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Yead Mahmud, Md. Rashed-Ul-Islam, Md. Obaidul Islam, Tanvir Siddike Moin, Khandaker Tanzim Rahman

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Assessment of the Carbon Footprint and VOCs Emissions Caused by the Manufacturing Process of the Footwear Industry in Bangladesh

Yead MAHMUD, Md. RASHED-UL-ISLAM*, Md. Obaidul ISLAM, Tanvir Siddike MOIN, Khandaker Tanzim RAHMAN

Institute of Leather Engineering and Technology, University of Dhaka, Dhaka-1209, Bangladesh
*rashed.ilet@du.ac.bd

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ABSTRACT

Every industry has an impact on the environment, either good or bad, and leather and footwear industries are no exception. For the footwear industry, the main environmental impacts are the releasing of volatile organic compounds (VOCs) and solid wastes. The pressure of reducing harm to the environment is coming from both the consumers and the legislation. CO_2 and VOCs are hazardous to human health and also trigger serious environment problems, such as ozone layer depletion, offensive odour, photochemical smog, acid rain and many others. Adhesives, finishing products and cleaners contribute to VOCs emissions in the footwear manufacturing industry. VOCs emission may also arise from primers, separating agents, printing inks or finishing pastes. Some most commonly produced VOCs in the footwear manufacturing industry are benzene, toluene, styrene, ethylene, xylene, acetaldehyde, formaldehyde, methyl ethyl ketone, chlorobenzene, phenol etc. All of these cause severe health problems in humans and have an adverse effect on the environment. An increasing number of footwear factories adversely affects the environment and human health. One of the largest environmental impacts of shoe industry comes from the manufacturing stages of the shoe's life cycle. This study was carried out to measure the carbon footprint and VOCs emissions among ten selected footwear factories. The results revealed that the total energy footprint for one pair of shoes is 18.004826 MJ, the water footprint is 8.37167 litres and the carbon footprint is 9.174979 kg CO_2 eq. The highest impact in terms of the carbon footprint lies in the shoe manufacturing process with a 5.85109 eq. CO_2 (kg). The total VOCs consumption for a fashion shoe is around 36.5 g/pair on average. There should be an initiative taken with the aim of adjusting the choice of methods, materials, machines and the monitoring systems as well as the safety policy for the workers and the environment.

KEYWORDS

Carbon footprint, VOCs, Footwear, Pollution

INTRODUCTION

The footwear industry is not considered particularly harmful for the environment. However, producing and using shoes on a grand scale has the potential for generating significant harmful environmental impacts. According to the 'World Footwear Yearbook' the worldwide production of footwear reached 23.0 billion pairs. Bangladesh has been ranked eighth in terms of footwear production in the world in 2016, producing

370 million pairs of shoes or 1.6 percent of the total output. A Study shows that a typical pair of running shoes made of synthetic materials is 14 ± 2.7 kg of CO_2 eq. during its life cycle. A single shoe can contain 65 discrete parts that require 360 processing steps for the assembly [1]. These processes involved in footwear manufacturing, like pattern making, cutting, sewing, lasting and finishing, are all associated with different types of health hazards. But most insidious of all are the toxic organic solvents which are particularly present in the adhesives and also in the hardeners, cleaning solutions and degreasers used in the shoemaking process [2]. The footwear sector of Bangladesh is now at a stage where it can have a larger role in country's export fortunes in the next decade. According to the Leather Goods and Footwear Manufacturers and Exporters Association of Bangladesh (LGFMEAB), more than 51 of the foreign companies have expressed their interest to establish joint-venture footwear units in Bangladesh [3]. Bangladesh has become an attractive destination for investors from different countries due to some influencing factors like low labour cost, availability of raw materials, good quality product, exchange rate advantage etc. [4]. The increasing number of footwear factories negatively affects the environment and human health. One of the largest environmental impacts of shoes comes from the manufacturing stage of shoe's life cycle; and surprisingly, the majority of the people who have participated in a survey on this subject believes that shoes only have an environmental impact after they have been thrown out. In the stage of manufacturing, vast amounts of machines and chemicals are required to produce shoes. To power these machines, a great amount of fossil fuels is needed and these fossil fuels produce greenhouse gases when burned. Coal is one of the sources of energy that is very often used to power these factories as it is quite cheap compared to oil or other sources of energy. Burning coal produces carbon dioxide, which eventually ends up in our atmosphere, contributing to the greenhouse effect [5].

The footwear manufacturing process includes exposing a number of harmful compounds, such as volatile organic compounds, toxic organic solvents, hydrocarbons, adhesives, shoe polishes etc. [6]. VOCs are injurious to human health and also trigger serious environmental problems, such as ozone layer depletion, offensive odour, photochemical smog and acid rain. Adhesives, finishing products and cleaners contribute to VOCs emissions in the footwear manufacturing industry. VOCs emissions may also arise from primers, separating agents, printing inks or finishing pastes. Some of the most commonly produced volatile organic compounds in the footwear manufacturing industry are benzene, toluene, styrene, ethylene, xylene, acetaldehyde, formaldehyde, methyl ethyl ketone, chlorobenzene, phenol etc. All of these cause severe health problems in humans and have a negative effect on the environment as well. Therefore, up-to-date information is essential for the industry owners to take proper action in preventing and minimizing the load of pollution caused by the carbon footprint and VOCs emissions. The aim of this paper was to measure the amount of the carbon footprint and VOCs emissions caused by the footwear industry and assess its current state.

EXPERIMENT

Materials and Methods

For this research 10 factories for the carbon footprint and VOCs emissions analysis were selected. The study was carried out from October 2018 to April 2019. The geographical locations of the factories are from Dhaka to Gazipur.

The LCA measuring SimaPro software version 8 was chosen for measuring the carbon footprint and the VOC Environmental Meter (PCE-VOC) {measuring range 0.00 … 9.99 ppm or mg/m^3, resolution 0.01 ppm or mg/m^3, accuracy ± 5% of measured value} was used to measure the amount of volatile organic compounds emissions from the selected footwear factories.

Measurement of Carbon Footprint

The carbon footprint was measured by breaking down the materials needed for producing one pair of shoes and also its parts. After calculating the mass of each and every material, the corresponding carbon emission was found by determining the equivalent amount of CO_2 with the help of the SimaPro software.

Measurement of VOCs

VOCs measurement was done by using the VOC Environmental Meter (PCE-VOC) in the footwear industry environment. The values were displayed in ppm.

VOCs Measurement Data Analysis

The measurement data for the carbon footprint and VOCs emissions was processed and analysed in the Microsoft Excel computer program. Each value was taken several times and then the average was determined.

RESULTS AND DISCUSSION

The carbon footprint and VOCs emissions values were taken from 10 different factories. Based on our findings the average normalized values are shown in Table 1, 2, 3 and 4 as a calculated average from those 10 selected factories.

A breakdown of shoes' mass by part and by material is illustrated in Table 1 and 2. The paper in the packaging, upper leather, lining leather (pig), fabrics and the interlining used in shoes' upper part, EVA in the midsole, and PU in the outsole made up the majority (62.2%) of shoes' mass. The breakdown of materials is also shown in Figure 1. Calculating the quantity of materials with their respective emissions' factors [7], it was determined that 9.174979 kg CO_2-eq. of greenhouse gases was emitted in the material-processing phase of the shoemaking process.

Shoe designers should focus on upper and sock lining materials, specifically textiles, polyester, and polyurethane, in order to reduce the materials' impact.

Table 1. Breakdown of materials of a reference shoe

Footwear Manufacturing	Quantity (per pair)
Materials	Mass (g)
Cow leather	135
Lining leather (pig)	90
Fabrics and interlining (textile)	44
Glue	167
EVA	22
Solvent	50
Paper	372
Lace	15
Sole (PU)	268
Water per pair, litre	334
Energy per pair, MJ	3.31

The following Table 2 visualizes the results obtained through our research, the database of the SimaPro software.

Table 2. Footprint of materials for one pair of shoes

Processes	Materials	Quantity (kg)	Footprints for one pair of shoes		
			Energy (MJ)	Water (l)	CO2 eq. (kg)
Textile production	Fabric and interlining	0.03721	1.55623	2.47092	1.15420
Rubber production	Sole	0.38010	0.76028	2.44021	0.98013
Plastic production	EVA	0.02486	0.02275	0.09765	0.04987
	Laces	0.01309	0.06989	0.39428	0.06798
Pig leather production	Pig leather	0.09298	5.90E-05	n.d.	0.00198
Cow leather production	Cow leather	0.13987	0.18185	1.17219	0.01730
Chemicals production	Glue	0.18001	n.d.	n.d.	0.13445
	Solvents	0.04899	0.02399	0.07985	0.11586
Paper production	Paper	0.26985	12.13855	1.67823	0.80129
Shoe manufacturing		1 pair of shoes	3.25101	0.03712	5.85109
Transport 15 km (incl. fuel cons.)			2.17E-04	1.22E-03	6.29E-04
Total			18.004826	8.37167	9.174979

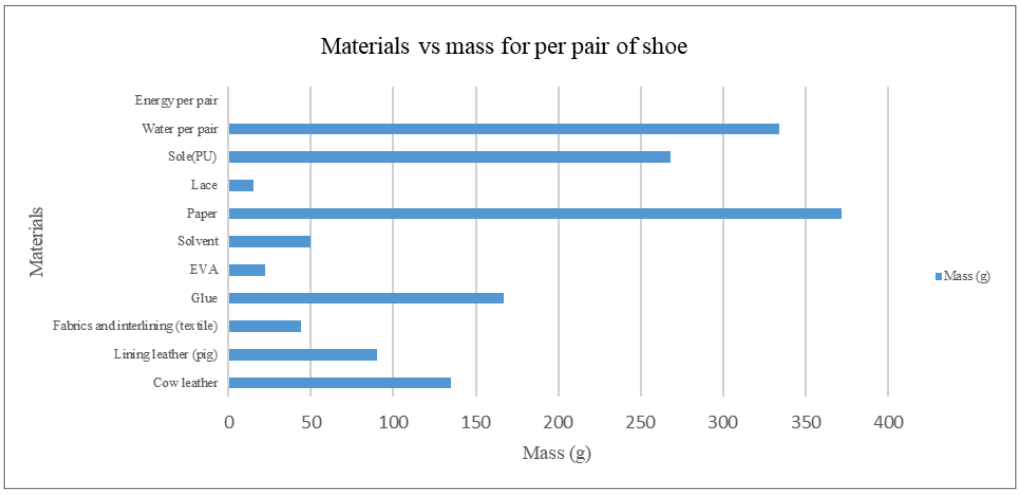

Figure 1. Materials vs. mass per pair of shoes

Carbon Footprint

In Table 2, the calculations were based on the weight of each material. The total energy footprint is 18.004826 MJ; the total water footprint is 8.37167 litres; and the total carbon footprint is 9.174979 kg CO_2 eq. The highest impact in the energy footprint is in the production of paper with a 12.13 MJ, which is invested into the production of the box and the paper packaging. The footprint for one pair of shoes is illustrated in Figure 2.

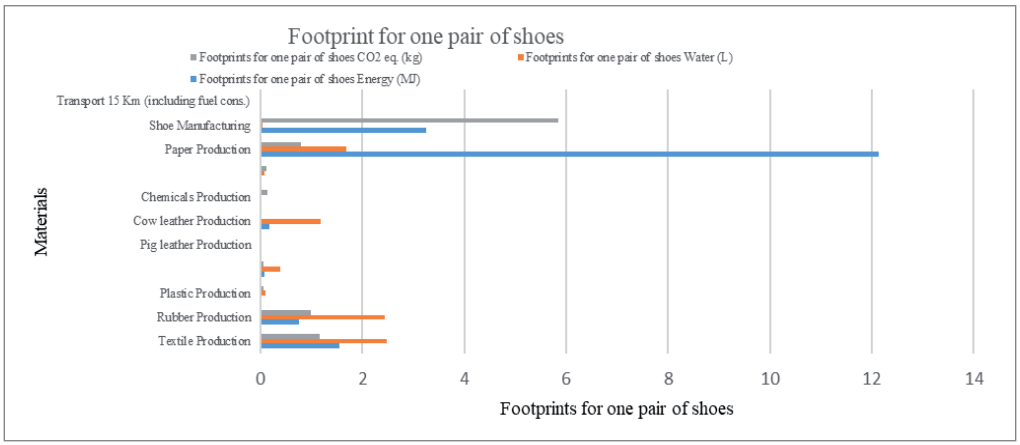

Figure 2. Footprint of materials for one pair of shoes

The smallest energy footprint is in the production of pig leather, 5.90 E-05 MJ. The two largest water footprints are in the production of the textile fabric and the interlining (2.47 litres) and in the rubber production, needed for making the soles out of PU (2.44 litres). The total carbon footprint is 9.17 kg of carbon dioxide equivalents. The greatest impact in the carbon footprint is in the production of shoe manufacturing with a 5.85 kg of CO_2 equivalents.

Water and Energy Resource Used

The water and the energy footprint is showed above with the carbon footprint results. Moreover, the general data used can be seen in Table 3.

Table 3. Normalized values of water and energy for one pair of shoes

Energy use per pair	3.31 MJ
Water use per pair	0.036 l
Incineration	20-50%
Reuse rate	3-7%
Repair rate	2-6%

The energy required to produce one pair of shoes was determined to be 3.24 MJ and the water footprint was 0.036 L. The incineration rate is 20-50%. The reuse rate is 3-7%. The repair rate is 2-6%.

VOCs Emissions

The total VOCs consumption for footwear varies depending on the type of footwear being produced. In our study, fashion shoes have a solvent consumption of 36.5 g/pair.
For fashion shoes (see Table 5) the process of sole assembly (joining the “fashion materials”) generates the highest amount of solvents emissions in the whole shoemaking process (>40%). The finishing of the shoes – colouring, brilliant varnishing etc. – also generates high emissions (~20%). VOCs emissions caused by the process of making fashion shoes is illustrated in Figure 3.

Table 5. Breakdown of materials of a reference shoe

Operation	VOCs Input (g)	VOCs Input (%)
Stitching	2.30	6.30
Homogenizing	0.30	0.82
Heal Seat	5.10	14.00
Preparing	0.10	0.27
Sole Preparation	4.50	12.32
Sole Assembly	15.30	41.20
Printing	1.60	4.38
Finishing	6.80	18.63
Cleaning	0.50	1.36
Total	36.50	100.00

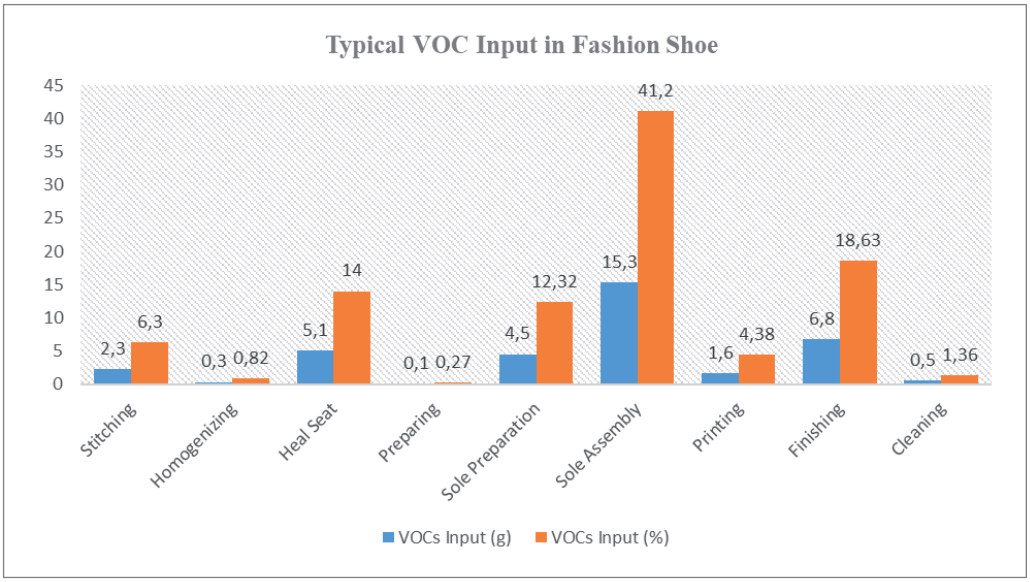

Figure 3. Typical VOCs input for a fashion shoe

CONCLUSION

The dangers of VOCs were identified some years ago and sufficient concern was raised in order to ensure the development of the legislation. The carbon footprint and VOCs can aggravate the condition of both the environment and human beings. This study provides the quantitative information about the VOCs and the carbon footprint, such as that the total energy footprint for one pair of shoes is 18.004826 MJ, the water footprint is 8.37167 litres and the carbon footprint is 9.174979 kg of CO_2 equivalents. For one pair of fashion shoes, VOCs are around 36.5 g/pair on average. But these factors depend on some sub-factors, such as whether the VOCs arise from adhesives, finishing products or cleaners etc. If the amount of these factors exceeds the standard value, then it can adversely affect our society. Once the hazardous elements and their risks have been identified, further steps can be taken in order to either eliminate hazardous materials and processes or find less hazardous substitutes. The next step is then to minimize the emissions from the factories into the environment by suitable means.

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