Life Cycle Assessment of Leather Shoe Manufacturing Process Based on Simapro

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Abstract

The Eco-indicator 99 ecological index was used to do the life cycle assessment of the manufacturing process of cotton-padded shoes [leather winter shoes with cotton or fur padding] and the 'nude' shoes [ladies court shoe styles often with a pigskin lining]. The study was based on the total life cycle assessment (LCA) and the SimaPro software. The results showed that the basic skill stages of nude/court shoes and the vamp process of the same shoes had the greatest impact on the environment. The effect was 45.66 % and 52.05 %,respectively. The weighted and single value results for nude/court leather shoes and cotton-padded/winter shoes were concentrated on the effect on human health, reaching 78.62% and 79.01%, respectively. In addition, the cotton-padded/winter shoes had the largest contribution.

1 INTRODUCTION

With the improvement of people's living standards, the consumption of shoes in China has increased greatly. According to statistics, in 1950, one person just needed one pair of shoes per year, this had increased to 2.6 pairs of shoes in 2005.[1] So there was rapid development of the footwear industry. The leather shoe manufacturing process would produce large amounts of wastes such as the leather scrap, waste plastics, rubber, and the exhaust gases of the adhesive solvent volatilisation. The wastes may have caused much

A

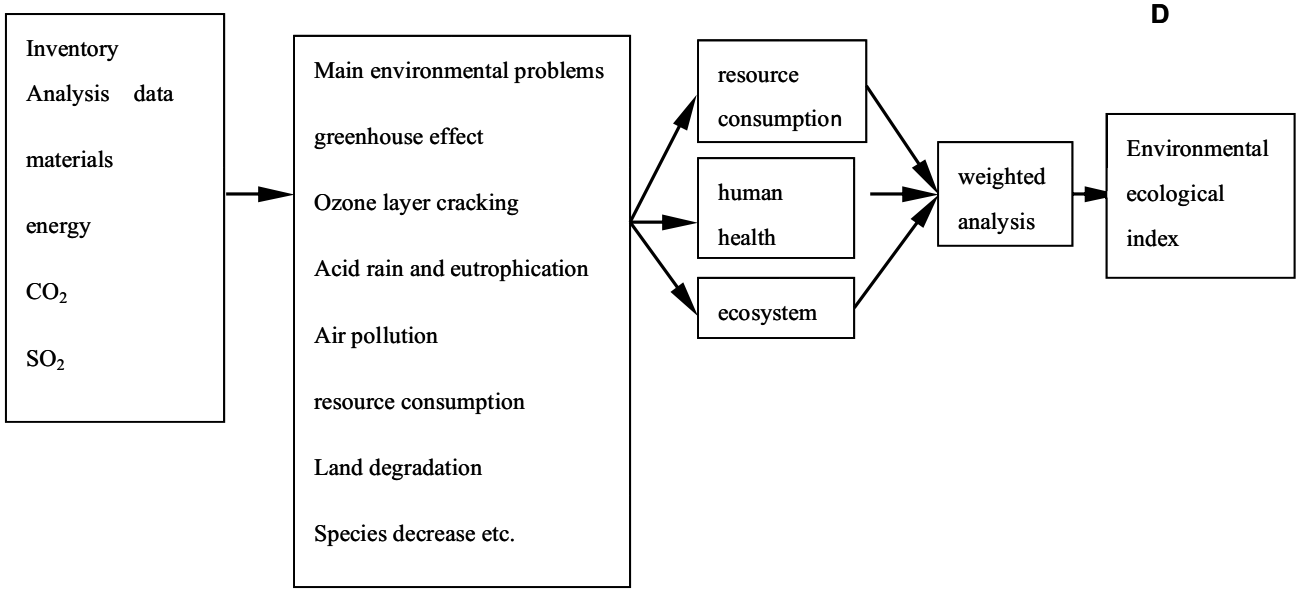
B

C

C

D

'Cotton Shoes' are cotton-padded leather shoes for winter wear. Usually, cotton-padded shoes are lined with pigskin or fur. (see illustrations A, B and C). 'Single Shoes' may be referred to as 'nude shoes' [ladies court shoes] usually lined with pigskin and are intended for spring or autumn wear (see C and D).



Quantitative analysis model of eco-indicator.

harm to human health and the environment.[2] Traditional design of footwear rarely considered questions such as the recycling of footwear waste and its whole life cycle assessment and other issues.[3]

Therefore, information about solutions of environmental pollution problems was urgently needed to meet the rapid development of the leather shoe manufacturing industry.

LCA (Life Cycle Assessment) is a compilation and evaluation of the input, output, and potential environmental impacts of a product.[4] This method is widely used to evaluate the environmental compatibility of products.[5-6]

This study explored the life cycle assessment of the manufacturing process of cotton-padded/winter shoes and nude/court shoes. It was based on the total life cycle assessment (LCA) and the SimaPro software. The manufacturing operation of the shoes was quantified. The analysis mainly focused on resources, energy consumption and pollutant emissions. Meanwhile, the life cycle weighted results and single value analyses were compared between the two kinds of shoes. The effect of wastes on the environment generated by the LCA system analysis of the shoe-making process will be conducive to the implementation of cleaner production, improvement of the environmental management level of the shoe factory and the corporate image and expansion of the market share.

2.RESEARCH METHODS AND DATA COLLECTION

2.1 Environmental impact assessment method based on LCA

The Eco-indicator 99 ecological index was used to do the life cycle assessment of the manufacturing process of the two kinds of shoes. It was based on SimaPro (academic version) 7.

SimaPro Software

The SimaPro software was developed by Netherlands PR Consultants company and it was one of the most widely used LCA software applications in the world. SimaPro 8.1 could help people to collect, analyse and evaluate environmental information. According to the ISO14040 series standards, a complex product life cycle could be simulated and analysed more systematically and transparently.[8-10] SimaPro could provide an inventory of databases, including a number of commonly used processes. Meanwhile, it could provide a variety of important impact assessment methods.[11-12]

The Impact assessment of the study used the Eco-indicator 99 impact evaluation indicator model provided by the SimaPro software. This method divided the data of the product inventory analysis into the various environmental problems, according to the environmental mechanism and categories. All of the environmental problems would be normalised, and ultimately attributed to resource consumption, human health and ecosystem damage. On the basis of the certain weighted coefficients, we could obtain the ecological index value of the product. The data analysis process model is shown in Fig. 1.

2.2 Key parameters and data sources

LCA evaluation is divided into 4 stages: the determination of the target and scope, inventory analysis, impact assessment and interpretation of results. This paper mainly studied the impact of the manufacturing process of the shoes on peopleís health and the environment.

The research included cutting, vamp and the sole attachment process. It covered the substrate, supplementary materials, adhesives and energy consumption *etc*., with a pair of shoes as a functional unit. Of course, this study does not include energy and resource consumptionís contribution to environmental pollution occurring during raw material production, plant construction and machine production processes.

The data in the LCA inventory analysis is composed of real and background data.[13] Real data can be obtained directly from the production unit or experience of the evaluation object.[14] Background data is universal, this refers to the life cycle inventory data of raw materials, energy, transportation, waste disposal *etc*. that support the production of the evaluation object, usually the average data of the country or region is used.[15]

Leather shoe manufacturing process technology is relatively mature. The production line of the factory is complete, but the degree of mechanisation is not high in some processes, such as some parts of the process, the bottom attachment stage, and cleaning, etc. So, it requires skilled manual operation by the workers to reach production requirements. The real data for this paper is actually collected from a shoe-making enterprise in Fujian, China. After reading the relevant literature, as well as screening and testing, this paper was chosen to use the Ecoinvent database in the impact evaluation phase (LCIA).[16] The reason for choosing the Ecoinvent database is that it covers a wide range of data, including unit processes, system processes, system boundaries and assignments. A large number of Ecoinvent background reports are available on the Ecoinvent website or on the Ecoinvent CD (see Appendix).

3 RESULTS AND DISCUSSION

3.1 Inventory analysis

3.1.1 Life cycle inventory of the cotton-padded/winter shoes and the nude/court shoes

All life cycle system input and output inventory of a pair of nude/ court shoes processes are shown in Tables I, II and III

All life cycle system input and output inventory data of a pair of cotton -padded/winter shoes processes are shown in Tables IV,V and VI

TABLE I
Data for nude/court shoes – Cutting process

Input stage		Output stage	
Raw material (g)		Products and by-products (g)	
Creamy white serpentine sheepskin*	105.1	Vamp	60.0
The first layer of pink dyed pigskin lining**	39.0	Vamp lining	24.0
The split of pink water dyeing pigskin lining	11.8	Shoes accessories	4.0
Rose gold mirror PU	4.7	Insoles	3.0
White adhesive interlining	23.6	Heel	27.0
619# thermoplastic heel	47.6	Tipping	8.8
618# thermoplastic heel	11.0	Vamp strip	4.8
Energy consumption (kwh)		Leftover bits and pieces	111.2
Swing arm machine [clicking]	0.05		
Cutting machine	0.03		

Note: * Serpentine is a leather style texture. Usually this pattern is embossed at a temperature of around 120°C. In addition, there is a similar process using hot foil or created by sewing.
**This is grain layer pigskin drum dyed pink used for the lining of nude/court shoes.

TABLE II
Data for nude/court shoes – Vamp process

Input stage		Output stage	
Raw material (g)		Products (g)	
Vamp	60.0	Uppers	106.0
Vamp lining	24.0	Solid waste (g)	
Shoes accessories	4.0	Instep folding	1.3
Insoles	3.0	Shoe lining waste	2.0
Heel	27.0	Heel scrap	0.1
Tipping	8.8		
Vamp strip	4.8		
Adhesive (g)		Waste gas (g)	
Powder to mortar	3.0	Powder to mortar gas	2.1
Neoprene	4.0	Neoprene gas	2.8
Vinyl acetate	1.0	Vinyl acetate gas	0.7
Energy consumption (kwh)			
Sewing machine.	0.0033		
Hemming machine	0.0123		
tipping machine	0.0055		
Drying line machine	0.0478		
Trimmer machine	0.0187		
Pounder machine	0.0044		
Line machine	0.0494		

SimaPro, through the input of the raw materials and energy, can form a complete logistics flow structure. The tree structure chart of the two kinds of shoes are shown in Figs. 1 and 2. The red line thickness represents the proportionate energy loss.

3.1.2 The result: Discussion interpretation of the inventory analysis

According to the purpose and the analysis of the data in the production process of leather shoes, we classified the results of leather shoe production inventory and obtained the impact evaluation. It was based on Eco-Indicator 99. The impact analysis categories included characterisation, risk analysis, normalisation, weight and single value.

The object of the characteristic analyses were carcinogens, atmospheric organic pollution, atmospheric inorganic pollution, climate change, radioactive substances, ozone layer destruction, biological toxicity, acidification/eutrophication, land use, depletion of mineral resources.

The weighted analysis was used to evaluate which damages were more important according to weighted factors, and the evaluation categories included human health, ecological quality and resource loss.

The single value analysis included characterisation, risk analysis, normalisation and weight (relative importance) which could be used as a reference for decision makers to consider whether the raw materials

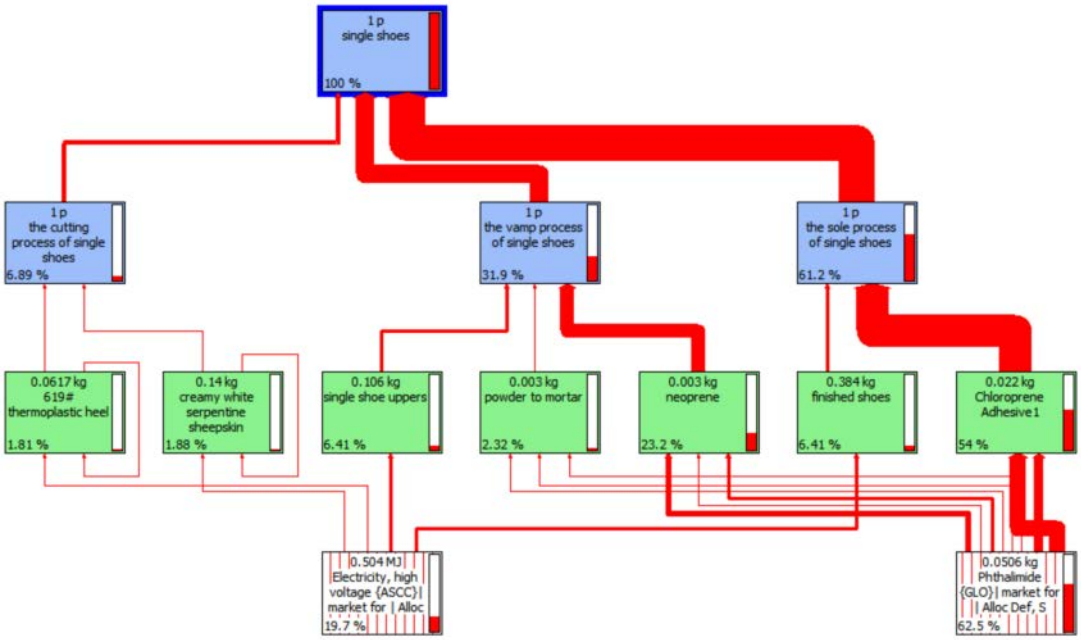


Figure 1. The tree structure chart of the nude/court shoes.

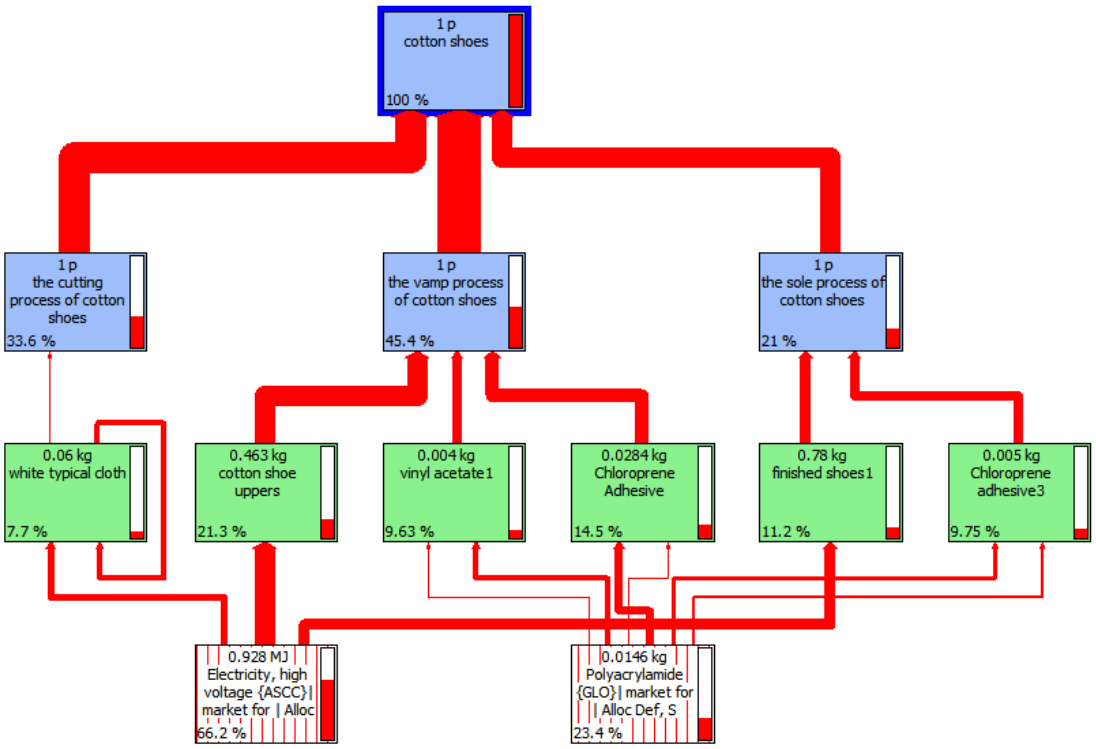


Figure 2. The tree structure chart of the cotton-padded/winter shoes.

and processes of leather shoes were friendly to the environment.

3.2 Impact evaluation

3.2.1 The characterisation and the weighted results for the nude/ court shoes

The result of the characterisation is the parameter that reflects the absolute quantity of pollutants in the process of shoe making. On the basis of the nude/court leather shoes production inventory, the SimaPro software was used to calculate the characteristic and weighted results of the life cycle of each pair of shoes, and the results are shown in Figs. 3 and 4.

According to the environmental impact of the contribution rate, the sole process , cutting process and the vamp process accounted for 61.2%, 6.89% and 31.9%. For carcinogenic substances and organic pollutants, the environmental impact of the sole process contributed the most, reaching 81.58% and 90.34%. At this stage, large amounts of adhesives were used and they produced carcinogenic and atmospheric organic pollutants. The environmental impact of land use in this stage also accounted for 54.72%.

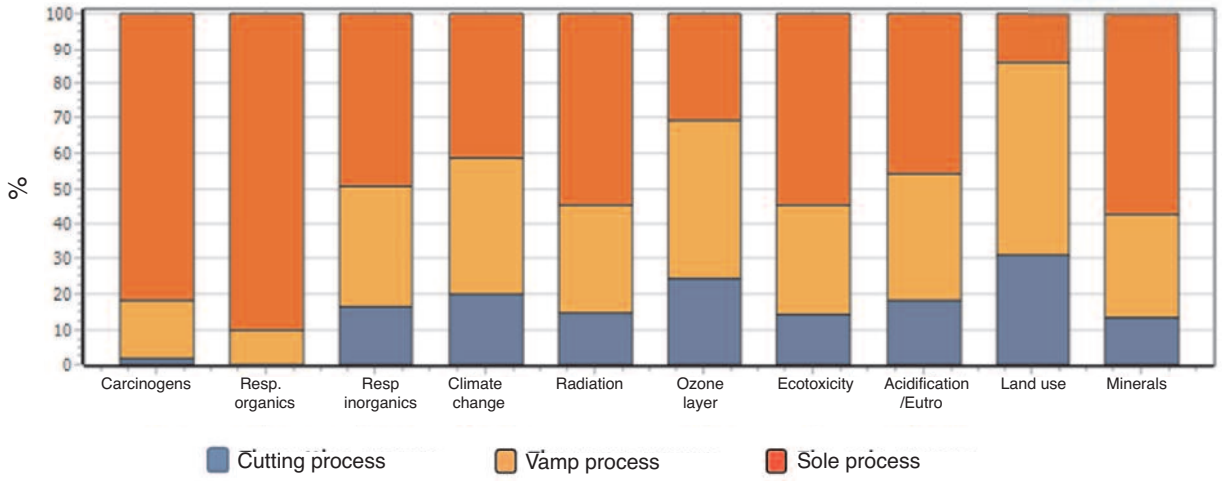


Figure 3. The characteristic results of the life cycle of a pair of nude/court shoes.

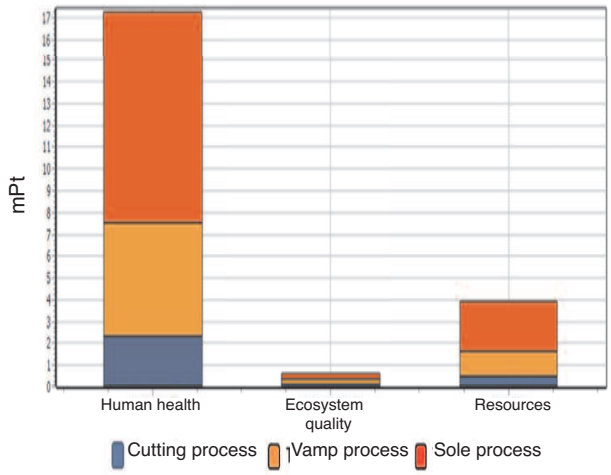


Figure 4. The weighted results of the life cycle of a pair of nude/court shoes.

Note: Figures 3 and 4 and others show a measure of the environmental impact. In this paper, in the manufacturing process of shoes there are ten parameters for the environment, such as carcinogens, respiratory organics, respiratory inorganics, climate change effects, radiation, ozone layer damage, ecotoxicity, acidification, land use, minerals. These parameters are finally normalised into three indicators, including human health, ecological quality, and resources.'mPt' are units representing the total impact on the environment. For example, it gives the scores of environmental impact indicators of various elements in the production process of nude leather shoes, including energy consumption, adhesive, excipient.

Drawn from the above analysis, in the nude/ court leather shoe making process, the greatest impact on the environment was mainly from the adhesive which was used in the sole stage. And the second largest was the vamp process because of the power input.

Therefore, the main impact presented on the destruction of the ozone layer and land occupation is shown in Fig. 4.

So we can see from Fig. 4, the greatest impact on the environment was mainly the cutting process in the nude/ court shoe manufacturing, it reached 79.01%, this was followed by the loss of resources. For the three impact categories, the sole process contribution was the largest and the cutting stage was the minimum. Through the analysis, the effects on human health were the main consideration in the nude/court shoe manufacturing. So the key control procedure was the sole stage.

3.2.2 The characterisation and the weighted results of the cotton-padded shoes

The weighted and characteristic results of the life cycle of a pair of cotton-padded shoes are shown in Figs. 5 and 6.

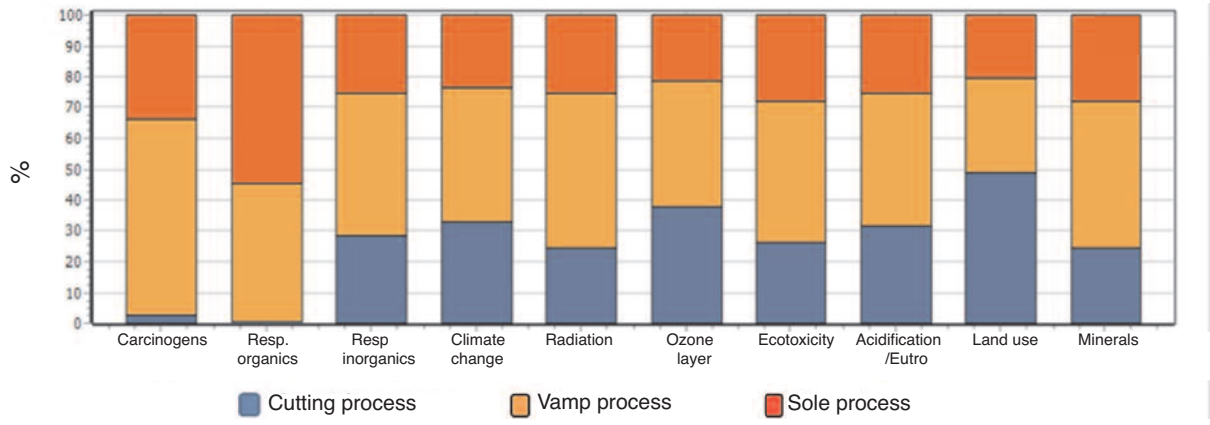


Figure 5. The characteristic results of the life cycle of a pair of cotton-padded/winter shoes.

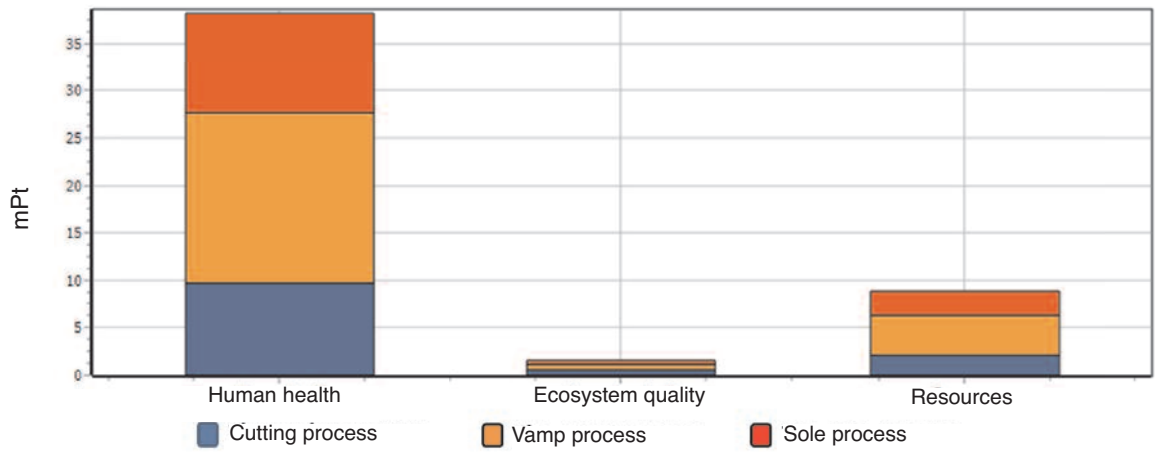


Figure 6. The weighted results of the life cycle of a pair of cotton-padded/winter shoes.

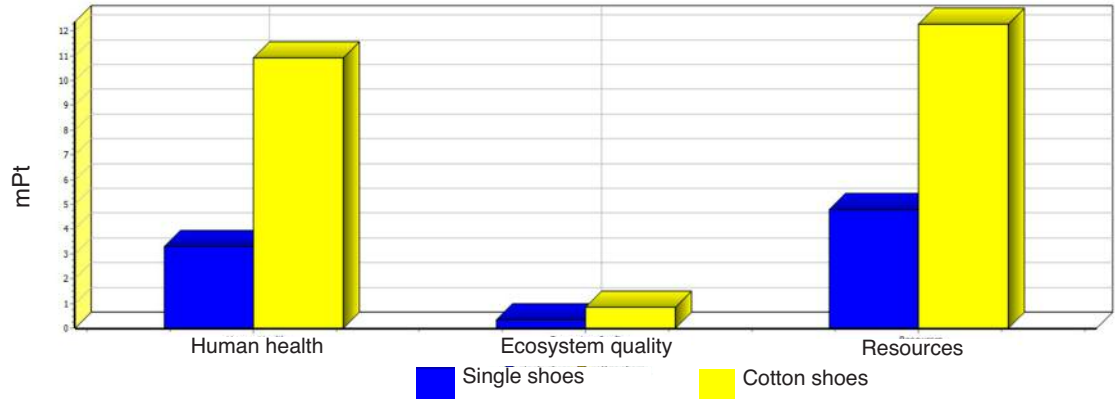


Figure 7. The weighted results of the life cycle of the shoes. NB Blue / single shoes = court shoes. Yellow cotton shoes = padded winter shoes.

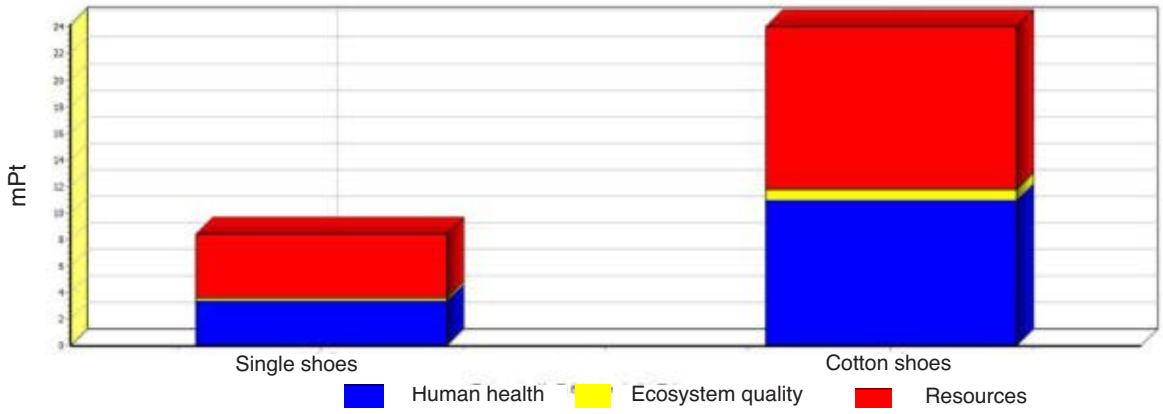


Figure 8. The single results of the two shoe styles. Single shoes = court shoe style; Cotton shoes = padded winter shoes.

The quantitative relationship between the process and environmental impact in the production of leather shoes can be seen from Fig. 5. According the contribution to the environmental impact, the vamp process, cutting process and the sole process accounted for 45.4%, 33.6% and 21%. Concerning carcinogenic substances and organic pollutants, the environmental impact of the cutting process contributed scarcely 2.70% and 0.46%. This stage had the greatest impact on land use, reaching 48.89%.

In the vamp process, carcinogenic substances had the greatest impact on the environment and it accounted for 63.52%. That was due to the complex raw materials and the large use of adhesives.

In the sole process, due to the grinding impurities and the volatilisation of adhesive, the impact on the atmospheric organic pollutants reached 54.53%.

From the above analysis, in the process of cotton-padded/winter shoes production, the adhesive and grinding impurities had the biggest impact on the environment. The leftover material had the greatest impact on land use in the cutting process.

The life cycle of weighted results is shown in Fig. 6. The figure also shows that the effect of the cotton-

TABLE III
Data for nude/court shoes – Sole process

Input stage		Output stage	
Raw material (g)		Products (g)	
Upper	106.0	Finished shoes	383.7
Heel	27.0	Solid waste (g)	
interfacing	2.5	Head of mill	0.9
Shoe heel	74 .0	Crampon waste	2
Latex pad	3.0	Feathering head of mill	11.7
Outsole	63.4		
Midsole	108.0		
Inner sole	3. 0		
Crampon [metal components]	1.9		
Adhesive (g)		Waste gas (g)	
Chloroprene adhesive	11	Chloroprene adhesive gas	7
Vinyl acetate	7	Vinyl acetate gas	4.8
Finishing (g)			
Sponge	0.3		
Fillers	13.3		
Shoe box	301		
Energy consumption(kwh)			
Lasting pincers	0.0165		
Counter lasting machine	0.0057		
Counter preforming machine	0.0127		
Edging machine	0.0089		
Heel nailing machine	0.0017		

TABLE IV
Data for cotton-padded/winter shoes—Cutting process

Input stage		Output stage	
Raw material (g)		Products and by-products (g)	
Nativo Black*	452.3	Toe	76.0
Breathable Po Yf**	40.6	Zipper strip	8.0
Black velvet	178.	Heel piece leather	69.0
Black PU	8.1	Shoe strip	25.0
2MM ribbon	9.9	Boot legs	93.0
White typical cloth	20.1	Accessories	6.4
White lining cloth	13.4	Vamp lining	140.0
White lining glue cloth	3.5	Lining cloth	29.2
605#thermoplastic heel	23.6	Heel	18.9
Thermoplastic pieces	10.7	Tipping	8.5
Bastard cut elastic band	12.4	Sock liner	8.0
Leftover bits and pieces	290.6		
Energy consumption (kwh)			
Swing arm machine	0.07		
Cutting machine	0.04		

*Nativo Black is a style of black leather.
**Breathable Po Yf is a synthetic shoe material

padded/winter shoes process on human health was the largest, reaching 78.62%. And that the vamp process had the largest impact of the three factors. The sole and the cutting process contribute almost the same. It was concluded that the influence of the cotton-padded shoes manufacturing process on human health should be considered comprehensively. Meanwhile, we need to focus on the analysis of the vamp process.

3.2.3 Comparative results of nude shoes and cotton-padded shoes

By using the method of comparative analysis, we compared the risk analysis and single value of the two kinds of shoes. The results are shown in Figs. 7 and 8, respectively.

Figure 7 shows that for both shoe styles the weighted results are mainly concentrated in the human

TABLE V
Data for cotton-padded/winter shoes—Vamp process

Input stage		Output stage	
Raw material (g)		Products (g)	
Toe	76.0	Uppers	463.3
Zipper strip	8.0	Solid wastes (g)	
Heel piece leather	69.0	Instep folding	1.3
Shoe strip	25.0	Shoe lining waste	2.0
Boot legs	93.0	Edging	0.7
Shoes accessories	6.4		
Vamp lining	140.0		
Lining cloth	29.2		
Heel	18.9		
Tipping*	8.5		
Inner sole	8.0		
Reinforcing band	2.1		
Logo label	0.1		
Frog	3.0		
Adhesive (g)		Waste gas (g)	
Vinyl acetate	4.0	Vinyl acetate gas	2.8
Chloroprene adhesive	28.4	Chloroprene adhesive gas	19.0
Energy consumption (kwh)			
Mangling machine	0.0066		
Hemming machine	0.0246		
Tipping machine*	0.0110		
Drying line machine	0.0956		
Trimmer machine	0.0376		
Pounder machine	0.0088		
Line machine	0.0988		

* As shown, tipping machine is mainly used for shaping the toe cap/upper of shoes at a temperature generally controlled at 100°C.

body health section, accounting for 78.72%, followed by the resource consumption, which accounted for 18.10%, then followed by the least amount of ecological quality, which accounted for 3.18%. Concerning the influence on the human body health, the contribution rate of cotton-padded/winter shoes was larger than that for nude/court shoes. These data suggested that the environmental impact of shoe making process mainly influenced human health. Due to the input of more raw materials and power consumption, the cotton-padded/winter shoes process was the biggest contributor.

Figure 8 shows that the cotton-padded/winter shoes process had the bigger influence. For the analysis of the three major categories, the largest impact was on the human body health. The next was resource consumption and the minimum was ecological quality.

As a result for considering the footwear industryís aim for clean production, we should consider mainly the cotton-padded/winter leather shoes manufacturing process as reducing the impact on human health.

4 CONCLUSIONS

The research object of this paper was a shoe factory in Jin jiang, Fujian. And we did the life cycle assessment of the shoe-making process. Through the previous research, we drew some main conclusions which were as follows:

(1) The production of the nude/court shoes needed leather material (195.1g), auxiliary material (318.0g), adhesive (39.0g), power consumption (0.2669kwh). Then wastes for the finished nude/court shoes (381.2g), adhesive waste gas (26.5g), and the solid waste (144.4g). For the cotton-padded/winter shoes, the production needed leather material (489.4g), auxiliary material (606.4g), adhesive (61.4g), power consumption (0.6268kwh). Then we have the wastes for finished cotton-padded/winter shoes (779.6g), adhesive waste gas (40.0g), and the solid waste (276.2g).

(2) From the eigen value analysis of two kinds of leather shoes, we can see that, for the nude/court shoes, the environmental impact of the sole process contributed 52.05%, and for the cotton/winter shoes, the environmental impact of the vamp process contributed 45.66%. The weighted analysis results show that the impact of nude/court shoe and cotton-padded/winter shoe making mainly focused on effects on human health, accounted for 79.01% and 78.62%, respectively.

(3) The weighted and single results of two kinds of shoes were concentrated on the human health effects, and the influence of cotton-padded/ winter shoes was

TABLE VI
Data for cotton-padded/winter shoes—Sole process

Input stage		Output stage	
Raw material (g)		Products (g)	
Upper	463.3	Finished shoes	779.6
Heel pieces	18.9	Solid waste (g)	
Outsole	288.0	Edging	23.4
Inner sole	24.0	Crampon waste*	0.9
Sock liner	8.0	Feathering head of mill**	10.0
Heel	34.2		
Latex pad	6.3		
Adhesive (g)		Waste gas (g)	
Chloroprene adhesive	10	Chloroprene adhesive gas	7
Vinyl acetate	17	Vinyl acetate gas	11.9
Finishing (g)			
Sponge	0.3		
Fillers	13.3		
Shoebox	301.0		
Energy consumption (kwh)			
Lasting pincers	0.0165		
Counter lasting machine	0.0057		
Counter preforming machine	0.0127		
Edging machine	0.0089		
Heel nailing machine	0.0017		

* Crampon waste comprises damaged rivets, hooks *etc.* which are mainly used to fix or decorate the heels of shoes.
**The 'Fathering head of mill' is an edging machine used to roughen the edge of the material of the shoe, including the upper vamp, quarter, lining *etc*, in order to improve adhesion. [Vertical drum sander].

the bigger. For the clean production of shoe-making industry we could mainly focus on cutting leather, adhesive upgrades and other aspects, such as leather scrap recycling, the use of water-soluble polyurethane adhesive and the new hemp fibre shoes *etc*.

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Appendix 1

Ecoinvent

In 1997, the Ecoinvent centre (formerly known as the "Swiss Life Cycle Checklist") was founded in Switzerland. Ecoinvent – the world's most consistent and transparent life cycle inventory database. Ecoinvent builds on more than 20 years of experience in LCA methodology development and LCI data compilation for different industrial sectors. Since 2003, Ecoinvent has enabled companies to manufacture their products more in harmony with the environment, policymakers to implement new policies, and consumers to adopt more environmentally friendly behaviour. Ecoinvent lays the foundation for LCA study. With over 14,700 LCI datasets in many areas such as energy supply, agriculture, transport, bio-fuels and bio-materials, bulk and specialty chemicals, construction materials, wood, and waste treatment, Ecoinvent is the most comprehensive, transparent, international LCI database.

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