EVALUATION OF ENVIRONMENTAL EFFECT OF PUMP SHOES IN TERMS OF MANUFACTURING PROCESS

CHI ZHANG[1], LEIYA LI[1], CARMEN GAIDĂU[2], JIN ZHOU[1*]

[1]National Engineering Laboratory for Clean Technology of Leather Manufacture, Sichuan University, Chengdu 610065, P.R. China; 1846119869@qq.com, 879781426@qq.com

[2]Leather Research Department, Leather and Footwear Research Institute Division, Bucharest 031215, P.R. Romania; carmen_gaidau@hotmail.com

Received: 20.06.2020 Accepted: 29.07.2021 https://doi.org/10.24264/lfj.21.3.1

EVALUATION OF ENVIRONMENTAL EFFECT OF PUMP SHOES IN TERMS OF MANUFACTURING PROCESS

ABSTRACT. China is the largest footwear producing country, as well as the largest country producing the footwear manufacturing waste. In order to achieve sustainable development in the footwear industry, we should pay attention to their environmental effect seriously. Therefore, by applying life-cycle assessment (LCA) protocol, we aimed to explore the effect of the manufacturing process on the environment of a classical style of pump shoes. Following guidelines of ISO 14010, we first determined the objective and the scope of this study; then, we collected input and output data from the shoe producing line of a shoe-making enterprise in Wenzhou, China; afterwards, we applied eFootprint software for LCA modeling; finally, we chose three LCA indicators for further analysis: Global Warming Potential (GWP, kg CO_2 eq), Primary Energy Demand (PED, MJ) and Abiotic Depletion Potential (ADP, kg Sb eq). Our results show that by producing one pair of pump shoes, the manufacturing process will emit 11.427 Kg CO_2 eq in terms of GWP, 232.621MJ in PED and 6.291×10-5Kg sb eq in ADP. Hence, by multiplying the number of shoes produced in China, negative environmental influences from shoe making industry were also dramatic. According to further contribution rate of all process, we found that materials such as the water-based binder and the plastic last used in manufacturing process accounted for the major reason. Overall, while considering the environmental effects from the shoe manufacturing process, we shall not ignore the environmental impact whilst producing the binder and the last. Moreover, by reducing binder usage or updating the shoe making technology, and recycling the last can be an efficient way to reduce the environmental effects from the shoe making industry.

KEY WORDS: shoe making process, life cycle assessment, polyurethane synthetic leather, pump shoes

EVALUAREA EFECTULUI PANTOFILOR CU TOC ASUPRA MEDIULUI DIN PERSPECTIVA PROCESULUI DE FABRICAȚIE

REZUMAT. China este cea mai mare țară producătoare de încălțăminte, precum și cea mai mare țară generatoare de deșeuri de la fabricarea încălțămintei. Pentru a realiza dezvoltarea durabilă în industria încălțămintei, ar trebui să acordăm atenție serioasă efectului acestora asupra mediului. Prin urmare, prin aplicarea protocolului de evaluare a ciclului de viață (LCA), ne-am propus să explorăm efectul procesului de fabricație a pantofilor cu toc clasici asupra mediului. Urmând instrucțiunile specificate în ISO 14010, am stabilit mai întâi obiectivul și domeniul de aplicare ale acestui studiu; apoi am colectat date de intrare și ieșire din linia de producție de pantofi a unei întreprinderi din Wenzhou, China; ulterior, am aplicat software-ul eFootprint pentru modelarea LCA; în cele din urmă, am ales trei indicatori LCA pentru analiză ulterioară: Potențialul de încălzire globală (GWP, kg CO_2 echivalent), Cererea de energie primară (PED, MJ) și Potențialul de epuizare abiotică (ADP, kg Sb echivalent). Rezultatele noastre arată că, în urma procesului de fabricare a unei perechi de pantofi cu toc, se vor emite 11,427 kg CO_2 echivalent în ceea ce privește GWP, 232,621MJ pentru PED și 6,291 × 10-5Kg sb echivalent pentru ADP. Prin urmare, prin multiplicarea numărului de perechi de pantofi produși în China, influențele negative asupra mediului din industria încălțămintei au fost, de asemenea, dramatice. Conform ratei suplimentare de contribuție a tuturor proceselor, am constatat că materialele precum liantul pe bază de apă și calapodul de plastic utilizate în procesul de fabricație au reprezentat motivul principal. În general, luând în considerare efectele asupra mediului generate de procesul de fabricație a încălțămintei, nu vom ignora impactul asupra mediului în timpul fabricării liantului și calapodului. Mai mult, reducerea utilizării liantului sau actualizarea tehnologiei de fabricare a încălțămintei și reciclarea calapoadelor pot reprezenta o modalitate eficientă de a reduce efectele asupra mediului din industria încălțămintei.

CUVINTE CHEIE: procesul de fabricare a încălțămintei, evaluarea ciclului de viață, piele sintetică poliuretanică, pantofi cu toc

ÉVALUATION DE L›EFFET DU PROCESSUS DE FABRICATION DE CHAUSSURES À TALON HAUT SUR L'ENVIRONNEMENT

RÉSUMÉ. La Chine est le plus grand pays producteur de chaussures, ainsi que le plus grand pays générateur de déchets de chaussures. Afin de parvenir à un développement durable dans l'industrie de la chaussure, nous devons prêter une attention particulière à leurs effets sur l'environnement. Par conséquent, en appliquant le protocole d'analyse du cycle de vie (ACV), nous avons entrepris d'explorer l'effet du processus de fabrication des chaussures à talons hauts classiques sur l'environnement. En suivant les instructions spécifiées dans l'ISO 14010, nous avons d'abord établi l'objet et la portée de cette étude ; puis nous avons collecté des données d'entrée et de sortie de la chaîne de production de chaussures d'une entreprise de Wenzhou, en Chine ; par la suite, on a appliqué le logiciel eFootprint pour la modélisation ACV ; enfin, on a choisi trois indicateurs ACV pour une analyse plus approfondie : Le potentiel de réchauffement global (GWP, kg CO_2 équivalent), la demande en énergie primaire (PED, MJ) et le potentiel d'épuisement abiotique (ADP, kg Sb équivalent). Nos résultats montrent que, suite au processus de fabrication d'une paire de chaussures à talons, 11,427 kg CO_2 équivalent seront émis en termes de GWP, 232,621MJ pour PED et 6,291 × 10-5Kg sb équivalent pour ADP. Par conséquent, en multipliant le nombre de paires de chaussures produites en Chine, les influences environnementales négatives de l'industrie de la chaussure ont également été dramatiques. Selon le taux de contribution supplémentaire de tous les processus, nous avons constaté que les matériaux tels que le liant à base d'eau et la forme en plastique utilisés dans le processus

* *Correspondence to: Assoc. Prof. Dr. Jin ZHOU, National Engineering Laboratory for Clean Technology of Leather Manufacture, Sichuan University; Chengdu 610065, P. R. China; (Fax: 008613880467494. zj_scu@scu.edu.cn).*

de fabrication étaient la principale raison. De manière générale, compte tenu des effets environnementaux générés par le processus de fabrication de la chaussure, nous n'ignorerons pas l'impact environnemental lors de la fabrication du liant et de la forme. De plus, la réduction de l'utilisation de liants ou l'amélioration de la technologie de fabrication des chaussures et le recyclage des formes peuvent être un moyen efficace de réduire les effets environnementaux de l'industrie de la chaussure.
MOTS-CLÉS : processus de fabrication de chaussures, l'analyse du cycle de vie, cuir synthétique polyuréthane, chaussures à talons hauts

INTRODUCTION

China is the largest shoe producer, trader and consumer in the world, and its annual production, exports and consumption of shoes counted for 60%, 70% and 20% of the world individually [1]. Shoe-making process mainly includes three kinds of pollution: solid waste [2], dust pollution and volatile organic compounds (VOC) [3-6], where binders are the major source responsible for VOC emission in the manufacturing process. Although consumption of binder per pair shoe is 40g, by counting the amount of production which is over two billion pairs [7], more than 80,000t binder is consumed in footwear industry in China. Based on this fact, Chinese environmental authorities have listed the footwear industry as "severe pollution and high environmental risk" product inventory since 2017 [8-9]. Meanwhile, China promised in the Paris Agreement to reduce the carbon dioxide emissions per unit of China's GDP by 60% to 65% from 2005 by 2030. Therefore, it is necessary to evaluate the environmental effect of the shoe-making process, so as that we can optimize the production process, reduce waste emissions and finally achieve the goal of sustainable development.

In the strategical viewpoint, by means of life cycle assessment (LCA), researchers could quantitatively comprehend the environmental effect in terms of consumption of resources and energy as well as the emitted environmental load [10] for varied industry areas. Currently, a number of research studies has been conducted. Mila *et al*. [12] studied the LCA of women's leather shoes from cattle raising to abandonment, and then they found solid waste and cattle raising processes were the biggest environmental impacts sectors. Meanwhile, Barling [13] further approved that the animal raising was the main process contributing to higher environmental impact when manufacturing a pair of women's leather shoes. Afterwards, Cheah *et al*. [11] evaluated the carbon footprint of a pair of running shoes made of synthetic materials and they showed 14±2.7 Kg carbon dioxide equivalent emission in the production process. Further, Li Rui [14] assessed the LCA of three types of adhesive shoes and two module shoes in Fujian and Shanxi areas in China. They analysed the major polluting part or process of each kind of shoe, based on which they provided suggestions to enterprise how to reduce pollutant generation. Additionally, Serweta *et al*. [15] calculated the carbon footprint of seven outdoor shoes and they also provided suggestions for optimizing the manufacturing the process. Zhang June [2] investigated the recycling of used shoes and recommended disassembling, shredding and reusing to dispose, rather than simple incineration. Although the above studies focused on LCA in footwear industry, limitations still existed. (1) Polyurethane (PU), as a widely used material, was rarely reported in its evaluation on environmental impact; (2) Since a great part of shoe-making is the assembling process, we are still lacking knowledge about how the assembling process is affecting the environment.

Therefore, the aim of this study was to assess the LCA of a pair of pump shoes, and then to figure out the main environmental impacts in the shoe-making process. According to the literature, we can assume that adhesive materials, as well as plastic related components would have a heavy influence on the environment.

METHOD

Drawing lessons from the structure in principles of ISO 14010, we decide to use four steps leading to a complete LCA process: objective and scope determination, inventory analysis, impact assessment and interpretation of results. In this study, we chose the pump shoe as the target, one pair as the unit, since it was the most classical shoe style for ladies and is prone to become the criteria for other footwear styles. The pump was 60mm heel-height and made of PU material as shown in Figure 1. All the original data below came from the average of three times manual measurement in a large-

scale factory that cooperated with us. In this evaluation, the process of shoe-manufacturing follows the one employed in this factory.

Figure 1. Basic Pump Shoe

Objective and Scope Determination

The objective is first set to assess the environmental impact of manufacturing a pair of pump shoes and then to identify the critical process while the shoe is manufactured. Besides, we will provide some advice according to our conclusion in this study for the factory to make it more environmentally friendly.

As for the scope determination, since shoe-making is a process of assembling a number of components with the help of electricity, other factors such as upstream materials producing process were not considered. Further, the scope of this study was defined as input, assembling and output sections. The input included raw material and electrical energy consumed in processing machinery; while the assembling parts covered main materials, such as the heel, the midsole, the outsole, the last and other materials used in manufacturing process (OMMP). The output would consider the shoes and the waste. The system's boundary was shown in Figure 2.

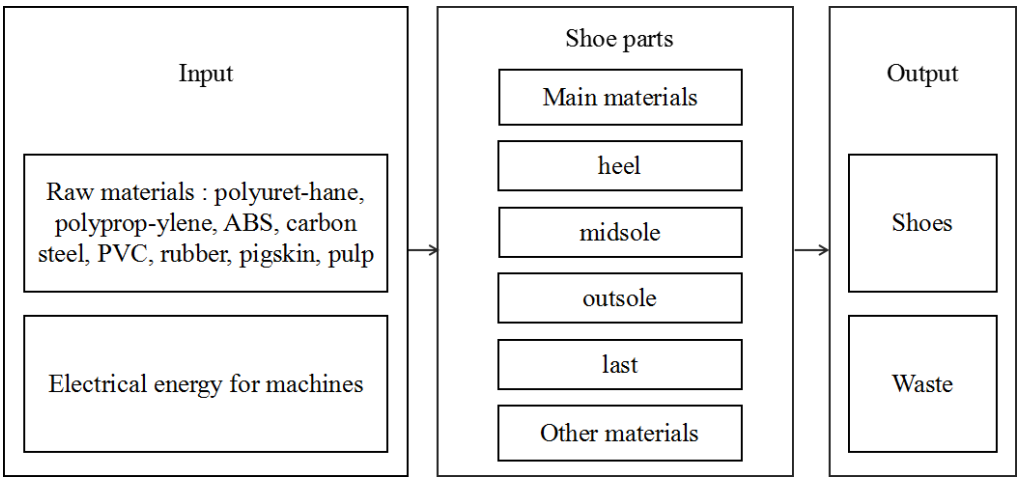

Figure 2. System Boundary of pump shoes

Inventory Analysis

LCI (life cycle inventory) refers to a listed target which required data collection process. According to the field data collection, we obtained all the necessary data for further modeling and they were shown in Table 1.

Table 1: LCA inventory data

Name	Material Name	Material Weight	Unit
PU	Polyurethane	44.2	g
Vamp lining	Pigskin	16.8	g
Front cap	Polyethylene	9.2	g
Back cap	Polyethylene	29.8	g
Heel	ABS	112	g
Mid sole	Pulp	24	g
Shank	Iron	40	g
Injection filler	Polypropylene	64	g

Name	Material Name	Material Weight	Unit
Single-layer sole	Polyunsaturate	84	g
Last	PVC	1104	g
Water-based binder	Polyurethane	46	g
Solvent binder	Polyurethane	30	g
Nail for heel	Carbon steel	2.8	g
Insole	Pigskin	4	g
Electricity	Electricity	0.1	kWh

Impact Assessment

We applied eFootprint software (IKE Environmental Technology Co., Ltd, China) for impact assessment. eFootprint is an online platform for LCA data reporting and analysis. It can be used to build life cycle models of various products and it includes the databases which satisfies most LCA modeling, such as China life cycle core database (CLCD), EU LCA database. Prior to modeling procedure, we determined that there is no by-products and renewable energy consumption in this study, so we would ignore the issues of waste regeneration. Meanwhile, materials whose weight accounted for less than 1% quantity of the production were filtered out.

This model refers to the cradle-to-gate procedure and a pair of shoes is considered as the basic unit. The upstream data of raw materials were from CLCD China ECER 0.8.1 and Ecoinvent database. The specific modeling and analysis processes were shown in Figure 3.

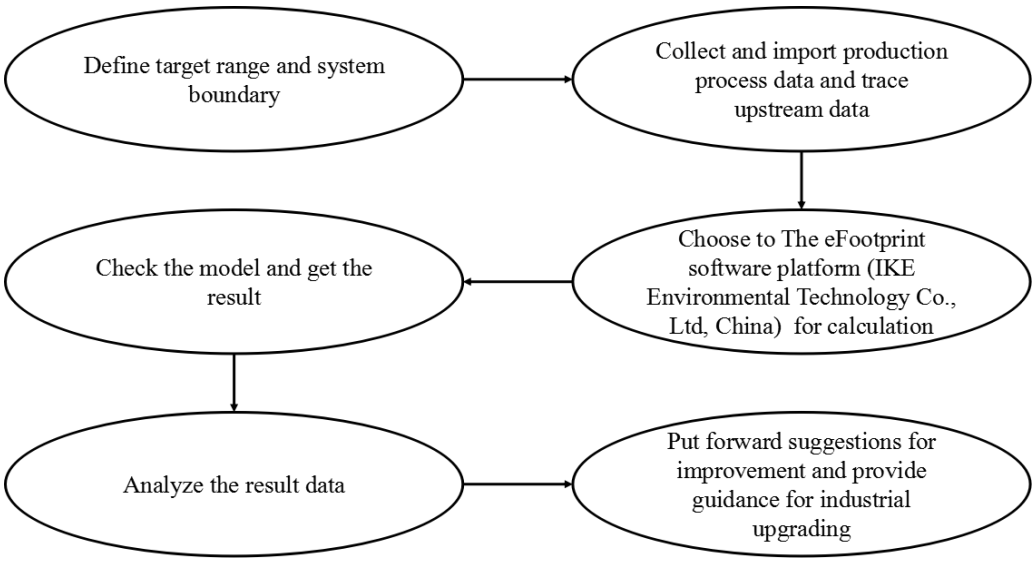

Figure 3. Flow chart of modeling and analysis

Interpretation of Results

In this study, we adopted three kinds of highlighted indexes: GWP, PED and ADP. GWP implies the strength of greenhouse gases using carbon dioxide (CO_2) as a benchmark; PED summaries the net increment of energy consumption; ADP indicates the non-biological consumption using Stibium (Sb) as a benchmark. Moreover, contribution rate of inventory data was also assessed. This indicator refers to the change of the index caused by a change rate of inventory data. By assessing the contribution rate of inventory in eFootprint, we could deeply comprehend our LCA results.

RESULTS AND DISCUSSIONS

Overall Environmental Impact Analysis

The main environmental impact types of the shoes were chosen as GWP, PED, and ADP.

GWP (total carbon footprint) of the shoes is 11.427 kg CO_2 eq, PED is 232.621 MJ, and ADP is 6.291×10-5 kg Sb eq.

Analysis of Environmental Impact of Each Manufacturing Section of the Shoes

The contribution rate of inventory data was shown in Figures 4-6.

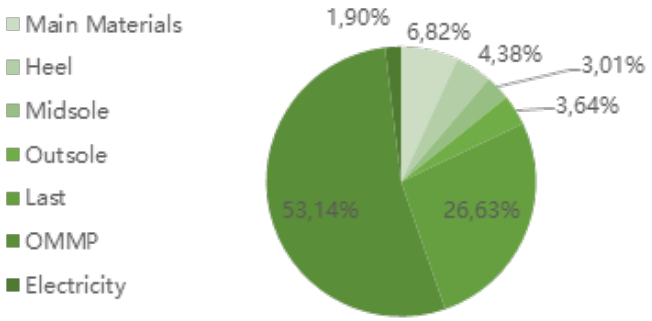

Figure 4. List contribution rate of PED (MJ)

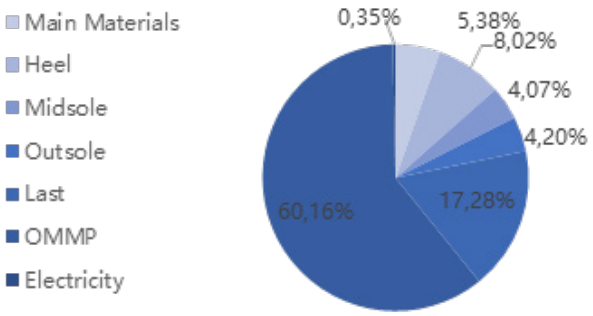

Figure 5. List contribution rate of ADP (kg Sb eq)

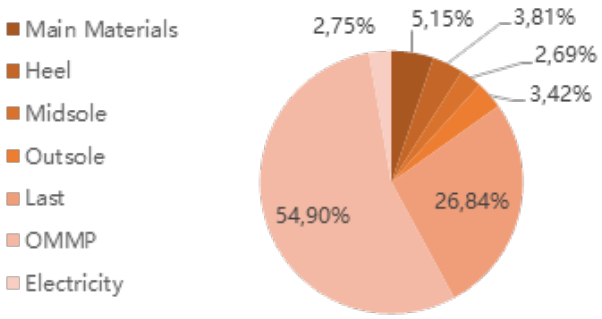

Figure 6. List contribution rate of GWP (kg CO_2 eq)

It could be seen from these figures that the shoes had a negative impact on the environment in general. The components assembled in the manufacturing process had the greatest negative impact on the environment, accounting for more than 50% of the three indexes. The last accounted for about 20%, while other parts had less impact.

By reviewing the major contributions, we found that OMMP contributed the most.

Within OMMP, water-based binder was the reason (Table 2).

Table 2: Contribution of other materials used in manufacturing process to LCA results

Part name	PED (MJ)	ADP (Kg SB eq)	GWP (Kg CO_2 eq)
Water-based binder	46.43	52.28	47.93
Solvent-based binder	6.58	7.41	6.79
Accessories	0.12	0.47	0.18

Discussions

In this study, we first assessed the LCA of a pair of pump shoes and found significant influences on environment; further, by contribution rate of all inventory, we highlighted that the key pollution factors were the water-based binder, solvent binder and the last. Our findings established a basis of LCA for women's shoes manufacturing process.

It was interesting that the adhesive materials, especially the water-based binder, used in the manufacturing process are a factor that contributed a lot to the LCA results. It might be postulated that adhesive materials easily emit VOCs. Naldzhiev *et al*. [16] found that polyurethane products might cause negative health effects at high concentrations, such as dizziness, eye irritation, skin irritation and pulmonary irritation. At present, a large amount of binder is used in footwear industry. Therefore, it is urged to reduce the use of adhesive materials or use an alternative technology to replace them.

Moreover, our outcomes also showed that the last was another contributor. Njati *et al*. [17] indicated that PVC products might increase the risk of lead poisoning due to its usual heavy metal additives. But in general mass production, shoe lasts are normally recycled or produced using recycling materials. Therefore, although the last contributed a significant portion to each environmental index, its actual influence on the environment was much lower. Additionally, according to improving the re-utilization of materials, we can reduce the impact of the last on the environment.

Although we finished the calculation and analysis of LCA method, there were limitations in our study inevitably: (1) Due to the limited tools, some materials could only be replaced by similar materials, such as synthetic leather material is a kind of complex material. But in this study, it was only considered as its main material polyurethane for calculation, which was a certain deviation from the actual, but still had a good direction guidance ability. We will improve the conditions of the study to carry out more detailed calculation of the various materials. (2) Our study only analyzed the environmental impact of the shoes, but it lacked the comparative analysis between the various production processes. Based on this study, the later research can establish models of other kinds of craft shoe-making and carry on the comparative analysis to find out the more environmentally-friendly process. Furthermore, some theoretical guidance should be made to upgrade shoe-making enterprise and even the whole industry.

According to our research above, we developed a protocol for footwear industry, such as how to collect the field data during the shoe making process and how to calibrate those data for LCA analysis. Secondly, we focused on pump shoes, which is a basic model in fashion shoes. Furthermore, according to this basic model, we could compare how the design or style in other fashion shoes affected the LCA results and then to develop a method to predict the LCA of other fashion shoes by means of simulation. The last one is that we used sourcing data of LCA from local database, which made the LCA results be more coordinated.

CONCLUSIONS

Overall, by LCA method, we quantitatively evaluated the environmental impact of the manufacturing process of women's single shoes. We can further summarize that while considering the environmental effects from the shoe manufacturing process, we shall not ignore the environmental impact whilst producing the

binder and the last. Moreover, reducing binder usage or updating the shoe making technology, and recycling the last can be an efficient way to reduce the environmental effects from the shoe making industry.

Acknowledgements

The authors appreciated supports from IKE in assisting LCA model and results interpretations; meanwhile we also thank the financial support from Natural Science Foundation of China (31700813) and supported by Sichuan Science and Technology Program (2020YFH0068).

Conflicts of Interest Statement

There are no conflicts of interest with other authors and institutions. No subjects or animals were included in this study. Neither participants nor informed consent were included in the study.

REFERENCES

1. APICCAPS, *World Footwear Year Book*, Portugal, Porto: Oiaria do Porto, **2019**.
2. Zhang, J., Research on the whole life cycle engineering of footwear products, Tianjin: Tianjin University of Science and Technology, **2012**.
3. Lu, G., Dong, L., Yanzhen, S., Investigation on the Occupational Hazards of Mixed Benzene Operation Factory in Jinshan District, Shanghai, *Labour Medicine*, **2001**, 05, 293-294.
4. Yang, G.-J., Qin, H., One case of leukemia detected in shoes factory physical examination, *Chinese Journal of Industrial Hygiene and Occupational Diseases*, **2005**, 03, 177.
5. Wu, P., Zhao, T., Zhang, S., Investigation of benzene harm in a leather shoes factory, *Occupational Health and Injury*, **2006**, 01, 80-81.
6. Feng, R., Lu, Y., Li, W., Organic solvent exposure survey in leather shoes manufacturing industry in Heshan, *Industrial health and occupation*, **2015**, 04, 41, 290-291.
7. Deng, Q., On the environmental pollution and protection of the shoe industry in China, *Chinese and Foreign Shoes*, **2000**, 4, 32-34.
8. Shao, L., Warning on volatile organic compounds (VOCs) in the footwear industry, *Chinese and Foreign Shoes*, **2017**, 8.
9. Shao, L., Recall case study of footwear recalls in 2017, *Chinese and Foreign Shoes*, **2018**, 000, 002, 27-28.
10. Yiping, D., Tian, Y.S., Narita, C., LCA general discussion, Industry Environment Management Association, Ministry of Publications, **2007**.
11. Cheah, L., Duque Ciceri, N., Olivetti, E., Matsumura, S., Forterre, D., Roth, R., Kirchain, R., Manufacturing-focused emissions reductions in footwear production, *J Clean Prod*, **2013**, 44, 18-29, https://doi.org/10.1016/j.jclepro.2012.11.037.
12. Mila, L., Domenech, X., Rieradevall, J., Fullana, P., Puig, R., Application of life cycle assessment to footwear, Int J Life Cycle Assess, **1998**, 3, 4, 203-208, https://doi.org/10.1007/BF02977570.
13. Barling, R.L., Carbon Footprint of a Shoe Produced by an International Enterprise with an Implemented Corporate Social Responsibility Strategy, Taking PUMA AG as Example, **2008**, Fachhochschule fur Technik und Wirtschaft, Berlin, Germany.
14. Li, R., A study of life cycle evaluation in leather shoe factory, **2017**.
15. Serweta, W., Gajewski, R., Olszewski, P., Zapatero, A., Lawinska, K., Carbon Footprint of Different Kinds of Footwear -- a Comparative Study, *Fibres Text East Eur*, **2019**, 27, 5(137), 140-149, https://doi.org/10.5604/01.3001.0013.2907.
16. Naldzhiev, D., Mumovic, D., Strlic, M., Polyurethane insulation and household products – A systematic review of their impact on indoor environmental quality, *Build Environ*, **2020**, 169, https://doi.org/10.1016/j.buildenv.2019.106559.

17. Njati, S.Y., Maguta, M.M., Lead-based paints and children's PVC toys are potential sources of domestic lead poisoning – A review, *Environ Pollut*, **2019**, 249, 1091-1105, https://doi.org/10.1016/j.envpol.2019.03.062.