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Going green: strategic evaluation of green ICT adoption in the textile industry by using bipolar fuzzy MULTIMOORA method

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DARJAN KARABASEVIC
PAVLE RADANOV
DRAGISA STANUJKIC
GABRIJELA POPOVIC
BRATISLAV PREDIC

ABSTRACT – REZUMAT

Going green: strategic evaluation of green ICT adoption in the textile industry by using bipolar fuzzy MULTIMOORA method

The widespread use of information and communication technologies in all fields has a direct impact on the way the world is viewed. In today's competitive international business environment, companies are increasingly investing in the search for new ideas and approaches in production. The use of information and communication technologies (ICT) is increasingly gaining in importance, especially in the situation of a dynamic market and increasingly demanding consumers. Today's business of contemporary organizations is not conceivable without the support of modern ICT systems. Therefore ICT has a great influence on modern society because the ways in which information and data are exchanged are higher than ever. Green information and communication technologies as one area that is new and in development tend to establish a balance between these technologies and the environment. Adoption of green information and communication technologies is not an easy task and is often related to certain limitations. Therefore, the aim of the paper is a strategic evaluation of green ICT and their implementation in the textile industry by using newly-developed bipolar fuzzy MULTIMOORA method. Effectiveness and efficacy of the proposed approach is demonstrated in the conducted illustrative case study.

Keywords: *Green ICT, ICT, textile industry, MCDM, bipolar fuzzy MULTIMOORA method*

Adoptarea metodei ecologice: evaluarea strategică a adoptării eco-TIC în industria textilă prin utilizarea metodei bipolare fuzzy MULTIMOORA

Utilizarea pe scară largă a tehnologiilor informației și comunicațiilor în toate domeniile are un impact direct asupra modului în care lumea este privită. În mediul de afaceri internațional competitiv de astăzi, companiile investesc din ce în ce mai mult în căutarea de noi idei și abordări în domeniul producției. Utilizarea tehnologiilor informației și comunicațiilor (TIC) capătă din ce în ce mai multă importanță, în special în situația unei piețe dinamice și a consumatorilor din ce în ce mai pretențioși. Afacerile de astăzi ale organizațiilor nu sunt concepute fără sprijinul sistemelor moderne TIC. Prin urmare, TIC au o mare influență asupra societății moderne, deoarece modalitățile prin care sunt schimbate informații și date sunt mai avansate ca niciodată. Eco-TIC, ca domeniu nou și în curs de dezvoltare, tinde să stabilească un echilibru între aceste tehnologii și mediu. Adoptarea eco-TIC nu este o sarcină ușoară și este adesea legată de anumite limitări. Prin urmare, scopul lucrării este o evaluare strategică a eco-TIC și implementarea acestuia în industria textilă, utilizând metoda bipolară fuzzy MULTIMOORA, dezvoltată recent. Eficacitatea abordării propuse este demonstrată în studiul de caz realizat.

Cuvinte-cheie: *eco-TIC, TIC, industria textilă, MCDM, metoda bipolară fuzzy MULTIMOORA*

INTRODUCTION

One of the biggest, oldest and most commercialized industries in the world is the textile industry. The textile industry is an important branch of the manufacturing industry and is of great importance for the economy of a country. Today, the textile industry is one of the most globalized industries. Accordingly, the prerequisite for success is the continuous monitoring of current market trends in terms of standards, raw materials and technical equipment of production [1]. The textile industry, as a very important industrial area is technically and technologically very demanding.

The opportunity for the growth of textile production can be exploited by those managers and organizations that are ready to change their business paradigms and that are open to creating changes and introducing new information and communication technologies (ICT) in production. It is emphasized that new technologies in the textile industry are developed in order to improve textile and clothing manufacturing and trade. Some of the goals which new technologies and above ICT should bring are: "1. providing response to new fashion trends; 2. ensuring the efficiency and effectiveness of mass production through the application of ICT (computer-aided design) and 3. adaptation to increasingly sophisticated customers (selling online through web platforms, offering added value through quality or price, ensuring a long term relationship etc.)" [2].

In today's competitive business environment, companies are increasingly investing in the search for new ways and approaches in production. The use of information and communication technologies plays a vital role and is increasingly gaining in importance, especially in the situation of a dynamic market and increasingly demanding consumers. Today's business of contemporary organizations is not conceivable without the support of modern ICT systems. Therefore ICT has a great influence on modern society because the ways in which information and data are exchanged are higher than ever [3].

The role of ICT is becoming increasingly important in all aspects of life (education, work, entertainment, health, etc.). Davison [4] point out that the term is used interchangeably in order to cover the full spectrum of existing and potential ICT that are used, including computers, personal communication devices, digital video and sound systems, email, the Internet, etc. ICT is mainly related to the technologies that are used for accessing, collecting, manipulating and presenting or transmitting the information. ICT technologies may include hardware (e.g. computers and other devices); software applications; and connectivity (e.g. Internet access, local area network infrastructure, video conferencing). Exactly what is most important about ICT is the increasing convergence of computer-based, multimedia and communication technologies, as well as the rapid rate of change that characterizes technologies and their use [5, 6]. ICT is most commonly related to two main components: information technology (IT) and communication technology (CT). IT mostly involves computer hardware and software, while CT is related to Internet communication [7]. ICT is a broader concept that includes communication devices, various services, video conferencing, online learning, etc., in order to provide users with access, storage, transmission and manipulation of information [8].

Veljović et al. [9] point out that the most important components of information and communication technologies are computers. At the same time, the application and development of digital communications enabled an easy, fast, efficient and inexpensive way of exchanging information. Therefore, ICTs include a diverse set of technology tools that are used to identify and organize data and information. Murray [10] states that ICT is expanding the concept of information technology in which particularly is highlighted the role and importance of the integration of communications, telecommunications and computers, as well as the necessary software, storage and audiovisual system that gives users the ability to access, store and further manipulate information.

Today's business of contemporary organizations is not conceivable without the support of modern ICT systems. Therefore ICT has a great influence on modern society because the ways in which information and data are exchanged are higher than ever. Green information and communication technologies as one area that is new and in development tend to establish a balance between these technologies and the environment. Also, as Din et al. [11] point out, green ICT, as a concept was introduced with the aim to support the implementation of the green environment, i.e. is aimed at conserving energy as one essential domain.

There is no universal definition of green information and communication technologies. Reimsbach-Kounatze [12] emphasizes that the "green ICT is about the study and practice of using computing resources in an efficient, effective and economical way". Sarkis and Zhu [13] states that "green ICT refers more to the hardware and other infrastructure that can be better managed and designed from an environmental perspective". Andreopoulou [14] states that green ICT "are ICT tools, certain services and technologies that in combination with green practices and green behavior contribute not only to the protection of the environment but also to the enhancement of the quality of life". Radu [15] emphasizes that coherence between ICT and the environment is relatively new and that the using of environmental criteria is often referred to as green ICT.

Adoption of green information and communication technologies is not an easy task and is often related to certain limitations. The process of evaluation of green ICT can be a challenging task. However, problem of green ICT evaluation can be easily solved by using multiple-criteria decision-making methods.

Decision making is a process that is constantly happening all around us [16]. In real-world situations, decision-making is most often made on the basis of the existence of a number of criteria, which are often conflicting; therefore, for solving such problems using of multiple-criteria decision-making methods (MCDM) is an option. MCDM enables the selection of a suitable alternative from a finite set of alternatives while respecting the values of the criterion attributes, i.e. it enables decision-making in the presence of multiple, often conflicting criteria [17–22]. Ishizaka and Nemery [23] indicate the growing use of MCDM methods because these methods primarily enable better decision-making and adoption of long-term and sustainable solutions.

The extremely rapid development of the MCDM field has also caused the creation of a wide range of MCDM methods, which have been applied so far in solving different types of problems. Some of the prominent and most applied methods are: SAW, AHP, ELECTRE, PROMETHEE, ANP, VIKOR, COPRAS and so on [24–26]. Also, it is important to note that for the needs of solving more complex problems, a whole generation of new MCDM methods and approaches have been proposed, such as: MOORA, MULTIMOORA, WASPAS, SWARA, ARAS, ARCAS, PIPRECIA, MAIRCA, EDAS, CODAS and so on [27, 28].

Based on the foregoing stated, the aim of the paper is the strategic evaluation of green information and communication technologies adoption in the textile industry by using newly-developed bipolar fuzzy MULTIMOORA method. Therefore, in order to present an MCDM for the purpose of green ICT evaluation, the remainder of the paper is organized into four sections. In Section 1, a literature review is provided. Section 2 contains the presentation of the applied methodology. A case study is introduced in Section 3, which is followed by the section presenting the conclusion.

THE COMPUTATIONAL PROCEDURE OF THE SVBFN-MULTIMOORA METHOD

Extension of the MULTIMOORA method based on Single-Valued Bipolar Fuzzy Numbers is proposed by Stanujkic et al. [29]. Brauers [30] initially proposed the well-known MOORA method, somewhat later Brauers and Zavadskas [31] have proposed MULTIMOORA method. So far, MULTIMOORA method has been applied for solving various problems in different fields, such as: economy [31–34]; personnel selection [35–38]; supplier selection [39, 40]; information and communication technologies [41, 42], robotics [43], comminution circuit design selection [44], assessment of the energy storage technologies [45], and so on.

The computational procedure of the SVBFN-MULTIMOORA method can be expressed as follows [29]:

Step 1. Evaluation of the alternatives in relation to the selected set of criteria for each decision-maker DM. In this step evaluation could be easily performed by using the nine-point Liker scale that is proposed by Stanujkic [29].

Step 2. Determination of the importance of the evaluated criteria for each DM.

Step 3. Determination of the group decision matrix, as it is proposed in [29].

Step 4. Determination of the group weights of the criteria, as follows:

$$w_j = \sum_{k=1}^{K} w_j^k \tag{1}$$

where w_j denotes the weight of the criterion j, and w_j^k denotes the weight of the criterion j obtained from the DM k.

Step 5. Determination of the significance of the evaluated alternatives based on the RS approach. This step can be explained through the following substeeps:

Step 5.1. Determination of the impact of the benefit and cost criteria to the importance of each alternative, as follows:

$$Y_i^{+} = \left(1 - \prod_{j \in \Omega_{max}}^{n} (1 - r_{ij})^{w_j}, -\left(1 - \prod_{j \in \Omega_{max}}^{n} (1 - (-r_{ij}))^{w_j}\right)\right) \tag{2}$$

$$Y_i^{-} = \left(1 - \prod_{j \in \Omega_{max}}^{n} (1 - r_{ij})^{w_j}, -\left(1 - \prod_{j \in \Omega_{max}}^{n} (1 - (-r_{ij}))^{w_j}\right)\right) \tag{3}$$

where Y_i^{+} and Y_i^{-} denote the importance of the alternative i obtained on the basis of the benefit and cost criteria, respectively; Y_i^{+} and Y_i^{-} are SVBFNs.

It is evident that A_w operator is used to calculate the impact of the benefit and cost criteria.

Step. 5.2. Transformation of the Y_i^{+} and Y_i^{-} into crisp values by using the Score Function, as follows:

$$y_i^{+} = s(Y_i^{+}) \tag{4}$$

$$y_i^{-} = s(Y_i^{-}) \tag{5}$$

Step 5.3. Calculation of the overall importance for each alternative, as follows:

$$y_i = y_i^{+} - y_i^{-} \tag{6}$$

Step 6. Determination of the significance of the evaluated alternatives based on the RP approach. This step can be explained through the following substeeps:

Step 6.1. Determination of the reference point (RP). The coordinates on the bipolar fuzzy reference point $r^* = \{r_1^*, r_2^*, ..., r_n^*\}$ can be determined as follows:

$$r^* = \left\{(<\max_i r_{ij}, \min_i r_{ij} > | \, j \in \Omega_{max}), \\ (<\min_i r_{ij}, \max_i r_{ij} > | \, j \in \Omega_{min})\right\} \tag{7}$$

where r_j^* denotes the coordinate j of the reference point.

Step 6.2. Determination of the maximum distance from each alternative to all the coordinates of the reference point as follows:

$$d_{ij}^{max} = d_{max}(r_{ij}, r_j^*) w_j \tag{8}$$

where d_{ij}^{max} denotes the maximum distance of the alternative i to the criterion j.

Step 6.3. Determination of the maximum distance of each alternative, as follows:

$$d_i^{max} = \max_j d_{ij}^{max} \tag{9}$$

where d_i^{max} denotes the maximum distance of the alternative i.

Step 7. Determination of the significance of the evaluated alternatives based on the FMF:

Step 7.1. Calculation of the utility obtained based on the benefit U_i^{+} and cost U_i^{-} criteria, for each alternative, as follows:

$$U_i^{+} = \left(\prod_{j \in \Omega_{max}}^{n} (r_{ij})^{w_j}, -\prod_{j \in \Omega_{max}}^{n} (-r_{ij})^{w_j}\right) \tag{10}$$

$$U_i^{-} = \left(\prod_{j \in \Omega_{min}}^{n} (r_{ij})^{w_j}, -\prod_{j \in \Omega_{min}}^{n} (-r_{ij})^{w_j}\right) \tag{11}$$

where and are SVBFNs.

Step 7.2. Transformation of the and into crisp values by using the Score Function, as follows:

$$u_i^{+} = s(U_i^{+}) \tag{12}$$

$$u_i^{-} = s(U_i^{-}) \tag{13}$$

Step 7.3. Determination of the overall utility for each alternative, as follows:

$$u_i = \frac{u_i^+}{u_i^-} \tag{14}$$

In the case when evaluation is made only on the basis of benefit criteria Eq. (14) is as follows:

$$u_i = u_i^+ \tag{15}$$

Step 8. Determination of the final ranking order of the alternatives by using theory of dominance.

A NUMERICAL CASE STUDY

In this part of the paper, a numerical case study is considered in order to highlight the proposed methodology. As stated before, there is a tendency towards using green ICT. A textile company has decided to introduce green ICT. For this reason, a team consisted of 3 DMs was formed in order to evaluate four alternatives designated as A_1, A_2, A_3, A_4. Based on carefully literature review [49–50], a total number of 5 evaluation criteria were selected: C_1 – Economic and energy efficiency; C_2 – Eco-friendliness; C_3 –Technology evolution; C_4 – Improved systems performance and use; C_5 – Overall impact of green ICT on the organization.

The ratings of the evaluated alternatives in the form of SVBFNs for the three decision-makers are shown in tables 1–3.

The group decision matrix is shown in table 4.

The group weights obtained from the three DMs by applying the PIPRECIA method [48] and by using equation (1) are accounted for in table 5.

Table 1

THE RATINGS OBTAINED FROM THE FIRST OF THE THREE DMS

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	<0.80, –0.20>	<0.80, –0.10>	<0.70, –0.30>	<0.80, –0.30>	<0.50, –0.20>
A_2	<0.40, –0.50>	<0.30, –0.30>	<0.40, –0.40>	<0.30, –0.30>	<0.20, –0.30>
A_3	<0.50, –0.30>	<0.40, –0.30>	<0.40, 0.10>	<0.50, –0.30>	<0.60, –0.50>
A_4	<0.90, –0.10>	<0.70, –0.10>	<0.70, 0.10>	<0.80, –0.30>	<0.70, –0.40>

Table 2

THE RATINGS OBTAINED FROM THE SECOND OF THE THREE DMS

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	<1.00, –0.10>	<0.90, –0.20>	<0.80, –0.20>	<0.60, –0.10>	<0.70, –0.10>
A_2	<0.60, –0.30>	<0.80, –0.40>	<0.70, –0.20>	<0.50, –0.30>	<0.60, –0.30>
A_3	<0.70, –0.30>	<0.50, –0.30>	<0.60, –0.20>	<0.80, –0.20>	<0.50, –0.30>
A_4	<1.00, –0.10>	<1.00, –0.10>	<0.70, –0.20>	<0.80, –0.20>	<0.80, –0.20>

Table 3

THE RATINGS OBTAINED FROM THE THIRD OF THE THREE DMS

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	<1.00, –0.20>	<0.90, –0.20>	<0.80, –0.20>	<0.70, –0.20>	<0.60, –0.20>
A_2	<0.50, –0.40>	<0.40, –0.20>	<0.50, –0.20>	<0.70, –0.30>	<0.50, –0.30>
A_3	<0.40, –0.20>	<0.50, –0.20>	<0.50, –0.10>	<0.80, –0.30>	<0.60, –0.30>
A_4	<1.00, –0.20>	<1.00, –0.10>	<0.60, –0.10>	<0.70, –0.20>	<0.60, –0.30>

Table 4

THE GROUP DECISION-MAKING MATRIX

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	<1.00, –0.16>	<0.87, –0.16>	<0.77, –0.23>	<0.71, –0.19>	<0.60, –0.16>
A_2	<0.50, –0.40>	<0.56, –0.29>	<0.55, –0.26>	<0.52, –0.30>	<0.45, –0.30>
A_3	<0.55, –0.27>	<0.46, –0.27>	<0.50, –0.13>	<0.72, –027>	<0.56, –0.36>
A_4	<1.00, –0.13>	<1.00, –0.10>	<0.67, –0.13>	<0.77, –0.23>	<0.71, –0.09>

Table 5

THE GROUP CRITERIA WEIGHTS				
Criteria	w_j^1	w_j^2	w_j^3	w_j
C_1	0.24	0.23	0.27	0.25
C_2	0.19	0.25	0.20	0.21
C_3	0.21	0.23	0.20	0.21
C_4	0.18	0.18	0.17	0.18
C_5	0.18	0.12	0.15	0.15
Total				1.00

Based on the ratings from table 4 and the weights from table 5, the overall significance, the maximum distance to the RS and the overall utility are calculated for each alternative in the next step. The overall significances accounted for in table 6, are calculated by applying equations (2)–(6).

Thereafter, the RP is determined by using equation (7). The maximum distances to the RP accounted for in table 7 are determined by using equation (8) and equation (9).

The overall utility shown in table 8 is calculated by applying equations (10)–(14).

Taking into consideration ranking orders shown in tables 6, 7 and 8, the most appropriate alternative is determined by the theory of dominance, as is shown in figure 1.

As can be seen from figure 1, the alternative denoted as A_4 is the most appropriate in the terms of evaluated criteria.

Additionally, to verify the reliability of the proposed approach and to confirm ranking orders obtained by using the SVBFN-MULTIMOORA method, a sensitivity analysis was conducted with the comparison of the ranking results obtained by using of SVBFN-MULTIMOORA method with 2 well-known and proven MCDM methods (TOPSIS and SAW). The obtained results of the conducted sensitivity analysis are shown in figure 2 and table 9.

It can also be concluded from table 9 that the small inconsistency in the ranking orders of the considered alternatives obtained by applying the TOPSIS

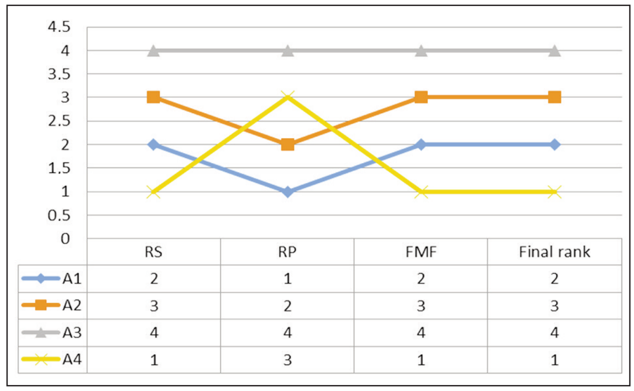

Fig. 1. The final ranking order of the considered alternatives by using theory of dominance

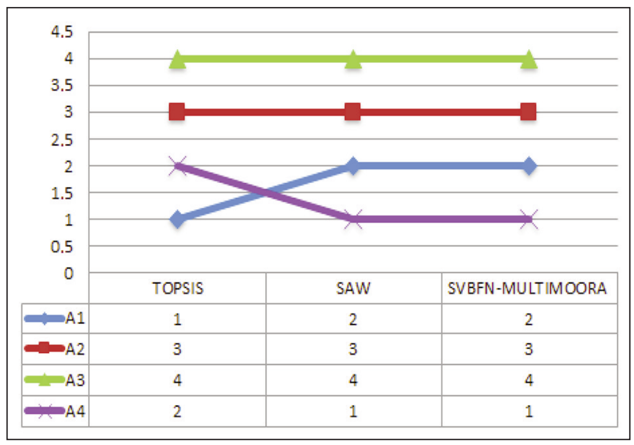

Fig. 2. Results of the sensitivity analysis

Table 6

THE OVERALL SIGNIFICANCES OF THE CONSIDERED ALTERNATIVES						
Alternatives	Y_i^+	Y_i^-	y_i^+	y_i^-	y_i	**Rank**
A_1	<1.00, –0.13>	<0.33, –0.07>	0.94	0.63	0.30	2
A_2	<0.40, –0.23>	<0.22, –0.12>	0.59	0.55	0.04	3
A_3	<0.38, –0.16>	<0.33, –0.13>	0.61	0.60	0.01	4
A_4	<1.00, –0.08>	<0.39, –0.10>	0.96	0.64	0.31	1

Table 7

THE RATINGS OF THE ALTERNATIVES OBTAINED BASED ON THE RP APPROACH							
Alternatives	C_1	C_2	C_3	C_4	C_5	d_i	**Rank**
A_1	0.12	0.13	0.01	0.09	0.08	0.01	1
A_2	0.25	0.22	0.11	0.06	0.07	0.06	2
A_3	0.29	0.28	0.20	0.14	0.16	0.14	4
A_4	0.13	0.10	0.11	0.15	0.19	0.10	3

Table 8

THE OVERALL UTILITY OF THE CONSIDERED ALTERNATIVES								
Alternatives	U_i^+	U_i^-	u_i^+	u_i^-	u_i	**Rank**		
A_1	<0.92, –0.32>		<0.86, –0.53>		0.80	0.67	1.20	2
A_2	<0.66, –0.46>		<0.77, –0.65>		0.60	0.56	1.07	3
A_3	<0.63, –0.35>		<0.86, –0.65>		0.64	0.60	1.06	4
A_4	<0.92, –0.24>		<0.90, –0.61>		0.84	0.64	1.30	1

Table 9

THE FINAL RANKING ORDERS OBTAINED BY USING THE TOPSIS AND THE SAW METHODS				
Alternatives	**TOPSIS**		**SAW**	
	C_i	**Rank**	S_i	**Rank**
A_1	0.527	1	0.646	2
A_2	0.498	3	0.538	3
A_3	0.488	4	0.531	4
A_4	0.526	2	0.672	1

method is caused by a very small difference in C_i values of alternatives A_1 and A_4 that are 0.527 and 0.526. Any slight change in the weight of the criteria or the ratings of the alternative probably would lead to the same ranking order of alternatives.

CONCLUSION

Information and communication technologies play a significant role in the processing of information and their transformation into knowledge, which is a basic condition for creating an information society. As stated before, green ICT as an area that is new and in development is directed towards establishing a balance between these technologies and the environment. Adoption of such technologies is a very complex and challenging task. In this paper, the application of bipolar fuzzy MULTIMOORA method is proposed for the evaluation of green ICT adoption in the textile industry. During the evaluation process, a total of three decision-makers (domain experts) were involved, who evaluated four alternatives. For the purpose of evaluation of alternatives, a total number of five criteria were used. When it comes to the determination of criteria, PIPRECA method was used, because of its simplicity and ease of use, especially when collecting attitudes from the experts who are not close with the MCDM methods. The final ranking of the alternatives was determined by applying the newly-developed bipolar fuzzy MULTIMOORA method. Alternative denoted as A_4 is the best in terms of evaluated criteria. Although the proposed method is relatively new, the same was an excellent choice for the given purpose. The proposed integrated approach that is based on the PIPRECIA and bipolar fuzzy MULTIMOORA method has proved to be easy, effective and applicable for the evaluation of green ICT adoption in the textile company.

Additionally, with the purpose of verification of the proposed approach, sensitivity analysis is conducted. The obtained results have confirmed adequacy and the applicability of the proposed approach. Also, the proposed MCDM approach could be used in other areas as well. As a direction for future research, the proposed model could be easily modified with additional criteria or sub-criteria, if needed. Besides, other methods for weights determination can be used as well, such as the fuzzy PIPRECIA method, the fuzzy AHP method, and the Plithogenic-CRITIC method.

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Authors:

DARJAN KARABASEVIC[1], PAVLE RADANOV[1], DRAGISA STANUJKIC[2],
GABRIJELA POPOVIC[1], BRATISLAV PREDIC[3]

[1]University Business Academy in Novi Sad, Faculty of Applied Management, Economics and Finance,
Jevrejska 24, 11000, Belgrade, Serbia
e-mail: pavle.radanov@mef.edu.rs, gabrijela.popovic@mef.edu.rs

[2]University of Belgrade, Technical faculty in Bor, VJ 12, 19210, Bor, Serbia
e-mail: dstanujkic@tfbor.bg.ac.rs

[3]Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia
e-mail: bratislav.predic@elfak.ni.ac.rs

Corresponding author:

DARJAN KARABASEVIC
e-mail: darjan.karabasevic@mef.edu.rs; darjankarabasevic@gmail.com

A comparative analysis of green logistic activities in German and Turkish textile enterprises

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MEHMET KÜÇÜK
MARCUS O. WEBER
CLAUS BÜHS
MARKUS MUSCHKIET

ABSTRACT – REZUMAT

A comparative analysis of green logistic activities in German and Turkish textile enterprises

The main goal of this research is to find out what are the apparel industry activities in the face of green perspective (environment-friendly perspective) in Germany and Turkey. The green perspective is an emerging idea and also has importance for the humanity and the universe. However it is obvious that the green perspective is very broad, it was decided to make this research in the field of supply chain management and the place of logistics in supply chain under the title of green perspective. In this context, a survey, face-to-face interviews were made with professionals in Germany and Turkey. These professionals were the managers who are taking part in the supply chain. In the conclusion part, German and Turkish companies' activities in the face of green perspective under the title of logistics were compared and evaluated.

Keywords: *green logistics, comparative analysis, Germany and Turkey, apparel industry*

O analiză comparativă a activităților logistice ecologice în întreprinderile textile din Germania și Turcia

Scopul principal al acestei cercetări este de a analiza activitățile industriei de îmbrăcăminte în contextul unei perspective ecologice în Germania și Turcia. Perspectiva ecologică este o idee emergentă și are, de asemenea, importanță pentru umanitate și univers. Cu toate acestea, este evident că perspectiva ecologică este foarte vastă și s-a decis efectuarea acestei cercetări în domeniul gestionării lanțului de aprovizionare și a locului logisticii în lanțul de aprovizionare, din perspectiva ecologică. În acest context, au fost realizate un sondaj și interviuri față în față cu profesioniști din Germania și din Turcia. Acești profesioniști au fost managerii care participă la lanțul de aprovizionare. În partea de încheiere, au fost comparate și evaluate activitățile companiilor germane și turcești în fața unei perspective ecologice ale logisticii.

Cuvinte-cheie*: logistică ecologică, analiză comparativă, Germania și Turcia, industria de îmbrăcăminte*

INTRODUCTION

In daily stories of record temperatures, extreme weather, floods and droughts, and of renewable energy, carbon footprints, recycling and energy efficiency, the environment is increasingly becoming headline news. Governments are moving slowly towards new international agreements that will start to address the impact of business on the environment, and these, undoubtedly, will place new requirements on every organization. Consumers expect every business to take responsibility for its actions to look at the way it operates and measure their environmental impact, then determine a strategy to reduce it (figure 1).

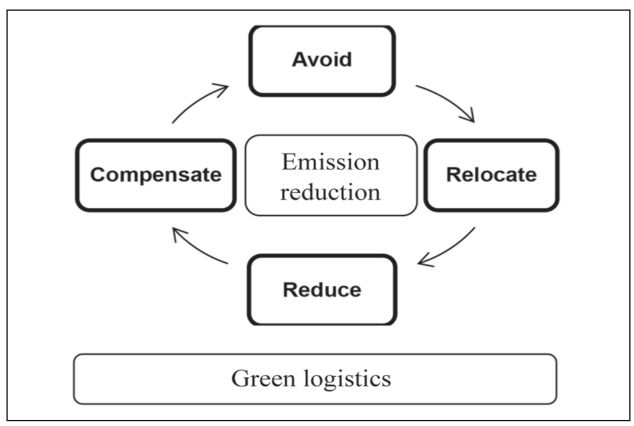

Fig. 1. Green Logistics Cycle [1]

According to McKinnon et al. [2], green logistic activities include measuring the environmental impact of different transportation strategies, reducing the energy usage in logistic activities, reducing waste and managing its treatment. In recent years there has been increasing concern about the environmental effects on the planet of human activity and current logistics practices may not be sustainable in the long term. Many organizations and businesses are starting to measure their carbon footprints so that the environmental impact of their activities can be monitored. Governments are considering targets for reduced emissions and other environmental measures. For this reason, there is increasing interest in green logistics from governments, companies, customers and also consumers.

Küçük [3] mentioned that especially in fashion industry, the ability to respond customer requirements on a timely basis has always been a fundamental element of the marketing concept. "Time-based competition" has become the norm in many markets, from banking to automobiles, also fashion.

According to Christopher and Peck [4], nowhere is this pressure more evident than in markets governed by fashion. "Fashion" is a broad term that typically encompasses any product or market where there is an element of style that is likely to be short-lived. Christopher and Peck [4] have defined apparel industry as typically exhibiting the following characteristics:

- ***Short lifecycles***; The product is often ephemeral, designed to capture the mood of the moment; consequently the period in which it is saleable is likely to be very short and seasonal, measured in months or even weeks.
- ***High volatility***; Demand for these products is rarely stable or linear. It may be influenced by the vagaries of weather, hit films, TV shows or even by pop stars and footballers.
- ***Low predictability***; Because of the volatility of demand it is extremely difficult to forecast with any accuracy even total demand during a period, let alone week-by-week or item-by-item demand.
- ***High impulse purchase***; Many buying decisions for these products are made at the point of purchase. In other words, the shopper when confronted with the product is stimulated to buy it, hence the critical role of „availability" and, in particular, availability of sizes, colors, etc.

In 2012, Sarkar investigated the potent tools for sustainable green marketing [5]. The article analyzed different dimensions and facets of green supply chain management, including the evolution of the concept, implementation strategy, linkage with transport systems, green innovations and sustainability issues and green logistics strategies for evolving integrated green supply chain management system.

In another study held in 2013, Perera et al. [6], attempt to quantify the environmental performance of supply chain of a manufacturing company. They used multi-criteria decision method for measuring the performance of the criteria that they determined. In the conclusion the proposed model was applied to a case study company to identify the key areas of environmental performance of the company's supply chain and to assess various product categories manufactured under those key areas.

Batra et al., in 2015 [7], made a research on greening the supply chain. They reviewed the literature on green supply chain & steps to be taken by the enterprises to achieve social, environmental & economic benefits.

Abdullah et al., in 2016 [8], investigated the involvement of Third Party Logistics (3PL) companies in applying Green Logistics initiatives in the event of rendering logistics services to its customers. They implemented this study in Malesia and utilized Malesia's terms and conditions only.

In a study from 2017 by Desore and Narula [9], they review today's literature related to sustainability issues of the textile industry for all over the world. The authors categorize the literature to discuss the drivers, barriers, and responses of firms in the textile industry in favor of sustainability.

The goal of a study by Gardas et al., in 2018 [10], is to identify the critical challenges to sustainable development in the textile and clothing sector. In this concept, fourteen critical points about the sustainable development of the textile and clothing sector were identified and a survey and their cause–effect relationship was determined using the DEMATEL method.

Samar Ali et al. in 2019 [11] was made a study about green practices in manufacturing sector and this study aimed to discriminate the sustainable and competitive performance of the Indian manufacturing sector and to comprehend the degree of the impact of green practices of supply chain management.

Table 1 was prepared by taking into account the 6main criteria (1 – Activities of customs administrations, 2 – Infrastructure, 3 – International transportation fee, 4 – Quality of logistic services, 5 – Punctuality of cargo transportation, 6 – Tracking possibility of cargoes) for evaluating the 160 countries' logistics

Table 1

LOGISTICS PERFORMANCE INDEX (LPI) RANK 2018 [12]

Country	LPI rank	LPI score	Customs	Infrastructure	Logistics competence	Tracking & tracing	Timeliness
Germany	1	4.20	4.09	4.37	4.31	4.24	4.39
Sweden	2	4.05	4.05	4.24	3.98	3.88	4.28
Belgium	3	4.04	3.66	3.98	4.13	4.05	4.41
Austria	4	4.03	3.71	4.18	4.08	4.09	4.25
Japan	5	4.03	3.99	4.25	4.09	4.05	4.25
Netherlands	6	4.02	3.92	4.21	4.09	4.02	4.25
Oman	43	3.20	2.87	3.16	3.05	2.97	3.80
India	44	3.18	2.96	2.91	3.13	3.32	3.50
Cyprus	45	3.15	3.05	2.89	3.00	3.15	3.62
Indonesia	46	3.15	2.67	2.89	3.10	3.30	3.67
Turkey	47	3.15	2.71	3.21	3.05	3.23	3.63

performance. According to this index while Germany is in the 1st place, Turkey is 47th.

The purpose of this study is to find out how are the real explanations of some hypothesis and also the comparison of Turkish and German companies' relevant activities. The first hypothesis is to determine the role of logistics in supply chain management. It affects the customer satisfaction and total cost reduction, as well as company profitability. This is particularly significant as companies are increasingly being driven by the goal of enhancing shareholder value, a key measure of corporate performance. The second is to determine the role of companies' social and environmental responsibility. The last hypothesis is to compare Turkish and German companies' relevant activities in the face of green perspective under the title of logistics.

Moreover, this study is giving a raft of options, suggestions and concrete advice on how to go green on logistics department in the apparel industry. It includes some interviews with the professional managers from Turkish and German companies. Although many of previous articles describe general topics in logistics or supply chain, this study would like to mention the environmental impact of logistics and supply chain under the consideration of sustainable aspects for apparel industry.

Most analyzed previous studies are descriptive on a national basis. In the literature, the studies based on green logistic activity in textile and apparel industry areas are limited. Especially there is no comparison of Turkey and Germany. Therefore, it is intended to fill this gap. For instance, the studies below have done recently in the literature about the green logistics.

MATERIAL AND METHOD

Material

This study is held as a comparative research of Turkish and German apparel companies, the material consists of 6 different Turkish and 6 different German apparel companies and their logistical activities.

Method

In this research which compares the environmental sensibility of logistics activities of the apparel companies in Turkey and Germany, the qualitative research method was used to reveal the similarities and strength and weaknesses of the companies.

The "Qualitative Research Method" was chosen during writing and assessing this research study. The qualitative method involves the gathering of a lot of information from few examination units through interviews and observations. There are three most common qualitative methods which are participant observation, in-depth interviews, and focus groups. Each method is particularly suited for obtaining a specific type of data.

- Participant observation; is appropriate for collecting data on naturally occurring behaviors in their usual contexts.
- In-depth interviews; are optimal for collecting data on individuals' personal histories, perspectives, and experiences, particularly when sensitive topics are being explored.
- Focus groups; are effective in eliciting data on the cultural norms of a group and in generating broad overviews of issues of concern to the cultural groups or subgroups represented [13].

From those methods, the most useful and impressive one was decided to use for this study; in-depth interviews. So the plan was to make some interviews with professional managers and perceive their point of views and opinions.

The interview is an effective method of collecting information for certain types of research questions and for addressing certain types of assumptions. There are two types of interviews: structured and semi-structured interviews. The choice depends on what the research topic is. In structured interviews, formally structured – without any adjustment and additional questions – and the same questions are asked to all of the respondents, whereas in semi-structured interviews, wordings, the level of language and the order of questions are flexible and may be adjusted. There may be also additional questions followed up [13].

Considering the different types of interviews and the research goals of this study, the "structured interview" type was decided to use. The reason of selecting the structured interview is to evaluate all companies equally. There were no adjusted questions or deviations varying from company to company.

Sampling

The samples of this study were selected upon purposive sampling. It was stated by Given [14] that purposive sampling is virtually synonymous with qualitative research. Purposive sampling is explained as: "It is one of the most common sampling strategies according to a criterion relevant to particular research questions. Furthermore, sample size may or may not be fixed prior to data collection, depend on the resources and time available, as well as the study objectives. Purposive sampling is accepted to be the most successful when data review and analysis are done in conjunction with data collection" [15].

The selected companies in the scope of the study are large-scale companies which have activities and investments in the field of textile and apparel logistics in Turkey and Germany. Responses were received via face-to-face and/or telephone interviews. However, 9 companies from Turkey and 10 companies from Germany were selected, the responses were collected hardly from 6 Turkish and 6 German companies.

Data Collection Method: Interviews

A survey was decided to conduct with Turkish and German apparel companies to evaluate the research questions. This survey would be like a short-interview with the companies' managers. In this interview, some questions were determined and would be asked.

During the preparation of these questions, the intent was to get direct, concrete and assessment-easy answers. For that reason; the questions which are shown below were prepared and asked.

Interview questions:

1. What do you think as a company about Green Perspective?
2. The main objective is to make money in the business but it is obvious that the process of Green Application requires some investments which mean additional cost. Could you please explain your standpoint according to this economical aspect?
3. Have you ever applied on Green Process for any departments of your company? If no, are you planning to do and in which department? If yes, when?
4. Do you really think that logistics should be environmentally friendly first? Or, are there some other departments which are more important and have priority on logistics?
5. What do you think about the environmental effect of logistics?
6. Do you think that your company has a productive logistical management system by the ecological point of view?
7. Do you take any precautions against your possible environmental effects of warehousing such as waste, package plastic and etc.? For example do you use recycled material?
8. Do you have as a company your own "Code of Conducts" about logistics?
9. Is it important for your company to determine your supplier to consider the environmental policy of their government/country?
10. How does the government act in the face of green perspective in Germany/Turkey? Is there any governmental inducement/obligation to improve your environment policy on green logistics?

Data Assessment Titles

In order to make the assessment more concrete, the questions were classified among themselves and titles which belong to each classes were identified. The evaluation of the answers collected from the companies, is in the form of the answers being classified under the titles below. Accordingly, the determined titles and the questions are:

- Green perspective and the industry: Question number 1
- Money or environment or both: Question number 2
- Until now…: Question number 3
- Precautions: Question number 7
- Supplier Selection and Environment: Question number 9
- Enough Governmental Inducements/Obligations: Question number 10
- Logistics & Environment: Question number 4, 5, 6 and 8.

FINDINGS

This study is based on qualitative research. The questions and the answers which were obtained through the interviews were discussed separately. The following titles below were analyzed by thinking of the interviewers' answers.

Green perspective and the industry

Turkish case

The general idea in the direction of the answers taken from the companies is, the environmental awareness of the companies is in the front lines among the commercial activities. Companies' sustainability strategy within the framework of the sustainability approach combines in two focus areas: the environment and people. In order to continuously improvement in accordance with the aims and targets which were set by the companies. They:

- Observe the current environmental legislation and discharge the legal obligations,
- Exhibit sensitive and effective behaviors against the environmental pollution,
- Reduce all the emissions and wastes by implementing an effective waste management system,
- Always and regularly observing the environmental management systems.

Additionally Turkish companies stated that, the aim is to have an integrated approach on sustainability where they are able to turn potential sustainability risks into opportunities which ultimately benefit their environment and their company. These opportunities include; waste management, pollution prevention, carbon footprint reduction, water and energy efficiency/production, and more efficient use of raw materials.

German case

During the interviews it was found out that, according to the ideas of the managers, the companies are more or less trying to do something good for the environment. For instance, they try to spread the warning that "do not print if not necessary" about printing. In their office and canteen, they split the rubbish into the categories of paper, plastic, glass and so on. Some of them have never heard the idea of green logistics and some of them have just comprehended the idea. It means, they do not think about the logistics part to do it green obviously.

However they have too much knowledge to do the production environmentally, it is also common that doing logistics green requires up-to-date information. There are no common activities with the logistics to do it green. According to the managers, until now, there have been a lot of studies, books, articles, materials also some workshops about the green production but not for green logistics. It is obvious that day-by-day some researchers in the industry, professors in the universities are doing a lot of research and process development. For that reason, in the production department besides products, the waste and the other things which are harmful for the environment are generated more than logistics department.

Money or environment or both

Turkish case

The general idea about this question is "The publicity of the social responsibility projects as such green applications, brings prestige and subsequently financial gain to the companies". Two companies among the all have the certificate of SA 8000, BSCI (Business Social Compliance Initiative) Oekotex Standard 100, GOTS, OEKO-TEX STeP and OCS.

The other one is a member of Climate Platform established by "Turkish Industrialists' and Businessmen's Association (Tüsiad)" and "Regional Environmental Center (REC)". It is obvious that these companies consider both the environment and their monetary assets. However, it was understood after the interviews with the rest of the companies that they care about the environment in theory, but they do not so successful in practice.

German case

If companies decided to be sustainable on ecology, it directly increases the value and image of the company very positively, so it brings to companies better financial results, prestige and productivity. Also the environment gives back the positive answer: If humans protect the environment, it also protects the humans. They think that the investment in green process is return on investment. Managers are aware of the fact that, if some investments are made to be more environmental friendly, it brings more things than money like good customer relations, profit, a good reputation and so on. They think that it is very necessary to save the planet with some investments but the investment should end up with some profit. If it brings profit then they see this situation as „set a sprat to catch a mackerel". So they set the sprats. From the answers of this question it is obvious that they consider both, money and environment together.

Until now…

Turkish case

All of the interviewed companies confirmed that they have been carrying out various activities and applications in order to protect the environment. One of these companies stated that it produces own electric power through own hydroelectric power plant. Another company calculates the carbon footprint of all activities involved in the production and also administrative areas. The reason behind this act is to reduce their emissions within the scope of their fight against climate change. Apart from this, the most common practice in companies, in this context, is measuring the amount of water used and making efforts to reduce the amount of it. Converting all of the lights to the led system in order to reduce the amount of energy consumed in the lighting also reflects another example in common. The recycling and re-usage of the wastes generated from the daily activities of the employees can be shown as another application.

German case

Until now, according to German companies, safety of the employees always comes first. All production sites are run based on European safety standards. Then they of course take measures under the title of being green. For instance, using of recycled material, collecting all the wastes in a daily base and etc. They added as the common answer that if you do not recycle the wastes in a daily or weekly base, the general cost of these activities would be higher at the end. They also split up their daily wastes as plastics, papers, glass… from production, warehouse, and daily activities to use them for recycling. As mentioned before, one of them gave as an example that they use big windows to exploit natural heating energy to heat the company with less electric energy.

General Precautions for Environment

Turkish case

Each company has some precautions which have been put into practice according to companies' own principles to protect the environment. For instance the cardboard boxes which used for transporting the products. The cardboards are supported for being more stable to use them longer. In this way both the operational costs and the amount of the waste generated are reduced.

The waste of the cardboard boxes and plastic packaging materials are collected and delivered to the licensed companies which collect the wastes and disposal. Also the wastes generated in the company are also classified and send for recycling. In addition, most of the companies force both the customers and the employees to use biodegradable plastic bags.

Another company which is also very active in retail activities started a recall for the apparel products which are not used any more for recycling. In this context, it has been emphasized that the unused apparel products can be utilized by reusing or recycling and at the same time, the future waste can be reduced.

Another company which has ISO 14001 environmental management system certificates was steer to new sustainable production methods and product development which is environment friendly. In these new product development projects, the consumption of the water and energy resources is measured in consideration of environment and human health. In this way, the use of resources such as water, electricity and natural gases can be decreased and the wastes that are generated as a result of the production can be minimized.

German case

Actually companies are very careful about the universe. It could be true that money has the priority like in every business which runs after some profit but companies are also very keen on environment. It is obvious that they have to take some precautions against the environmental effects of their business because of the laws and other regulations. Accordingly, they obey these laws and have some precautions.

As the precautions, for instance; they use recycling bins for all their waste, for example; fluorescent light bulbs, fabric wastes, plastic wastes and waste papers. They collect these materials in every department for recycling. Recycling provides on the one hand getting rid of the wastes from the company and also from environment; on the other hand these materials cost with a cheaper price. The easiest example, also they gave this example, is plastic hangers, because as everybody knows in the apparel industry, a lot of hangers are needed to protect the shape of the products well. So, the hangers which are made of recycled material, as the first reason the companies get these hangers cheaper and secondly they are produced with less emitted CO_2.

Supplier Selection and Environment

Turkish case

According to the interviews, it is very important for the rest of the companies, while this situation is not a very important issue for one of the companies. With regard to the general judgement of all company managers, except one of them, they select their suppliers in accordance with the criteria determined by the companies' previous experiences. The environment oriented selection of the suppliers becomes one of the most indispensable criteria. The criteria that the suppliers are expected to fulfil can be listed as follows: Conformity with laws and regulations, no child labor, non-discrimination, balanced wage system and social rights, the conditions related to the working hours, healthy and safe working conditions and protection of the environment (HSE).

German case

There is a common idea that "environmental policy of suppliers' government/country is of course important to consider". Some of the companies also have some code of conducts to select their supplier/producer. There is a further answer that, European companies with European suppliers/producers do not think about the policy because they all have the same regulation. But the main company may request the fulfilment of requirements in the written and signed form from the supplier/producer.

If the producers/suppliers are not in Europe, they request some certificates but how they get the certificate and what are the terms and conditions to get it are also important.

Enough Governmental Inducements/Obligations

Turkish case

Although in Turkey "green logistics" is not yet made mandatory by laws and regulations, this concept is on the agenda of the sector. In Turkey some fines are applied when the carbon footprint limit of the companies is exceeded. Furthermore, the regulation on following up the greenhouse gases emissions was brought into force in 2019. It has been determined in the regulation that all the emissions will be monitored in the businesses according to the scope of the activity. For that reason, most of the companies make their own carbon footprint measurements in Turkey.

German case

There are certainly both inducements and obligations for companies not to harm environment. The general idea which is understood during the interviews is the obligations and also some inducements for environment and environmental activities have beyond measure importance and these rules or obligations are indispensable for the managers. Managers believe that owing to these obligations and inducements, companies regulate their business activities by the thinking of environment. They also think that sometimes government sets up some rules which are not very logical and companies are not sure whether these rules help to improve environmental effect of companies activities or not. Nevertheless, they are happy that the governments are very keen on protecting the environment and they also think that the European Union has one of the strictest rules in the world.

Logistics & Environment

Turkish case

The common answer from companies about the importance of the logistics activities among other departments in terms of environment; the important point for the companies are human right, labor standards, environment, fight against corruption. That is why, all the activities about environment are carried out considering all the departments.

All the companies think that logistics activities have a negative impact on the environment. For that reason the vast majority of companies follow the carbon footprints including all logistics activities. However this is not just for a measurement of logistics activities. Companies carry out various sustainability projects in order to reduce the carbon emissions year by year. One of the companies also monitors the fuel consumption of each vehicle belonging to the company to determine the carbon emission rate on a yearly base.

One of the companies replied negatively and the rest of them think that they have a productive logistics management system because of the follow-up the carbon footprint about the question of the productive logistical management system by the ecological point of view. One of the companies supported the having an efficient logistic management system with ISO 14001:2004 Environmental Management Systems Certificate, ISO 50001 Energy Management Systems Certificate and Global Recycling Standard certificates that the company has.

It has been understood that the companies have a general code of conducts. There are categorized generally; social performance (such as human rights, employee safety), environmental performance (such as energy and water efficiency), supply chain performance, product and production performance, social responsibility performance. According to the answers, the logistic activities counted in the environmental performance. However, none of these companies have a logistic-wise code of conduct until now.

German case

The general idea about the logistics is that when companies have the environmental glasses on, only focusing on logistics is not enough to be green. Supply chain has much more importance than logistics. According to this manager being green of anything is to save resources as the best way or also it can be said that to get rid of the unnecessary processes. It means the elimination. After the elimination, managers can organize the remaining processes easily and more productively. So they will be green as a result automatically. It means to be green is the end of the processes not the beginning. The meaning of this conversation about the question; supply chain is more important. It is obvious that to be green is an achievement at the end of an efficient supply chain.

The general idea about the environmental effect of logistics, it is huge but if it is compared with the other departments (production, sourcing…) it is low.

Companies answered the question about productive logistics management system in common that there are not many companies in the clothing industry performing an environmental management system. Also it is common for them not to think that their companies have the productive environmental logistics management system. But just one company indicated that they have very productive logistics management system by the ecological point of view, not in the German part of their business but they have it in the USA and in the UK part. To get positive response from the environment, they optimized their transportation routes, calculated the quantity of the liter of petrol consumed and carbon footprints of the activities and so on.

About the code of conduct question, companies stated that they do not have any written „Code of Conduct" on logistics. But they try to organize their activities as sufficient as possible and not to harm the environment.

RESULTS

Within the scope of this study, logistic activities of the companies operating in Turkish and German textile sector were compared under the environmental title. Logistics, in the concept of fast fashion is an important term with variety of applications in order to reduce the cost and improve the value on the products. However, logistic activities also have an impact on the environment like every other activity in the companies.

In this study, the applications about the logistics were compared through the answers received by Turkish and German textile companies. So the opinions about the answers are shown below.

- Green perspective and the industry: While the practices in two countries are similar, the environmental sensitivity of the sector is supported by various environmental legislations.
- Money or environment or both: While Turkish companies consider the environment and the money as a minority, they mostly consider the environment theoretically, but in practice they are very weak. German companies on the other hand, approach this issue more rationally. They consider both the environment and the money together theoretically and practically supporting with the environmental certificates.
- Until now…: Turkish and German companies seem to have done as much study on environment as until now. These studies are mostly focused on production. Such as measuring and following the carbon footprints, separating and sending to recycle the wastes generated in companies day-by-day, using recycled materials as much as possible. As a matter of fact, German companies are very careful to take various precautions considering the health of the employees at the focus of all the work done. It is necessary to point out that a Turkish company established its own hydroelectric power plant in order to provide own electric energy which cannot be ignored as a study done for the environment.
- General Precautions for Environment: Both Turkish and German companies take various precautions to protect the environment. Such as, using recycled materials, modifying the materials to use for a longer time, carrying out various projects supported by environmental laws.
- Supplier Selection and Environment: Both Turkish and German companies consider the environment when choosing suppliers. However, the price offered by the supplier is in front of the environment for Turkish companies. This situation is mostly in the direction of environment for German companies.
- Enough Governmental Inducements/Obligations: "Green logistics" in Turkey is a slightly newer concept than Germany. Within this context, the carbon footprint boundaries of companies are followed in Turkey. However, in Germany there are many applications on "green logistics". Some of those; selection of the transport type, regulation of the transport time, road optimization, following the occupancy rate of the vehicle, considering the age of the vehicle and the type of the fuel, carbon footprint of the vehicle and so on. Accordingly, it can be said that German government has a tighter control mechanism then Turkey.
- Logistics & Environment: Both Turkish and German companies are convinced that logistic activities effect the environment negatively. While few Turkish companies are involved in carrying out various projects to overcome this negative effect, all German companies have undertaken various studies keeping the governmental auditing in this regards. Both companies are convinced that focusing on logistics alone should not be sufficient in terms of environmental conscience. The important thing in this regard is that focusing on the supply chain from the very beginning to the end.

Logistics is a concept that provides added value on products and decreasing the expenditures. Particularly within the context of logistic activities, countries that have a geographical advantage can further increase the benefits that they provide from the logistic activities. In addition to the benefits provided by logistics activities, there are also some environmental threats.

Conducted examinations and the information based on the activities of the two countries' companies show that the activities carried out by the companies in Turkey in order to minimize the damaging effect of logistics are more inadequate than the ones in Germany. When the governments are compared in the same direction, it will be seen that the compulsory conditions of the statutory audits are performed more imperatively by German government than Turkish government. Turkish government should increase the inspections about the environment to industrial enterprises or resettle such as additional taxes and so on. Turkey became a party to the UN Framework Convention on Climate Change (UNFCCC) on 24 May 2004 and the Kyoto Protocol on 26 August 2009. So Turkey needs to apply more environmentally friendly strategies both in accordance with the UNFCCC and the Kyoto Protocol.

By closing the gap between the countries, not only governments but also companies need to take precautions to at least reduce the carbon emissions [16]. In this context, the auditing on carbon emissions can be increased and some more taxes can be applied. In addition, in order to solve the problems related to logistics, necessary legal arrangements should be made about the sector and a significant control mechanism should be developed together with standards.

In order to benefit more from the geographical superiority as a country which is surrounded on three sides by the sea needs to have better sectoral infrastructure. At the same time, the problems should be solved in areas such as the situation of the ports, combined transportation possibilities, balance between transport modes and their competences, qualified human capital, technology, know-how and legal regulations.

The need of qualified personnel should be resolved to give more importance to the colleges and universities which provide training on logistics in Turkey. In this context, the curricula of colleges and universities offering logistics should be rearranged to follow the developments around the world.

The scope of the concept of green logistics can be expanded with further studies by using this study. For instance, it will be possible to contribute to the literature by analyzing the application of different sectors from different countries.

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Authors:

MEHMET KÜÇÜK[1], MARCUS O. WEBER[2], CLAUS BÜHS[2], MARKUS MUSCHKIET[2]

[1]Ege University, Engineering Faculty, Textile Engineering Department, Turkey

[2]Niederrhein University of Applied Sciences, Faculty of Textile and Clothing Technology, Germany

Corresponding author:

MARCUS O.WEBER
e-mail: marcus.weber@hs-niederrhein.de

A review: life cycle assessment of cotton textiles

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FANGLI CHEN
XIANG JI
JIANG CHU
PINGHUA XU
LAILI WANG

ABSTRACT – REZUMAT

A review: life cycle assessment of cotton textiles

A significant amount of research has been published on the environmental impact assessment of cotton textiles using the life cycle assessment (LCA) method. This review summarized and analysed the findings of these publications, and presented valuable insights for identifying the hotspots that have considerable potential for reducing the environmental burden of cotton textiles. The relevant papers were selected according to two criteria: life cycle assessment of cotton textiles or footprint of cotton textiles. Subsequently, key features were screened and critically analysed: functional unit, system boundary, data sources and geographic location, and impact assessment methods and impact categories. We found that there is an emerging market demand to transform conventional cotton to organic cotton. From the global perspective, a spatially explicit LCA of cotton textiles should be conducted. In addition, a comprehensive and holistic life cycle impact assessment containing more impact categories that are appropriate to cotton textiles is required. LCA is a well-justified approach among practitioners and researchers and has been widely applied to the topic of cotton textiles. This methodology should be studied and developed further to more precisely evaluate the environmental impacts of cotton textiles.

Keywords: *cotton, environmental impacts, footprint, life cycle assessment, review, textiles*

Studiu: evaluarea ciclului de viață al materialelor textile din bumbac

Multiple cercetări au fost publicate cu privire la evaluarea impactului asupra mediului al materialelor textile din bumbac, folosind metoda evaluării ciclului de viață (LCA). Acest studiu a identificat și a analizat rezultatele acestor publicații și a prezentat informații valoroase pentru identificarea punctelor importante, care au un potențial considerabil de reducere a presiunii asupra mediului create din producerea materialelor textile din bumbac. Lucrările relevante au fost selectate în conformitate cu două criterii: evaluarea ciclului de viață al materialelor textile din bumbac sau amprenta materialelor textile din bumbac. Ulterior, caracteristicile cheie au fost examinate și analizate critic: unitatea funcțională, limita sistemului, sursele de date și locația geografică, metodele de evaluare a impactului și categoriile de impact. S-a constatat că există o cerere pe piața emergentă pentru transformarea bumbacului convențional în bumbac organic. Din perspectiva globală, ar trebui implementată o metodă LCA explicită spațial pentru materialele textile din bumbac. În plus, este necesară o evaluare cuprinzătoare și holistică a impactului ciclului de viață, care conține mai multe categorii de impact, adecvate pentru materialele textile din bumbac. LCA este o abordare bine justificată în rândul practicienilor și cercetătorilor și a fost aplicată pe scară largă în ceea ce privește materialele textile din bumbac. Această metodologie ar trebui studiată și dezvoltată în continuare pentru a evalua mai precis impactul asupra mediului al materialelor textile din bumbac.

Cuvinte-cheie*: bumbac, impact asupra mediului, amprentă, evaluarea ciclului de viață, studiu, textile*

INTRODUCTION

Cotton is the most widely utilized natural fiber in the world, and has comprised approximately one third of the textile fibers market in 2000–2016 [1]. Cotton is grown in subtropical, seasonally dry tropical areas, primarily in the Northern Hemisphere. Approximately 32 million hectares of agricultural land is allocated for cotton plants in more than 75 countries, including India, China, the United States, Brazil, and Pakistan, which are the main producers of cotton and account for more than three-quarters of global cotton production. According to the Food and Agriculture Organization (FAO), global cotton consumption is ~31.8 million tonnes, with > 20 million tonnes of cotton being used for textile fibers. Approximately 8 million tonnes of cotton was traded in the global market during 2016/2017 [2].

The entire life cycle of cotton textiles is long and complex, and includes cotton cultivation and harvest, manufacture (ginning, spinning, weaving, dyeing, cutting and sewing, and ironing), consumption (retail and use), and disposal. Generally, cotton is considered to be an environmentally friendly fiber since it is grown and not manufactured. However, it consumes large quantities of water during the agricultural phase, and fertilizer and pesticides are also required, which can lead to eutrophication and toxicity. According to Cotton Inc. [3], global cotton accounts for 3% of land use, 3% of global agricultural water, and 5.2% of global pesticide sales. Previous life cycle assessment (LCA) studies have found that cotton cultivation has significant environmental impacts due to the use of pesticides, fertilizers, and water [4]. Dyeing is the most contaminative process in the life cycle of cotton textiles, the numerous inputs of chemicals such as dyes, wetting agents, and softener account for a huge environmental burden. Water usage for washing during the use phase of cotton textiles has also attracted attention. There have been many initiatives to reduce the environmental burden of cotton products, for example, by growing organic cotton and recycling cotton textiles. Over the past decades, the Better Cotton Initiative (BCI) and Cotton made in Africa (CmiA) as well as other programs have brought momentum to the movement for improving the environmental performance of cotton [5]. The long and complex supply chain of cotton in addition to the numerous associated environmental impacts requires a comprehensive methodology to evaluate the overall environmental burden.

Meanwhile, some practitioners are required to demonstrate how their cotton products or services reduce the environmental burden. LCA is an effective method for providing an interpretation of the entire life cycle of products. Since the introduction of the International Organization Standardization (ISO) 14040:2006 and ISO 14044:2006, LCA has been widely applied in the textile industry as a decision support tool for evaluating the environmental impacts of products and services [4]. The framework of LCA traditionally involves: 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; 4) interpretation. The first step defines the purpose of the study, the product, system boundaries, and the function unit according to ISO 14040:2006 [6]. Inventory analysis is the foundation of impact assessment. The reliability of the results is partially dependent on the quality of the collected data. Many existing life cycle impact assessment (LCIA) databases provide convenience to practitioners. The impact assessment phase aims to evaluate the potential environmental impacts, transforming the life cycle inventory (LCI) into the potential environmental impacts through the use of characterization factors.

The aims of this review are to: i) explore and document the current state of LCA research with regards to the environmental burden of cotton textiles, ii) identify possibilities for reducing the environmental burden of cotton textiles, and iii) identify possible improvements for the existing LCA evaluation methods used in the cotton textile industry. By reviewing and comparing previous studies we further aim to illustrate the differences between methods and results, and in turn discuss their limitations as a means of providing an initial guide for data collection and method selection among practitioners.

IMPACT ANALYSIS OF COTTON PRODUCTS

Impact analysis of cotton fiber

Impact analyses of cotton fiber have focused on the impacts of the cultivation phase of cotton. The boundary has always been set as from cradle to gate (ginning). The functional unit is 1000 kg (or 1 kg) of cotton lint. Different studies have assessed the environmental performance of cotton in different regions, identified the potential to reduce the environmental burden, and compared the performance of different measures for reducing the environmental impacts.

Water use for cotton production differs considerably between countries due to the variations in climatic conditions and those that are required for cotton production. A report by Chapagain et al. aimed to assess the "water footprint" of worldwide cotton consumption by identifying the location and character of the related impacts [7]. The author analysed the largest 15 cotton producing countries, and found that climatic conditions were highly related to water use and cotton yields. The climatic conditions of Syria, Egypt, Turkmenistan, Uzbekistan, and Turkey – where the evaporative demand is high while effective rainfall is very low – are less appropriate for cotton cultivation because of the irrigation demand, which increases the environmental burden to local water resources. In addition, partial irrigation leads to low cotton yields. Optimal climatic conditions for cotton production are in the USA and Brazil, where evaporative demand is low and cotton can be grown without irrigation. The global cotton trade ensues that most of the cotton produced in a region is actually utilized in another, and countries that import cotton indirectly deprive water resources of the export countries through global trade. Approximately 84% of the water footprint of cotton consumption in the EU 25 region prior to 2005 was located outside Europe, with major impacts having affected India and Uzbekistan in particular. With regards to sustainable water management, it is feasible to hypothesize that improvements may be possible from the cotton consumption perspective if a degree of responsibility for the impacts is taken by consumers.

Cotton made in Africa (CmiA) is cultivated by small-scale famers under rain-fed conditions in crop rotation with other cash or subsistence crops. Agricultural inputs such as fertilizers or pesticides are low and the harvest is performed exclusively by hand. This extensive cultivation practice was found to have significant advantages over other methods in a report by CmiA., which evaluated the cradle to gate environmental impacts of cotton lint made in Africa (functional unit of 1000 kg cotton lint) [8]. Climate change, eutrophication, and acidification were assessed in the report using the Center voor Milieukunde at Leiden (CML) impact assessment methodology framework.

Additionally, water use and water consumption were investigated. Freshwater use includes the withdrawal from surface water, ground water and rainwater and water consumption means that the water removed from but not returned to the same basin. The impact on climate change was quantified as 1037 kg CO_2 eq., which was lower than the global average (1801 kg of CO_2 eq.) [9]. The freshwater used to produce 1000 kg CmiA was determined as ~3400 m^3, but the blue water (surface and ground water) consumed was found to be very small due to the precipitation in this region being sufficient to meet the water demand for growing cotton. The eutrophication impact was evaluated as 20.4 kg PO_4^{3-}, to which soil erosion made a significant contribution. In this report, the emission of N and P was modeled and it found that soil erosion and the nutrient content of the soil were determined to be sensitive parameters with regards to eutrophication, with the potential for eutrophication differing between regions. However, this regional difference of has not yet been considered in existing life cycle impact assessment of cotton.

Xinjiang, China, has become one of the most important cotton producing regions and has the highest yields worldwide. Günther et al. focused on the agricultural greenhouse gas emission and phosphorus consumption during the cultivation of cotton in Xinjiang, which measured as carbon footprint and phosphorus footprint, respectively [10]. Results showed that fertilizer production contributed 63.9% of the carbon footprint (total 4.43 kg CO_2 eq./kg fiber) due to the energy use during the fertilizer production phase. The phosphorus footprint of cotton was 101g P/kg fiber mainly from the high input of phosphorus fertilizer, which also indicated a high potential of eutrophication. Therefore, reduced fertilizer application and reuse of plant residues are the most probable ways to reduce the carbon and phosphorus footprints of cotton production. A limitation of this study was that it was carried out in a dryland area, hence, the findings should be combined with an analysis of the water footprint as a means of moving towards a more holistic picture of the environmental impacts of cotton.

As mentioned, cotton cultivation has considerable environmental impacts. Organic cotton that avoids the use of artificial fertilizers and pesticides has been encouraged by specialists [11]. A report published by Textile Exchange, a non-profit organization, addressed the LCA of organic cotton for the top five countries involved in organic cotton cultivation: India, China, Turkey, Tanzania, and the USA, which were found to collectively account for 97% of global cotton production [12]. The LCA of organic cotton were based on the CML impact assessment methodology framework. Comparison of organic and conventional cotton was made using the Cotton Inc. (2012) study of conventional cotton. The results indicated that organically grown cotton had the following potential impact savings over conventional cotton: 46% reduced global warming potential (GWP), 70% reduced acidification potential (AP), 26% reduced eutrophication potential (EP), 91% reduced blue water consumption, and 62% reduced primary energy demand (non-renewable). The lower agriculture inputs (e.g., mineral fertilizer, pesticides) as well as the practices required by the principles of organic agriculture accounted for the lower environmental impact of organic cotton. However, it should be noted that the low blue water consumption of the organic cotton cannot be attributed exclusively to the organic cultivation operations, since the irrigation requirements of a crop are mainly determined by climatic conditions, and the actual water usage is also influenced by irrigation techniques.

The recovery of cotton from discarded cotton presents a potentially wise strategy for reducing the environmental burden of cotton. A study undertaken by Esteve-Turrillas and Guardia [13] compared the environmental impacts of recovered cotton with virgin cotton. Findings showed that the use of recovered cotton avoided impacts related to cultivation and the dyeing process, although electricity consumption was relatively higher for recovering cotton (functional unit of 1 kg of colored cotton yarn). The results also illustrated a great advantage of recovered cotton because it was found to save 13.98 kg CO_2 eq. with respect to GWP, 0.32 kg SO_2 eq. for AP, 0.033 kg PO_4^{3-} eq. for EP, and 5594 kg water for the water use. However, the data of this study was taken from literature that was based on different regions and methods, hence, the advantages of recovering cotton may have been overestimated.

Many efforts have been made by the cotton industry in different countries to meet international obligations regarding emission reductions. The Australian cotton industry has made particular advances in this regard. Hedayati et al. assessed the effects of an array of on-farm mitigation options as a means of providing farm-level strategies for reducing emissions [14]. The climate change impact evaluation using the Intergovernmental Panel on Climate Change (IPCC) method of cotton lint on a cradle to port basis was determined as 1601 kg CO_2 eq. per tonne of cotton lint. The hotspots assessment found that the production and use of synthetic nitrogen fertilizers made the largest contribution to the emissions profile (46% of total). Farm level management options to minimize the life cycle of greenhouse gas (GHG) emissions were also compared. The results indicated that GHG emissions could be reduced by i) 5.9% through the controlled-release of stabilized N fertilizers, ii) 8.1% by changing from diesel to solar-powered irrigation pumps, iii) 3.4% by changing from diesel to biofuel-powered farm machinery, iv) 3.9% by changing from continuous cotton to a cotton-legume crop rotation, and v) 2.1% through the use of N fertigation. This study therefore demonstrated opportunities to reduce GHG emissions at the farm level.

Other strategies to reduce the environmental burden of cotton include the reuse of clothing (e.g., second-hand clothing) and cotton recycling to produce other products. A new technology has been reported recently for producing cellulose carbamate fibers using discarded cotton textiles as the raw material [15]. The authors compared the environmental impacts of two cellulose carbamate (CCA) fibers under different production scenarios with cotton fiber. The data for the reference cotton was taken from van der Velden, N. M., et al. and Shen and Patel, et al. [16–17]. Two CCA fiber production scenarios were modelled with Sustainability tool for Ecodesign, Footprints & LCA (SULCA). Assumed that CCA Intergrated fiber was produced in a factory integrated with a pulp mill, which included water circulation, recycling of chemicals and using renewable energy. CCA Standalone fiber was produced in a stand-alone factory, which represented a non-optimized process. 1 tonne of CCA Integrate fiber had a GWP value of 1979 kg CO_2 eq., which was ~30% lower than of that for the reference cotton fibers. However, CCA Standalone fiber generated twice of GWP of cotton fibers (6020.1 kg CO_2 eq.). The water use of CCA Integrated fiber and CCA Stand-alone fiber were 31 m^3 and 86 m^3 respectively, which is much lower than cotton (4342 m^3 per tonne of cotton fiber). Paunonen et al. concluded that the reuse of discarded cotton for CCA fiber can considerably reduce water use [18]. However, due to the huge contribution to GWP, it should be suggested to integrated spinning factory with pulp mill to optimized the production of CCA fiber.

In addition to an intensive water use, cotton production is also characterized by intensive land use during the cultivation phase. However, these two impacts are seldom addressed as impacts further down the cause-effect chain. Sandin et al. contributed to the developed of methods for characterizing the impacts of water and land use in the LCA, and assessed the impacts of water use and land use with respect to textile fibers [19]. The study used four indicators proposed by Pfister et al. to characterize the impact of water use: a midpoint indicator (water deprivation) and three endpoint indicators (human health, ecosystem quality impact, and resources) [20]. Sandin et al. also used the method proposed by Schmidt for characterizing the impact of land use on biodiversity [19, 21]. The results showed that the location of operations significantly influenced the impact of water use. The transformation of natural land had a greater impact on biodiversity than the occupation of land. Moreover, the study highlighted that the methodological aspects of both water and land use impact assessment require further research down the cause-effect chain.

To balance the economic and environmental performances of cotton cropping systems, Ullah et al. performed an eco-efficiency analysis [21]. The authors assumed that farm size was a possible factor in the performance variation, and their results demonstrated that the use of pesticides and fertilizers, field emissions, field operations, and irrigation were the main sources of environmental impacts. Findings revealed that the production of 1 kg of seed cotton delivered at the farm gate could generate a GWP of 3–3.4 kg CO_2 eq. and could require 5–6 L of water, with no significant differences being observed with farm size. Small farms were found to have a potentially higher eutrophication impact in comparison to larger farms, but this could be counterbalanced by higher profits. Unfortunately, the study illustrated that the combination of high economic returns with low environmental impacts was seemingly impossible under the assumed conditions. However, the greatest potential for balancing economic and environmental performances was found to be through the reduction of pesticides and fertilizers with no effect on yield.

Impact analysis of cotton clothing

Cradle to grave LCA can be used to assess the advantages of recycling clothing, address environmental performance of garments, and identify the hotspot during the life cycle of a T-shirt or a pair of jeans, for example. The impact categories selected to address environmental burden of products are different from each study depending on the purpose and the chosen LCA methodology. The most utilized life cycle impact assessment (LCIA) methods in cotton textile are environmental design of industrial products (EDIP), ReCiPe and CML.

Woolridge et al. conducted a LCA for the reuse/recycling of donated waste textiles from an energy saving perspective [23]. To address the net energy saving from reused textiles, the authors used a case study of a charity bank, which recycled clothing and textiles by providing a collection and distribution infrastructure for donated second-hand clothing, textiles, shoes, and accessories. The energy use required for reuse and recycling was mostly attributed to the use of polyester packaging/bags and transportation. In comparison to virgin materials, 1 tonne of second-hand clothing was found to save 65 kwh energy (i.e., 97.4% of the energy used for virgin cotton clothing).

Many charity organizations collect used clothing and either resell or donate them. Not all clothes are suitable for reuse, and only ~60% may be recycled. The potential to reduce the environmental burden of recycled textiles was quantified by Farrant et al. [24]. The authors assessed the environmental benefits of reusing clothes by the EDIP method and a functional unit of 100 pieces of 100% cotton T-shirt. The concept of a “replacement rate” was introduced to evaluate the replacement of new clothes by second-hand clothing. Compared with directly discarded cotton T-shirts, reuse via second-hand shops in Estonia was found to decrease i) the GWP by 14%, ii) acidification impacts by 28%, and iii) nutrient enrichment impacts by 25%.

Baydar et al. used LCA to compare the environmental impacts of eco-T-shirts (produced from organically grown cotton and processed with green dyeing recipe) to those of conventional T-shirts [25]. Comparison was made of their contributions to global warming, acidification, aquatic and terrestrial eutrophication, and photochemical ozone formation using a functional unit of 1000 items of knitted and dyed cotton T-shirt (200 kg total weight). The environmental impacts over the period from cotton cultivation to disposal were assessed using EDIP 2003. The results revealed that the eco T-shirts had a lower impact potential across all of the observed categories. The most dramatic decrease in impact potential was observed for aquatic eutrophication potential (AEP) (up to 97% reduction), which related to the elimination of nitrogen and phosphorus containing chemical fertilizers during the cotton cultivation stage. GWP was by far the largest environmental impact for both conventional and eco T-shirts, with the main impact coming from the use phase (evaluated as 4140.4 kg CO_2 eq.), and this was followed by the cultivation and harvesting phase and then the fabric processing phase. In terms of AP, the use stage was found to make a considerable contribution to acidification that resulted mainly from wastewater treatment (51%), soap production (25.3%) and electricity consumption (22.4%). The elimination of certain chemicals during wet processing resulted in a significant reduction across all impact categories. Although the authors concluded that the use of organic cotton can significantly reduce environmental impacts, any immediate transition to organic cotton cultivation was considered to be challenging. Gradual reductions in the application of fertilizer and pesticides were determined as being more feasible for reducing the environmental impacts.

The LCA of a product includes the challenges of globalized production and consumption, and requires a spatial LCI to be developed. Steinberger et al. established a cradle to grave spatially explicit LCI for a cotton T-shirt and a jacket at the country level [26]. The cotton T-shirt was produced in India and the polyester jacket was manufactured in China, and both were consumed in Germany. The LCI included CO_2, SO_2, NO_x and particulate emissions, as well as energy use, which were disaggregated by country. The LCI of the T-shirt and jacket showed striking differences, > 70% of the CO_2 emissions and energy use associated with the T-shirt occurred in the consumption country, whereas > 70% CO_2 of emissions associated with the jacket occurred in the producing country. This striking difference of the CO_2 emission was related to the different washing frequency of two apparels (50 times and 6 times for the jacket). For SO_2, > 60% of emissions occurred in the production country for both the T-shirt and the jacket due to the combustion of fossil fuel in production phase. The difference in the emission of CO_2 and SO_2 of two garments was mainly depended on the location energy infrastructure. Analysis of the use-phase indicated the importance of consumer behaviour (e.g., washing machine temperature settings and air versus laundry drying) over equipment efficiency. In addition, the lifetime of a garment was also found to play a significant role in the contribution to environmental impacts, a longer lifetime increased the environmental impacts of the use phase, whereas the daily environmental burden of a garment being worn decreased. These findings indicate the necessity of a functional unit that provides the lifetime of a garment when conducting a LCA of clothing.

Large environmental impacts for cotton textiles are caused during the use phase, especially with respect to energy consumption for washing and ironing clothes. Cartwright et al. assessed the cradle to grave environmental impacts of a shirt using a functional unit of a button-up, short-sleeved, uniform work shirt made of 65% polyester and 35% cotton [27]. The shirt was washed 52 times over a 2-year lifespan. The environmental impacts (energy, water use, and GWP) were analysed for four distinct phases: material acquisition, shirt manufacturing, use and disposal. The total life-cycle energy use of the shirt was 102 MJ, the cumulative water use was 2728 l, and the GWP was 5.7 kg CO_2 eq. The results showed that the amount of resources used and the GWP were highest during the shirt's use phase, which accounted for 64% of total energy use, 72% of total water use, and 76% of the overall GWP. This was due to four main processes in: water heating, washing, drying, and transportation. The study concluded that more effort should be made to improve the environmental performance of the use phase, for example, by increasing equipment efficacy.

Hackett et al. addressed the cradle to gate phases of the life cycle assessment of a pair of denim jeans and a T-shirt [28]. The system boundaries that were assessed included: raw material production, fabric production, garment manufacturing, and transportation and distribution. The study showed that cotton fiber cultivation and harvesting made the most significant contributions to the overall environmental impacts, and that these originated from the use of fertilizers, pesticides, and irrigation water. The authors suggested that initiatives could therefore encourage the cultivation and harvesting of organic cotton that remove the use of artificial fertilizers and pesticides. However, due to concerns over low yields and finances, the transformation from conventional cotton to organic cotton was considered as having a long way to go. Limitations of the study included that the data came from existing LCAs, and that the comparison between the selected apparel was less meaningful because the environmental impacts of the cotton apparel varied from countries and the results are highly dependent on chosen methodology, hence, we suggested that the comparison of environmental impacts between two type different apparel (e.g. T-shirt versus jeans) should be based on LCIA results that evaluated under similar systems.

Zhang et al. aimed to identify hotspots in the life cycle of cotton textiles for the purpose of improving their sustainability [29]. The functional unit was one 100% cotton long-sleeved T-shirt and the scope was from cradle to grave. The data were obtained from a representative mill and from questionnaires for the use phase in China. Abiotic depletion, AP, GWP, photochemical ozone creation potential, EP, water use, and toxicity were assessed using CML 2001 and USEtox model. From a life cycle perspective, the study showed that cotton cultivation, dyeing, making-up, and the use phase were the main contributors to the environmental impacts. The author concluded that improving a product's environmental sustainability is not only a matter for the government and suppliers, but also for consumers.

In 2015, Levi Strauss and Co. conducted an LCA to assess the environmental impact of a pair of Levi jeans. The functional unit was one pair of women's Levi's 501 medium stonewash-jeans (340 g) that were made of cotton [30]. The LCA analysed the environmental impact of the denim during the entire life span, which encompassed the production of the raw materials, the manufacturing process, logistics, garment use, reuse of the denim, recycling, and disposal. The LCA focused on the product's use phase and end-of-life disposal phase because these are critical stages in a product's life cycle, which depend on consumer behaviours. ReCiPe 2008 was used to assess climate change potential, water consumption, EP, land occupation, and abiotic depletion. One pair of Levi's 501 denim jeans were found to emit 33.4 kg CO_2, to consume 3781 kg water and 48.9 g PO_4^{3-}, and to occupy 12 m^2/year of land. The study demonstrated that fiber production and consumer care activities consumed most of the water during the entire life cycle (91%), whereas fiber production consumed 68% and consumer care activities (e.g., cleaning and washing) consumed 23%. The results showed that consumer care contributed the largest impact (37%) to climate change over the life cycle. Moreover, processing factors such a washing frequency, washing water temperature, and the use of a washing machine were found to influence GHG emissions. The fabric product had the second largest impact on climate change (27%). Fiber cultivation had the highest impact on eutrophication due to the use of fertilizer and pesticides (Levi Strauss & CO, 2015). This study provided a comprehensive assessment of the environmental burden of a pair of cotton jeans, which could be used for improving the performance of jean.

The textile industry uses chemicals intensively in production phase. Toxicity assessments are therefore performed, and it is important that the results are both relevant and representative because it is crucial that there is confidence in the results. Three methods for strategic product toxicity assessment were compared by Roos and Peters as a means of disclosing the inherent characteristics of chemicals used in cotton manufacturing [31]. The differences resulting from the choice of toxicity assessment method were illustrated and compared using the wet treatment of a cotton T-shirt. The results showed that three different toxicity assessment methods did not give a consistent evaluation of the different chemicals used in the wet treatment. For example, optical brightener received a high score in the score system method but a very low score from USEtox. This was considered to mainly relate to the environmental persistence of organic chemicals, a property that is handled differently in these toxicity assessment methods.

Roos et al. calculated the GWP using ReCiPe and toxicity using USEtox, and used the score system as a supporting method [32]. The study addressed the importance of the life-cycle perspective as a means of avoiding improving part of a system in a manner that negatively affects other parts of the system. The environmental impacts of two white nightgowns were compared, whereby one was bleached and one was not. The results showed that, contrary to expectations, the environmental burden associated with the bleached nightgown over its life cycle was lower than that of the unbleached gown, owning to a shorter lifespan for the unbleached gown. A shortcoming was identified during the impact assessment step, many textile chemicals lacked character factors CFs and could not therefore be included in the LCA calculations. This represents an aspect for further study in the methodology of chemical assessments. From this study, we proposed that the operational lifespan of products should be determined when conducted LCA, which significantly influence by consumer behaviours. Assuming that consumers dispose of clothes when they are worn out, a long-life span ensures a lower replacement rate for consumers, which may be more environmentally friendly from a comprehensive perspective.

The carbon footprint of a pure cotton shirt (average weight of 0.28 kg) from cultivation to use stage in China was evaluated by Wang et al. using the IPCC method. This study constructed an operable carbon footprint assessment method and framework at the product level to establish the provision of a carbon labelling system [33]. The calculated carbon footprint was 8.771 kg CO_2 eq., and the indirect carbon footprint accounted for most of the total carbon footprint over the shirt's life cycle (96%) owing to the use of energy and materials. The industrial production process contributed 57% of the total carbon footprint, 36% for raw materials, 11% for use phase. A limitation of the study was that it only assessed climate change. According to previous research, the consumption of water and land use are other hotspots for cotton textiles. The authors emphasized that a product should be assessed in a comprehensive manner to inform consumers sufficiently, when develop environmental impact polices making or management decision. We proposed that a comprehensive ecolabel will be an effective way to reduce the environmental burden of garments.

DISCUSSION

Goal and scope

LCA of cotton textile aims to assess the environmental impact of cotton textile during the life cycle. The entire life cycle of cotton textiles includes many processes, and is related to many regions and has a long time-span. It can be separated to four main processes: cotton cultivation, production, use phase, and disposal (figure 1).

From the reviewed LCA studies on cotton, the system boundaries were always either from cradle to gate (fiber) or from cradle to grave (textiles). However, the gate can refer to a farming gate, ginning gate, factory gate, or family gate. Many studies for cotton fibers have focused on the environmental contribution of cotton cultivation beginning with cotton cultivation and ending at ginning, and used a functional unit of 1 kg/tonne of cotton lint. Others investigations have

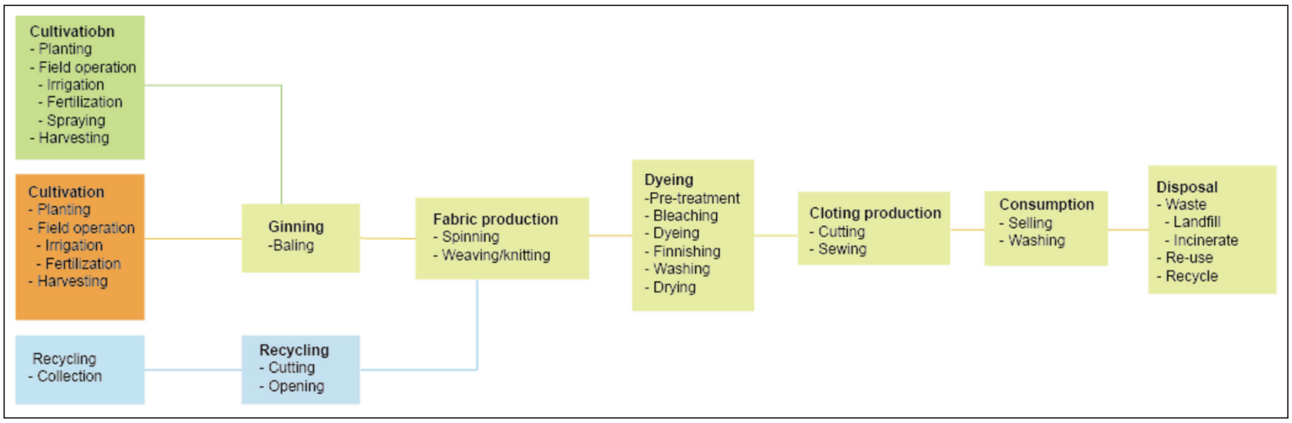

Fig. 1. Process of life cycle of cotton textiles

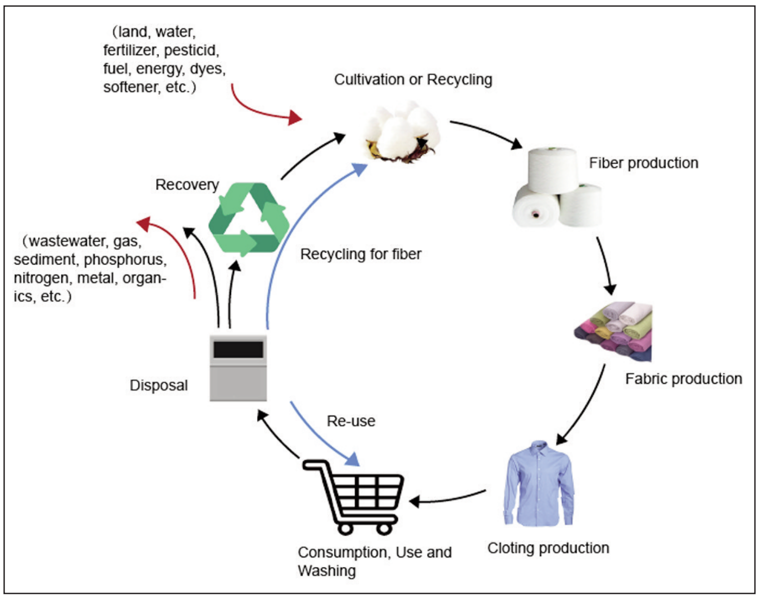

Fig. 2. The whole life cycle of cotton textile

aimed to evaluate the environmental burden from a holistic perspective that contains more processes. For cotton textiles, many researchers chose the functional unit as one piece of cotton garment, and ended at either the use phase or disposal stage. The inputs such as land use, water consumption, chemical inputs and output (e.g. wastewater, gas emission, metal and organics) will be documented and assessed (figure 2).

Impact assessment results

The most widely used LCA methods for cotton textiles have been EDIP, CML and ReCiPe, which are comprehensive methods that contain many environmental impact categories (table 1). The impact categories and their characterization as well as applicable locations vary between methods and studies. GWP, AP, EP, and water consumption are the most common impact categories in the LCA of cotton textiles (table 1). USEtox model focuses on the toxicity assessment that has been applied in the textile industry in recent years. The carbon footprint and water footprint are specialized parameters for evaluating the effects of GHG emissions and water consumption, which are concentrated on a smaller scope containing only one impact category. In the LCA assessment of cotton textiles, the selected impact category indicators for GWP, AP and EP are mid-point indicators, which evaluate the impact of the pollutants by using the equivalency of a reference substance. In terms of the impact assessment of acidification and eutrophication with respect to cotton textiles, the impact categories may include freshwater acidification/eutrophication or terrestrial acidification/eutrophication, depending on the characterization method used and issues being addressed. Water scarcity categories have been developed to address the different water stresses in various regions, and can report the water consumption effects in a location-specific way. There is a possibility that cotton industry areas may be affected by water stress. However, water consumption assessment of cotton textiles in an LCA is often reported in a loading assessment level by simply including the volume of water used. Few studies have applied water scarcity or assessed the water consumption effect down the cause-and-effect chain.

From the published LCA results for cotton textiles, it is difficult to form a consistent conclusion with regards to which factor contributes most to the overall environmental burden. This is due to the different assessment methods, locations, and production technologies amongst other reasons. However, it is possible to summarize the possibilities for reducing environmental impacts. A cradle to grave LCA of a piece of a cotton garment that contains comprehensive impact categories can support decision makers, although data quality is a high requirement. LCAs of a pair of jeans and a piece of T-shirt were reported in [25, 29, 30]. The most common impact categories in these studies were GWP, AP, EP, and water use.

The life span of cotton garments is separated into four phase cotton cultivation, production, use, and disposal. Cotton cultivation, wet processing during

Table 1

SUMMARY OF LIFE CYCLE ASSESSMENT OF COTTON TEXTILE			
Textile products	**Source**	**Method**	**Impact categories***
Cotton fiber	Chapagain et al., 2005 [7] Paunonen et al., 2019 [18] Günther et al., 2017 [10] Sandin et al., 2013 [19]	footprint	CF, EF, PF, WF
Organic cotton fiber	CmiA., 2014 [8] Textile Exchange, 2016 [5]	CML	AP, ADP, EP, FWAE, GWP, HTP, OLD, PED, TEP, WU, WC
Organic cotton fiber	Textile Exchange., 2016 [5]	USEtox	TP
Cotton lint	Hedayati et al., 2019 [14]	Australian impact method, Australian Indicator Set V3	GWP
Cotton fiber	Paunonen et al., 2019 [18]	ReCiPe	GWP
Seed cotton	Ullah et al., 2016 [22]	CML 2001	ADP, AP, EP, HTP, FWAE, GWP, OLD, TEP, WU
Recycled clothing	Woolridge et al., 2006	footprint	EF
Cotton T-shirt	Farrant et al., 2010 Baydar et al., 2015	EDIP	AP, AEP, GWP, OD, POFP, TEP
A work shirt	Cartwright et al., 2011	EDIP	GWP
Denim jean	Hackett et al., 2015 [28]	ReCiPe 2008	AD, EP, GWP, LO,WU,
Cotton T-shirt	Zhang et al., 2015 [29]	CML 2001	AD, AP, EP, GWP, POCP, WU
Cotton T-shirt	Zhang et al., 2015 [29] Roos and Peters, 2015 [31]	USEtox	EP, HTC, HTNC
A cotton nightgown and a cardigan	Roos et al., 2015 [31]	ReCiPe	GWP
A cotton nightgown and a cardigan	Roos et al., 2015 [31]	USEtox	TA
A pure cotton shirt	Wang et al., 2015 [33]	Footprint	CF

Note: * CF – carbon footprint; EF – energy footprint; PF – phosphorus footprint; WF – water footprint; AP – acidification potential; ADP – abiotic depletion potential; EP – eutrophication potential; FWAE – fresh water aquatic ecotoxicity; GWP – global warming potential; HTP – human toxicity potential; OLD – ozone layer depletion; PED – primary energy demand; TEP – terrestrial eutrophication potential; WU – water use; WC – water consumption; TP – toxicity potential; AEP – aquatic eutrophication potential; OD – ozone depletion; POFP – photochemical ozone formation potential; AD – Abiotic depletion; LO – Land occupation; POCP – photochemical ozone creation potential; HTC – human toxicity-cancer; HTNC – human toxicity-non cancer; TA – toxicity assessment.

production and the use phase have been found to be the main contributors to the overall environmental burden across all impact categories. In the cultivation phase, the intensively use of water, fertilizers, and pesticides have been reported as contributing most of the environmental impacts and can be considered as hotspots. Water consumption is highly related to the climatic conditions of a cotton growing region, and areas with a low evaporative demand but high effective rainfall are more attractive for cotton cultivation. Synthetic fertilizers have the potential to contribute considerably to eutrophication due to their nitrogen and phosphorus contents, whereas pesticides can negatively affect freshwater and terrestrial toxicity [17]. Wet processing during the production phase is another hotspot across the indicators of water consumption, GWP, AP, EP and toxicity. Most of the environmental burden has been found to originate from diverse chemical inputs (e.g., acids, alkalis, dyes, metals, and organic compounds) in the dyeing phase. An additional hotspot is the use phase, the high contribution of energy use to global warming during this phase is due to water heating, washing, drying, and ironing. Washing detergent has also been reported to account for high AEP. Furthermore, studies have illustrated that different consumer behaviours (e.g., life time span, frequency of use, and washing habits) can result in quite different environmental consequences related to energy and water use.

Strategies for reducing environmental impacts

Strategies for farm operations, organic cotton cultivation, to recycling of cotton textiles can all contribute to a reduction in environmental impacts. Opting for organic cotton versus conventional cotton is one strategy for reducing the environmental impacts of cotton cultivation, it avoids the use of artificial chemicals such that impacts related to the GWP and eutrophication are reduced. However, the cost and yields of organic cotton mean that there is still a long way to go to switch from conventional cotton to organic cotton. As mentioned previously, the various chemical inputs during wet processing can result in wastewater that contains high concentrations of pollutants. Feasible strategies include using substitute chemicals that have a lower environmental burden or recycling without dyeing. From a holistic life cycle perspective, cleaner consumption is more important than cleaner production due to its long-life span during the use phase. Lower water temperatures and hand washing have also been suggested by previous studies. However, the impacts related to detergent have seldomly been considered in the impact assessment of cotton textiles.

Limitations and potential improvements

As mentioned, LCA methods for cotton textiles contain many impact categories. However, many studies have only included a limited number of environmental indicators. Comprehensive impact categories that include eutrophication, acidification, and ecotoxicity could make cradle to grave studies more scientific and credible. This could also avoid missing potential hotspots, especially when new techniques are applied in the cotton textile industry. In addition, a more comprehensive water footprint that includes water scarcity would be more appropriate and relevant to current research.

The environmental impact assessment of cotton textiles in use phase was found to have high contributions to water consumption and energy use and results more uncertainties owing to various consumption behaviours. The results of LCIA are sensitive to parameters such as washing frequently, lifespan. Hence, the lifespan, washing frequency, washing temperature and other related operations in consumer care phase must be determined when assess the environmental impact of cotton garment in use phase. Moreover, the functional unit for use phase should be 1 mass of cotton garments per month or year.

Cotton textiles are characterized by a global circulation, moving between different regions through a long and complex chain. LCIA practitioners should recognize that the impacts of this movement depend on the array of locations involved [34]. Impact categories such as acidification, eutrophication, and water use are more site-specific. Site-dependent characterization models have rapidly developed in the past decade. Regionalized methods have included impact categories such as acidification [35, 36], eutrophication [37, 38], water scarcity, and their related impacts on human health and ecosystems [20, 39, 40]. Therefore, LCIA practitioners should chose appropriate methods to produce more accurate results as a scientific reference for decision makers.

Many sectors that use LCA require evaluation results to be of an increasingly high quality. Hence, there is a need for characterization models to include toxicity persistence and bioaccumulation assessments as well as generic exposure/effects assessment.

Furthermore, future LCAs of products such as cotton, which have long chains and are related to many regions during their entire life time, should involve a site-specific exposure/effects assessment.

CONCLUSIONS

We reviewed LCA research findings on the environmental burden of cotton fibers and textile products, which considered the degree to which eco-products or strategies can reduce the environmental impacts in comparison to convention cotton.

It can be concluded that cotton cultivation significantly contributes to the environmental burden of cotton due to the use of water, fertilizers, and pesticides. Cotton cultivation that is located in regions where precipitation can meet the water demand and evaporation is low is recommended if they do not increase the burden on local blue water resources.

Furthermore, the cultivation of organic cotton can significantly reduce the environmental burden of cotton fiber. During the manufacturing phase, the use of water, energy, and chemicals is traditionally high. Alternative chemicals that reduce the environmental burden should be encouraged. In addition, cleaner consumption is more important than cleaner production due to the significant contribution of the use phase to global warming and water scarcity. Consumption habits such lower water temperatures during clothes washing and the use of second-hand clothing should also be encouraged for consumers.

LCIA based on regional differences may be the next step for assessing the environmental burden of cotton due to the global consumption and production of cotton textiles. Regionalized LCIA is a credible method for i) determining the optimal locations for factories or suppliers, and ii) resource management and sustainable development. Moreover, comprehensive impact categories with a cradle to grave approach can disclose the environmental burden. The risk of simply shifting pollution and other environmental issues from one phase to another could be avoided by using more developed LCA methods that have the potential to cover the significant impacts in various categories. A credible LCA of cotton can support sustainable decision-making by providing a comprehensive and structured account of the potential environmental impacts.

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ADDITIONAL INFORMATION

Correspondence and requests for supplementary material of this paper should be addressed to the corresponding author.

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Authors:

FANGLI CHEN[1,2], XIANG JI[1,2], JIANG CHU[1,2], PINGHUA XU[1,2], LAILI WANG[2,3,4]

[1]School of Fashion Design & Engineering, Zhejiang Sci-Tech University, Hangzhou, Zhejiang 310018, China
e-mail: cathychen2016@163.com (C.F.), jixiang549961547@163.com (J.X.), chujiangZSTU@163.com (C.J.), shutexph@163.com (X.P.)

[2]Zhejiang Sci-Tech University, Engineering Research Center of Clothing of Zhejiang Province, 310018, Hangzhou, China

[3]Silk and Fashion Culture Research Center of Zhejiang Province, Zhejiang Sci-Tech University, 310018, Hangzhou, Zhejiang, China

[4]Zhejiang Academy of Ecological Civilization, Hangzhou 310018, China

Corresponding author:

LAILI WANG
e-mail: wangll@zstu.edu.cn