Comprehensive assessment methods of environmental impacts during textile production

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ABSTRACT – REZUMAT

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As an important part of textile production, the dyeing process not only makes the greatest contribution to water consumption and wastewater discharge, but its use of synthetic dyestuffs has a negative impact on all forms of life. To assess the environmental impact of textile production, it is necessary to assess the environmental impact of the dyeing process. Comprehensive assessment methods can convert multi-dimensional environmental impacts into unified quantitative indicators and enable comparisons between different products or environmental impact categories. In this study, five comprehensive assessment methods (i.e., ReCiPe, Eco-Indicator 99, Nike MSI, Environmental Price, and Environmental Profit & Loss) were applied to evaluate the environmental impact of the cotton fabric dyeing process. Furthermore, a preliminary assessment framework was constructed which could provide a reference for industry experts to establish uniform environmental assessment standards. The results indicate that diverse methods are recommended to be applied in parallel to analyse the environmental impact of textile products, and the use of individual comprehensive environmental assessment methods has its limitations and characteristics. Among the five methods, the ReCiPe method stands out as one of the most advanced LCA methodologies with the widest range of midpoint impact categories and a global-scale calculation mechanism. The scoring method offers sufficient possibilities to compare the severity of different environmental impacts caused by the dyeing process, and the monetary value model can be used as a more intuitive tool to characterize environmental impact no matter from the midpoint or endpoint.

Keywords: *comprehensive assessment methods, environmental impacts, textile production, single point, monetary valuation*

Metode de evaluare a impactului asupra mediului în timpul producției materialelor textile

Ca parte importantă a producției materialelor textile, procesul de vopsire nu numai că are cea mai mare contribuție la consumul de apă și la evacuarea apelor uzate, dar utilizarea sa de coloranți sintetici are un impact negativ asupra tuturor formelor de viață. Pentru a evalua impactul asupra mediului al producției textile, este necesar să se evalueze impactul asupra mediului al procesului de vopsire. Metodele de evaluare pot converti efectele multidimensionale asupra mediului în indicatori cantitativi unificați și pot permite comparații între diferite produse sau categorii de impact asupra mediului. În acest studiu, au fost aplicate cinci metode de evaluare (cum ar fi ReCiPe, Eco-Indicator 99, Nike MSI, Environmental Price și Environmental Profit & Loss) pentru a evalua impactul asupra mediului al procesului de vopsire a materialelor textile din bumbac. În plus, a fost construit un cadru de evaluare preliminară care ar putea oferi o referință experților din industrie pentru a stabili standarde uniforme de evaluare a mediului. Rezultatele indică faptul că diverse metode sunt recomandate a fi aplicate în paralel pentru a analiza impactul asupra mediului al produselor textile, iar utilizarea metodelor individuale de evaluare a mediului are propriile limitări și caracteristici. Iar dintre cele cinci metode, metoda ReCiPe se evidențiază ca una dintre cele mai avansate metodologii LCA cu cea mai largă gamă de categorii de impact median și un mecanism de calcul la scară globală. Metoda de punctare oferă suficiente posibilități pentru a compara severitatea diferitelor tipuri de impact asupra mediului cauzate de procesul de vopsire, iar modelul valorii monetare poate fi folosit ca un instrument mai intuitiv pentru a caracteriza impactul asupra mediului, indiferent dacă este de la punctul median sau de la punctul final.

Cuvinte-cheie: *metode de evaluare, impactul asupra mediului, producția de textile, un singur punct, evaluarea monetară*

INTRODUCTION

The textile industry is responsible for significant global environmental impacts [1]. Energies, freshwater, and chemicals are consumed in the textile production process, causing water scarcity, water pollution, air pollution, and other environmental impacts [2]. To quantify the negative environmental impact of the various production stages of the textile industry and analyse a single product's environmental impacts, life cycle assessment (LCA) is widely used in the carbon, water, and chemical footprint measurements applied in a cradle-to-grave or cradle-to-gate scenario [3]. These footprint indicators above focus on specific environmental impacts respectively. For example, carbon footprint is used to quantify the global warming potential impact of greenhouse gas emissions; water footprint is used to quantify the environmental impacts of water consumption and wastewater discharge. However, in the actual circumstances, textile production involves diverse kinds of environmental impacts. Correspondingly, the multi-dimensional indicators of environmental impact assessment can express multiple environmental impact categories simultaneously. For instance, Product Environmental Footprint (PEF), a multi-criteria measurement of the products' environmental performance throughout the life cycle, includes global warming potential, human toxicity, eutrophication, land use, etc. [4, 5].

From what has been clarified, a single environmental impact assessment indicator can only quantify the environmental impact of a certain aspect, and the multi-dimensional environmental impact assessment indicator integrates various environmental impacts with different quantification units. It is challenging to execute comparisons between different products or environmental impact categories without transforming the impacts into a uniform indicator [6]. Based on this relation, it is essential to use a simple procedure that can be ideally applied consistently to all pollutants emitted and give comparable results between products or environmental impact categories [7]. Several different comprehensive impact assessment methodologies have been proposed, and several of them have been implemented in software commercially available on the market [8].

Table 1

DEFINITION OF COMPREHENSIVE IMPACT ASSESSMENT METHODS	
Comprehensive impact assessment methods	**Definition**
Scoring	A scoring mechanism that incorporates different impact characteristics into its formula design aims to assess the comprehensive impact
Monetary valuation	Monetary valuation is the practice of converting measures of social and biophysical impacts into monetary units and is used to determine the economic value of non-market goods, i.e. goods for which no market exists

Scoring and monetary valuation are common forms of comprehensive impact assessment methods, and the definitions of environmental impact assessment methods are detailed in table 1 [9]. The most typical scoring methods are Eco-Indicator 99 (EI99) and ReCiPe. Both of them are developed to determine the environmental impacts resulting from a product. EI99 is considered to be a comprehensive damage approach that is developed to simplify the interpretation and weighting of assessment results [7, 10]. ReCiPe, combining the advantages of the midpoint-based life cycle impact assessment approach and endpoint-based approach, has been thought to be one of the most advanced LCA methodologies around the world [11]. Another scoring method, the Nike Materials Sustainability Index (Nike MSI) was proposed in 2012 to evaluate the potential environmental impacts of materials in the product creation process, aiming to guide product creation teams in selecting materials that possess a lower environmental impact [12]. A comprehensive assessment method called Environmental Price and Environmental Gain and Loss (EP&L) is expressed in monetary values. Environmental prices are developed to express environmental impacts in monetary units at three levels: the pollutant level (a value for emissions of environmentally damaging substances), the midpoint level, and the endpoint level [13]. This method is used to assess the damage caused to the environment and humans by business activities, although many activities are not currently reflected in market prices [14].

Using different comprehensive assessments of the environmental impact of specific industrial processes would make the results more credible. Among textile production, the dyeing process makes the largest contribution to water consumption and wastewater discharge, and the use of synthetic dyestuffs has a negative impact on all forms of life [15, 16].

Therefore, the environmental impact analysis of the dyeing stage of cotton production can be a good case study for the comprehensive environmental impact assessment study of textile products. It can also provide data and scenarios for the comparative study of different comprehensive environmental impact assessment methods. In this paper, ReCiPe, EI99, Nike MSI, Environmental Price, and EP&L were applied to the environmental impact assessment of the cotton fabric dyeing process and a preliminary assessment framework was constructed. In addition, the methodological differences between these five methods as well as the practical implications were discussed. This study aims to serve as a reference for practitioners seeking to select suitable product environmental impact assessment methods and provide inspiration for the establishment of a unified environmental assessment mechanism.

METHODOLOGY AND DATA

Comprehensive assessment methodology

There are two mainstream ways to quantify the environmental impacts: problem-oriented (midpoint) and damage-oriented (endpoint). The definitions of environmental impact quantification methods are detailed in table 2 [17].

These two methods can be used to achieve a comprehensive evaluation through characterization, normalization, and weighting. The schematic diagram of the comprehensive environmental impact assessment related to the midpoint and endpoint approach is shown in figure 1. The two approaches are consistent models that can work together. The midpoint characterization is more directly linked to the environmental impacts and has relatively higher scientific

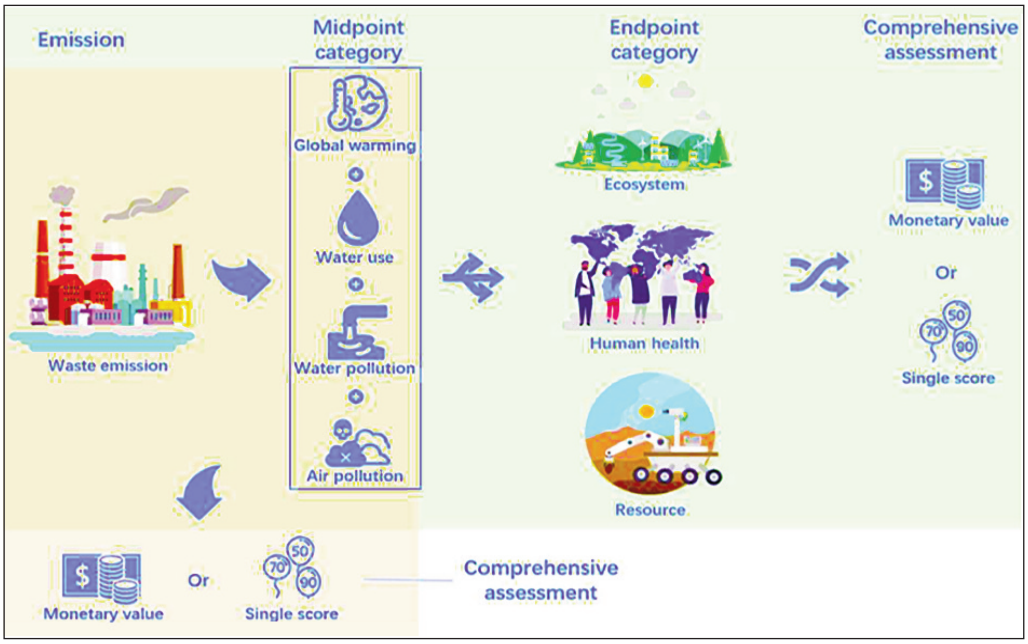

Fig. 1. Schematic diagram of comprehensive environmental impact assessment

Table 2

DEFINITION OF ENVIRONMENTAL IMPACT QUANTIFICATION METHODS	
Environmental impact quantification methods	**Definition**
Problem-oriented (midpoint)	The midpoint approach classifies impacts into different environmental themes in the underlying impact pathway such as global warming potential, water acquisition, water deterioration, air pollution, etc.
Damage-oriented (endpoint)	The endpoint approach transfers environmental impacts to concerning issues at the end of the impact pathway, such as human health, natural environment, and resource scarcity

validity, while the endpoint indicators are more understandable because they show the outcomes of the environmental impacts. Both approaches can be expressed with monetary value or a single score [18, 19].

The construction of the comprehensive environmental impact assessment framework proceeded according to the following stages: (i) The definition of the comprehensive environmental impact assessment; (ii) the selection of the objective and scope of research work; (iii) the determination of the expression of impact categories; (iv) data search and collection; (v) the creation of a calculation model for the comprehensive environmental impact assessment results (equation 1). The methodology of comprehensive assessment methods can be expressed as:

$$F = \sum F_i = \sum E_i \times f_{c,i} = \sum W_i \times f_{e,i} \times f_{c,i} \qquad (1)$$

As shown in equation 1, the comprehensive environmental impact assessment results are composed of several impact categories. The comprehensive assessment result of environmental impact i (F_i) is determined by multiplying the environmental damage value (E_i) with the comprehensively characterize factor ($f_{c,i}$). E_i can be further expressed as the product of pollution emission equivalent (W_i) and environmental impact characterizes factor ($f_{e,i}$).

The characterize factors of comprehensive assessment approaches are different according to ReCiPe, EI99, Nike MSI, Environmental Price, and EP&L (as listed in table 3). In the ReCiPe and EI99 methodologies, $f_{e,i}$ are endpoint impact factors, and $f_{c,i}$ are expressed in single score Pt. One Pt can be interpreted as one-thousandth of the annual environmental load of one average European inhabitant [8]. In the Nike MSI assessment framework, $f_{c,i}$ is expressed in point. It is not a substitute for full LCA studies nor does it provide endpoint assessment data. In the Environmental Price and PwC-EP&L methodologies, $f_{c,i}$ is expressed in monetary value. The $f_{e,i}$ of Environmental Price is the midpoint impact factor, and the $f_{e,i}$ of PwC-EP&L is the endpoint impact factor.

There are some differences in the detailed classification of impact categories among these five methods, but the important midpoint impact categories such as global warming potential, water pollution, and air pollution are all included in these methods. In this paper, we classified the midpoint impact categories into four indicators according to the impact categories of PwC-EP&L to demonstrate the case study results (as shown in table 4).

Data

These five kinds of comprehensive assessment methods were adopted in the evaluation of the environmental impacts of the dyeing process of cotton

Table 3

COMPARISON OF COMPREHENSIVE ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY				
Comprehensive assessment approaches	**Comprehensive impact assessment methods**		**Environmental impact quantification methods**	
	Scoring	Monetary valuation	Problem-oriented (midpoint)	Damage-oriented (endpoint)
ReCiPe	√($f_{c,i}$)			√($f_{e,i}$)
EI99	√($f_{c,i}$)			√($f_{e,i}$)
Nike MSI	√($f_{c,i}$)			
Environmental Price		√($f_{c,i}$)	√($f_{e,i}$)	
PwC-EP&L		√($f_{c,i}$)		√($f_{e,i}$)

Table 4

MIDPOINT IMPACT CATEGORIES SCHEME OF FIVE METHODS RELATED TO THE COTTON FABRIC DYEING PROCESS					
Impact indicators	**ReCiPe**	**EI99**	**Nike MSI**	**Environmental Price**	**PwC-EP&L**
Water consumption	Water consumption	–	Water use intensity	–	Water consumption
Greenhouse gases	Global warming	Climate change	Greenhouse gas intensity	Climate change	Greenhouse gases
Air pollution	Fine particulate matter formation; Photochemical ozone formation	Respiratory effects	Chemistry	Terrestrial acidification; Photochemical oxidant formation; Particulate matter formation	Air pollution
Water pollution	Freshwater ecotoxicity	Ecotoxicity; Carcinogens		Human toxicity; Freshwater ecotoxicity	Water pollution

fabric. The functional unit was defined as 1 kg of dyed cotton fabric. The data was collected from a textile-dyeing enterprise in Jiangsu Province (as listed in table 5) [20]. The characterize factors, normalization factors and weighting factors of ReCiPe, EI99 and Environmental Price were referred to the Simapro version 9.2.0.1. database. The data of PwC-EP&L and Nike MSI were obtained from PwC valuing

Table 5

THE COMPREHENSIVE ASSESSMENT RESULTS OF THE COTTON FABRIC DYEING PROCESS BASED ON FIVE METHODS									
Impact category			**ReCiPe (Pt)**		**Eco-indicator 99 (Pt)**		**Nike MSI (point)**	**Environmental Price ($)**	**PwC EP&L ($)**
			Human health	Ecosystems	Human health	Ecosystem quality			
Water consumption (m^3)	Freshwater	8.60	0.318	0.0314	–	–	8	–	3.55
Greenhouse gases (kg)	CO_2	12.1	0.219	0.0107	0.129	–	3	0.909	1.10
	CH_4	0.0576							
	N_2O	$2.44·10^{-4}$							
Air pollution (kg)	SO_2	0.01.34	0.0446	$1.18·10^{-4}$	0.0469	–	3.4	0.281	$5.41·10^{-4}$
	NOx	0.00337							
	NH_3	$2.10·10^{-7}$							
	NMVOC	$3.80·10^{-5}$							
Water pollution (kg)	Lead	$4.65·10^{-8}$	–	$9.62·10^{-10}$	$1.25·10^{-4}$	$9.36·10^{-11}$		$6.37·10^{-5}$	0.38
	Mercury	$9.76·10^{-10}$							
	Cadmium	$1.73·10^{-9}$							
	Arsenic	$3.98·10^{-8}$							
Total			**0.62**		**0.18**		**14.4**	**1.19**	**5.04**

corporate environmental impacts and Nike materials sustainability index methodology [12, 14].

RESULT AND DISCUSSION

The comprehensive assessment results of the environmental impacts of the dyeing process are tabulated in table 5. It can be seen that greenhouse gas emissions and water consumption occupy a considerable proportion of the total environmental impacts. Water pollution has the least environmental impact.

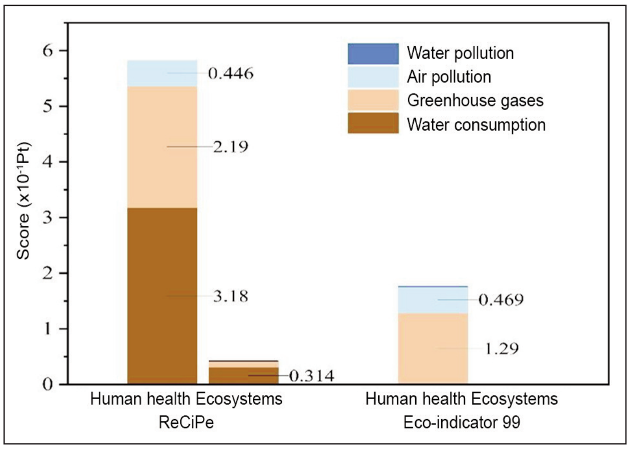

Fig. 2. Comparison of comprehensive assessment results between ReCiPe and EI99 method

At the endpoint level, the score gained according to the ReCiPe method is larger than that of the EI99 method (figure 2). This is because the EI99 method does not contain the impact category of water consumption, which leads to the underestimation of the total environmental impact. ReCiPe is suggested as a damage-oriented method better than EI99 because it expands the impact list of the ecosystem's damage category. In the resources damage category, the ReCiPe method provides more reliable cost parameters instead of the vague supplement of the energy requirement applied in EI99 [21].

Nike MSI evaluates the sustainability of products by assigning a numerical value to raw materials [22]. The base material score of cotton fabric is 26.8 points according to the Nike MSI scoring framework. In this study, we got a score of 14.4 points due to the environmental impact of physical waste was not included in the evaluation procedure (as shown in table 5). Nike MSI is not comparable with other methods because it is not based on life cycle assessment. It is a tool that engages designers to consider the sustainability issues of raw materials. Out of 100 points, a higher score means the material is more sustainable [12].

Environmental Price and PwC-EP&L express environmental impact in monetary value. From the results in table 5, it can be seen that the environmental impact monetary value of PwC-EP&L is larger than the Environmental Price (figure 3). The main difference between the two methods is that they are based

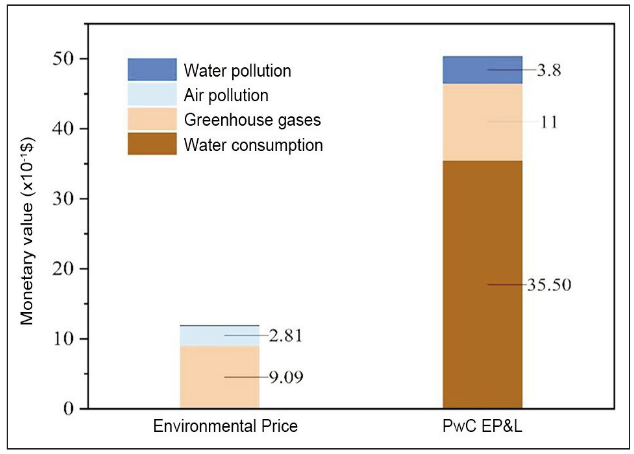

Fig. 3. Comparison of comprehensive assessment results between Environmental Price and PwC-EP&L method

on different study backgrounds. The Environmental Price was conducted in the Netherlands while the PwC-EP&L was conducted in the UK.

Besides, the impact category of water consumption in Environmental Price is not involved in the assessment system. It is the main reason that caused the gap between the two results.

Using the Recipe method in the scoring method and the PwC-EP&L method in the monetary valuation method to observe the environmental impact results, we found that water consumption accounts for 56.35% and 70.44% of the total environmental impact respectively. Therefore, we can formulate water-saving measures for the dyeing process in cotton fabric production from the perspective of water consumption. We can consider increasing the application of clean production technology to suppress wastewater discharge from the source. This includes adopting highly efficient and environmentally friendly dyes and chemicals and auxiliaries, adopting small bath ratio intermittent dyeing, pigment printing, digital ink-jet printing, transfer printing and other waterless printing and dyeing technical equipment. We can also adopt technologies such as condensed water reuse and reclaimed water reuse, counter-current rinsing by lattice, etc., to improve the water reuse rate.

Based on the above analysis, it is clear that both the scoring method and the monetary valuation method have their characteristics and limitations.

Scoring methods offer sufficient possibilities to analyse ecological impacts and make it relatively easy to compare different environmental impacts. The subjectivity of the weighting factors is one of the main weaknesses of this method because the weighting factors are often extracted from questionnaires with experts within the field [17]. As the uncertainty of different assessment systems is difficult to quantify, Goedkoop and Spriensma (2001). have developed three versions of eco-indicators, covering the perspectives of short-term (Individualist), long-term (Egalitarian) and balance (Hierarchist) effects. The three visions are applied in ReCiPe methods and EI99 methods, and the 'Hierarchist' version is often the default option for environmental impact assessment [23].

The monetary valuation method provides a new option for assessing the environmental impacts of goods that are not on the market, such as clean atmosphere or freshwater [24]. It can simplify many complex environmental metrics into a single unit, enabling businesses to make comparisons and prioritize environmental impacts, and hence to reduce impacts in the most influential stage or develop environmental-friendly products. The limitation of monetary valuation is mainly due to the choice of monetary factor which will be affected by many elements, especially time and region. The monetarization of environmental impact is under development, and its suitability to provide information for specific business decisions still needs to be evaluated on a case-by-case basis [14].

The midpoint and endpoint environmental assessment mechanisms and weighting factors that make up the indicators were developed based on the social values, context, and environmental issues of a particular region [7]. Therefore, the discrepancy in spatial boundaries among these methods is obvious, some are global, whereas others are limited to a specific region or country [24, 25]. These methods are currently still partially under development and none of them is a perfect approach to fully contain all environmental impacts.

CONCLUSIONS

This paper provided a review of existing comprehensive environmental impact assessment methods with a case study and constructed a preliminary assessment framework. Through decomposing impact pathways and highlighting their methodological discrepancy, this study could assist practitioners in choosing an appropriate method to implement comprehensive assessment according to their goals and data availability when conducting an environmental impact study. The assessment framework also provides a reference for industry experts to establish uniform environmental assessment standards. Among the five methods, the ReCiPe method finds its strength as one of the advanced LCA methodologies with the broadest categories of midpoint impact and a calculation mechanism with global scope. The monetary value model is easily understandable and can be used as a more intuitive tool to characterize environmental impact matter from the midpoint or endpoint. Assigning monetary value to the evaluation of environmental impacts allows companies to take sustainability into account when making decisions, thereby providing better outcomes for the environment and society. Additionally, this paper illustrates that these comprehensive assessment methods are not competitive absolutely because they provide distinct strengths and weaknesses and thus are recommended to be applied in parallel to analyse the environmental impact of textile products.

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