximum possible production points}} \tag{5}$$

Material points: as is indicated by the Higg Index and MSI [21]

Finish points: -4 for finished textiles

Maximum possible production points for the material, which is 50 (based on the Higg Index/MSI [21]

The normalized scores for cotton, wrinkle-free cotton, viscose rayon, wrinkle-free finished viscose rayon, and polyester fabric shirts were compared for the 'production' and 'use' phase in Table 4. It should be noted that while the 'production' score given by the Higg Index [21] is inclusive of chemistry, energy use/greenhouse emission, water/land use, and physical waste, the 'use' score investigated in this study includes only the energy points during washing, drying and ironing processes. Thus the direct comparison of scores for the 'production' and 'use' phases should not be made, though they can demonstrate the comparative environmental positions for the scenarios in each 'production' and 'use' phase. The normalized scores both for the 'production' and 'use' phases give higher values for more environmentally favored scenarios. The specific 'Energy points' of the 'production' phase of materials were also presented in Table 4.

The maintenance scores in Table 4 for different textile materials and maintenance options were calculated by equation (4) (from Table 2). For all material types, the washing conditions such as washer type, washing temperature, and filling load were set consistent, as those washing conditions are more likely to be influenced by the post-consumer washing behavior rather than material type. The common washing conditions applied in Table 4 were: drum type washer, 40 °C washing temperature, 100 % filling load. Excluding those common washing parameters, the maintenance conditions that would be mostly affected by the material type were identified as drying and ironing processes. Those two processes were varied in Table 4 such that: 1) cotton and viscose rayon required a machine drying (condenser type) and an ironing process due to the slow drying and easy

Table 4. Scenario analysis for 'production' and 'use' phases for a shirt made of different textiles

Phase	Material production [21]				Cleaning and ironing	
Impact	Energy points	Material points	Finish points	Production score (normalized)	Energy points	Maintenance score (normalized)
Calculation	Given by the higg index/MSI			(material+finish) / (max, 50)	Given by Table 2	(max-respective points) / max
Cotton	2.3	30.8	0	0.616	8.783	0.849
Cotton, wrinkle-free	2.3	30.8	-4	0.536	7.658	0.868
Polyester	2.1	27.3	0	0.546	0.939	0.984
Nylon 6	3.0	16.3	0	0.326	0.939	0.984
Viscose rayon	2.7	18.0	0	0.360	8.783	0.849
Viscose rayon, wrinkle-free	2.7	18.0	-4	0.280	7.658	0.868

*Note: Maintenance conditions were assumed for 1) cotton: condenser type drying, ironing; 2) cotton and viscose, wrinkle-free and viscose, wrinkle-free: condenser type drying, no ironing; 3) polyester and nylon 6: no drying, no ironing. All cases were assumed using drum type washer with filling load 100 % at 40 °C wash temperature.

wrinkling; 2) wrinkle-free cotton and wrinkle-free viscose rayon required a machine drying (condenser type) but no ironing; 3) polyester and nylon 6 needed neither a machine drying nor an ironing.

Comparing the production scores of the cotton shirt with and without wrinkle-free finish, the base material rating of wrinkle free shirt would give a lower score due to the negative environmental impact by finishing process. However, the wrinkle-free shirt's maintenance score (for the energy consumption) was higher than the unfinished cotton shirt due to no need of ironing during use. Also, the material production score for cotton was higher than that of polyester, showing the favored environmental choice of cotton over polyester until fabric production phase, while the maintenance score (or energy points) during use phase was on the contrary. The resulting ratings appeared realistic and well aligned with the first-guess from our maintenance behavior.

The relative positions of the environmental impacts during the pre-consumer phase of 'production' and the energy impact during the post-consumer phase of 'use' that were presented in Table 4 were illustrated in Figure 1. If the energy consumption at the 'use' phase is a major concern for a decision-maker, a polyester or nylon 6 shirt would be the environmentally favored choice in terms of post-consumer energy use. Between those two, polyester might be an environmentally favorable choice for its higher 'production' score. If the impact during the production stage is of particular interest for the stakeholders, the unfinished cotton would be a favorable choice, while the finished viscose rayon would be a very unfavorable choice. It should be noted that the overall rating for sustainability assessment is usually susceptible to the rating methodology, though the relative comparisons among different scenarios may stay still applicable. The rating model proposed in this study intended to provide an objective and quantitative rating scheme to measure the energy impact made by different maintenance options in 'use' phase of textile products.

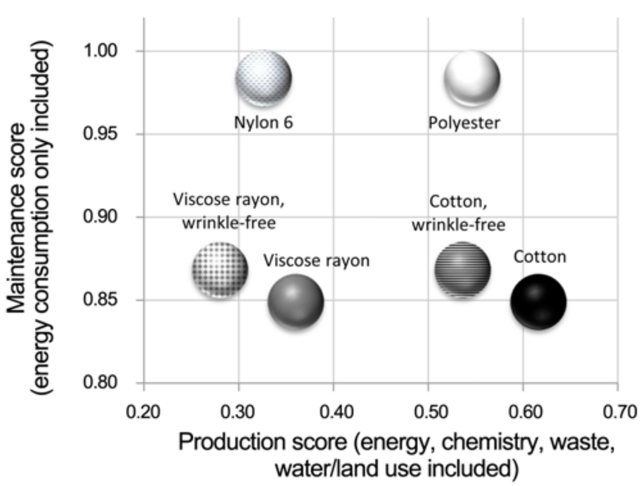

Figure 1. Scenario analysis for 'production' and 'use' phases for a shirt made of different textiles. *Note: Maintenance conditions were assumed for 1) cotton: 40 °C washing, condenser type drying, ironing, 2) cotton and viscose, wrinkle-free and viscose, wrinkle-free: 40 °C washing, condenser type drying, no ironing, 3) polyester and nylon 6: 40 °C washing, no drying, no ironing.

Scenario analysis for different maintenance options with different textile materials showed its applicability as a tool to provide an effective measurement of the energy impact. However, the proposed model has limitations in that the model considered only the energy consumption among the possible environmental impacts for the washing process. Especially, water usage is an important parameter of environmental impact during the washing process, and further study is required to count this impact. Furthermore, extended investigations are suggested to include the other environmental parameters such as bio-toxicity, greenhouse gas emission, and physical wastes. Also, the future study is recommended to experimentally verify the influence of post-consumer washing behavior on both the environmental impact and the washing performance.

Conclusion

This research intended to propose a rating model that measures the energy impact during the 'use' phase of the textile product lifecycle, made by the washing, drying, and ironing processes. To achieve the goal, the methodology of sustainability assessment for textile products was overviewed to learn about the gap in the currently available assessment.

Sustainability indices were mostly organization-centric and measured the economic, environmental and social aspects of the organization through a specific period of lifecycle, such as cradle to gate, or gate to gate of organization's interest. The methodology employed a specific rating model that the initial rates were weighted to generate the overall rate. Despite the efforts made in the textile sector to evaluate the sustainability, the impact influenced by the post-consumer maintenance behavior was not studied sufficiently, though the evidences show that the impacts made during the 'use' phase of textile products are significant.

The rating model was proposed to measure the energy impact during the maintenance of textile products by the washing, drying, and ironing processes. Five categories of maintenance condition including washer type, wash temperature, dryer type, filling load, and ironing need were made to choose, to give the initial score for the impact on energy consumption, and the summed score was normalized to fit in the scale of 0 to 1. Scenario analysis for the different maintenance conditions and materials demonstrated the applicability of the rating model as a simple yet valid quantification tool. With the limitations of the proposed model, future studies need to elaborate the rating methodology with more inclusive impact inventories and maintenance option.

Acknowledgements

This work was supported by the Research Institute of Human Ecology, Seoul National University [350-20130016]; and the SRC/ERC program of MOST/KOSEF [R11-2005-065].

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