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RESEARCH ARTICLE

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Environmental and human health impact assessment of major interior wall decorative materials

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Abstract Despite the growing interest in green products in the interior wall decorative material market, knowledge gaps exist because determining which product is more environmental and user friendly than the others is difficult. This work assesses the environmental and human health profiles of interior latex and wallpaper. Two interior latex products of different raw material ratios and one non-woven wallpaper product are considered. The environmental impact assessment follows life cycle assessment (LCA) methodology and applies Building Environmental Performance Analysis System (BEPAS). The human health impact is based on impact-pathway chain and is performed using Building Health Impact Analysis System (BHIAS). The assessment scope, associated emissions, and territorial scope of various emissions are defined to facilitate comparison study of interior wall decorative products. The impacts are classified into 15 categories belonging to three safeguard areas: ecological environment, natural resources, and human health. The impacts of categories are calculated and monetized using willingness to pay (WTP) and disability-adjusted life year (DALY) and summarized as an integrated external cost of environmental and human health impacts. Assessment results reveal that the integrated impact of interior latex is lower than that of non-woven wallpaper, and the interior latex of low quality causes low life cycle integrated impact. The most impacted categories are global warming, respiratory effects, and water consumption. Hotspots of product manufacturing are recognized to promote green product design.

Keywords life cycle assessment, human health impact, integrated assessment, interior wall decorative material, green product

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1 Introduction

Exposure to indoor air pollution may be responsible for nearly 1.6 million excess deaths annually and approximately 3% of the global burden of disease; decorating material is a major source of indoor pollutants (WHO, 2010). The constant improvement in people's health and safety awareness has shifted the research focus to indoor environment. The impact of decorating materials on natural resource and the ecological environment should not be ignored. Manufacture of raw chemical materials and chemical products accounted for 11.16% of total energy consumption in China in 2014, of which interior decorating materials account for a large percentage (National Bureau of Statistics of China, 2016).

In response to customer needs, so-called "green" products with reduced pollutants become popular in the market, which may add pressure to resource and ecological environment. Interior latex is the most commonly used interior wall decorative material followed by wallpaper. The use of latex paint is more evident in China than in Western developed countries. At present, the quality of latex paint in the market varies. Some manufacturers provide ultra-high-quality products to achieve the desirable publicity effect on human health protection, but the associated environmental impact of the products can be significant. Other manufacturers provide relatively low-end latex paint to reduce environmental impact. However, this product easily chips, peals, and bubbles, thereby leading to short life span and large material consumption. Identifying truly "green" products are difficult due to the absence of a nationwide and uniform system of green product evaluation for assessing the integrated impacts on environment and human health.

The Ministry of Construction joined with health, environmental protection, chemical industry, building materials, and other departments to compile the "Code for indoor environmental pollution control of civil building engineering" (GB 50325-2001) for controlling the pollution of indoor environment. The code put forward requirements to every link of a construction project. For the important source of indoor emissions, namely, decorating materials, the General Administration of Quality Supervision, Inspection, and Quarantine and the Standardization Administration issued 10 national standards, including "Indoor decorating and refurbishing materials—Limit of harmful substances," to improve product quality and the development of new products. In China, products are generally evaluated in accordance with the Product Quality Standard, which serves as the technical base of production, test, and quality evaluation. For interior wall decorative products, these codes and standards only have requirements for harmful substance contents and ignore their environmental impact. To provide theory basis for interior decorative material production, an integrated evaluation method that considers health effects and environmental impact should be developed.

This study applies an integrated method of life cycle assessment (LCA) and health impact assessment to facilitate a comparison study of latex paint and wallpaper and quantifies their superiority in terms of impact on environment and human health. Building Environmental Performance Analysis System (BEPAS) and Building Health Impact Analysis System (BHIAS) are adopted to perform environmental and health impact assessments, respectively. The research contributes to the interior decorative material industry in three aspects: 1) A new evaluation idea of life cycle environmental and health impact assessment for green product evaluation is proposed; 2) The integrated method framework, definition of assessment scope, associated emissions, and territorial scope of emissions in this study can be used to other indoor products (such as floor and chair), thereby providing a theory basis for sustainable production of interior decorative materials; 3) The comparison result can serve as a reference for improving sustainable production of latex paint and wallpaper.

2 Literature review

LCA is a quantitative tool for assessing the consumption of resources and the ecological damage associated with a product (or service) throughout its life cycle (Zhang et al., 2015). LCA has been used widely since the publication of ISO 14040 and 14044 (ISO, 2006a, 2006b). According to the standard ISO framework, the implementation of LCA consists of four phases: goal and research scope definition, inventory analysis, impact assessment, and interpretation. Researchers have developed many LCA-based environmental assessment systems with different impact assessment methods. No standard impact assessment method is available to date; however, the advantages of LCA as a tool in tracking the environmental impact of a specific product or process has been demonstrated through wide application to different products, including decorating materials (Yang et al., 2001; Liu et al., 2011; Ma et al., 2011).

In addition to environmental impacts, emissions associated with interior wall decorative products use can affect human health by worsening air quality. Long-term exposure to particulate matter ($PM_{2.5}$) can have detrimental chronic health effects, including premature mortality due to cardiopulmonary diseases and lung cancer (Burnett et al., 2014). Carbon dioxide is excluded as a pollutant, but its role as a climate change criminal in the distribution of vector-borne diseases, such as dengue fever and malaria, has been assessed by researchers (Acharya et al., 2018; Ferrao et al., 2018). In terms of health effects, researchers have focused on environmental hygiene and discussed the content of harmful substances contained in indoor decorative products and their toxicity to human body (Azuma et al., 2016) and emission rules (Skaar and Jorgensen, 2013). These studies have compared the content of various harmful substances of different decorating materials but have not quantitatively discussed the human health effects of the materials.

The concept of economic valuation of air pollution (EVA) is based on the impact-pathway chain. The EVA system consists of a regional-scale chemistry transport model called Danish Eulerian hemispheric model, address-level or gridded population data, exposure-response functions for health impacts, and economic valuations of the impacts from air pollution (Brandt et al., 2013b). This system is originally developed to calculate the external costs related to air pollution of a specific emission source, such as from specific power plants, and is then extended to assess health cost externalities related to entire emission sectors. However, EVA is inapplicable to a life cycle health study of a product because the original sources of emissions of a product come from many supply chain processes and thus cannot be traced.

This problem is solved by BHIAS (Kong, 2010), which is a system based on LCA principles and environmental priority strategies (EPS) for assessing the human health impact caused by emissions in building embodied phase, use phase, and demolition. The Centre for Environmental Assessment of Products and Material System developed EPS as an effective tool to promote a company's internal product development process (Steen, 2000). Human health is one of the five safeguard areas considered by EPS, which also follows the impact-pathway methodology. The

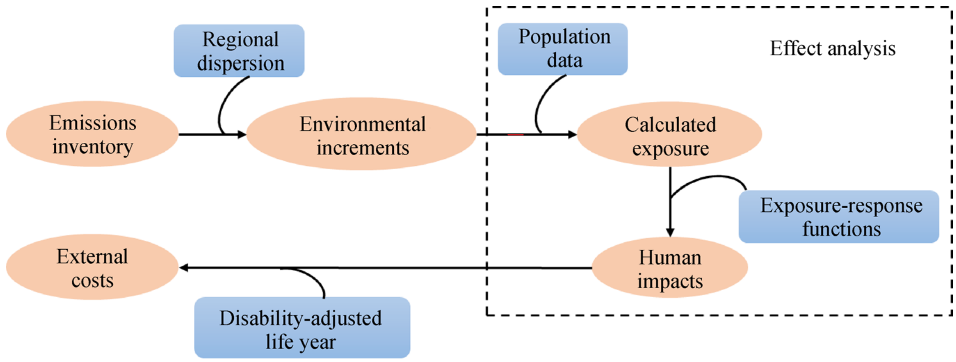

Fig. 1 Schematic of BHIAS

schematic of BHIAS is illustrated in Fig. 1. BHIAS uses emission inventory obtained through LCA method instead of a specific source. The emissions are divided into four categories according to four health effects: global warming-related diseases, respiratory effects, circulatory effects, and carcinogenesis. Regional dispersion is a process to set a territorial health impact scope for each category and transform emissions to environmental increments by multiplying them by fate factors calculated using three models (that is, global, city level, and indoor). Compared with EVA, this process simplifies the source-receptor relationships from nonlinear to linear relationships in proper territorial scopes. Effect analysis transforms the environmental increments to overall disease incidents added of people exposed to the emissions. Damages of emissions are generated and monetized by disability-adjusted life year (DALY), which is widely used to quantify human health impacts associated with life cycle emissions (Furberg et al., 2018).

Other human health impact assessment methods, such as IMPACT World + (Weldu et al., 2017) and Risk Assessment (RA) (Barberio et al., 2014), support quantitative evaluation of a product or manufacturing process but cannot be integrated with environmental assessment. Some LCA methods consider the safeguard area of human health impact, such as the widely used Eco-indicator 99 (EI99), EPS, and Impact 2002. However, they cannot integrate environmental and human health impacts into a single external cost value, thereby providing only limited support for decision making. Considering that BEPAS is LCA based with monetized health impact result that can be compared to environmental impact and used for ranking health risks (Brandt et al., 2013a), this research uses BEPAS to assess human health impact.

3 Methodology

In this section, the developed integrated assessment model is discussed. The Section first describes the application of LCA and EVA to interior wall decorative products and then presents the entire assessment process.

3.1 LCA for environmental impact assessment

3.1.1 Scope definition

An LCA study should be applied for comparison (Bueno et al., 2016). The scope definition should support the comparative purpose. For interior wall decorative products, the goal of the assessment is to compare the environmental impact relevant to the use of different products use to determine an eco-friendlier one. Most interior wall decorative products need auxiliary materials in use. For example, plaster board needs keels, fire proof coating, and glue. Auxiliary materials are indispensable for the use of the target product. In time dimension, environmental impact occurs in raw material acquisition, manufacturing, transportation, and use stage. No resource consumption occurs in use stage, but the harmful substances will be released to the room slowly and quietly, which will finally escape from the room to the outside atmosphere. Thus, the assessment scope should be the entire product system throughout the life cycle of the target product and its auxiliary materials.

The different product functions and ways of fulfilling them are not all of equal relevance. Therefore, as another part of scope definition, the determination of functional unit is necessary for calculations and comparison between different cases. Functional unit is “a quantified description of the performance of the product systems for use as a reference unit” (The Danish Environmental Protection Agency, 2004). For interior wall decorative products, the function is to decorate the wall for a period. Similar to the assessment goal, life span should be considered. The functional unit of interior wall decorative products is 1 kg of target product, excluding packaging material, used to decorate 100 m^2 of interior wall per year.

3.1.2 Inventory analysis

Inventory analysis compiles the inputs (resources) and the outputs (emissions) within the research scope. The inputs and outputs referred in inventory analysis are the most original and basic resources and pollutants, such as ore and nitric oxide. However, emissions associated with interior wall decorative products come from many supply chain processes. In general, the first-hand data from manufactures are always about intermediate products purchased from other manufacturers, sewage, or exhaust gas. Thus, the inventory analysis process involves many other products beyond the target product and auxiliary materials. A basic database is necessary to transform first-hand data to the required inputs and outputs.

3.1.3 Impact assessment

Impact assessment is the most technical and difficult among the phases. In Europe, researchers have proposed over 50 life cycle impact assessment (LCIA) models with different impact assessment methods (EPLCA, 2010). The methods can be grouped by the level of evaluation at midpoint, endpoint, or combined methods with sets of characterization factors at midpoint and endpoint. A comparison research of LCIA methods showed that endpoint LCIA provides different results and leads to dissimilar conclusions because of various impact categories, which are directly related to the context of creation (Bueno et al., 2016). The geographical scope of those categories may also be different, thereby leading to various characteristics that will interfere with the final results of the LCIA. This research aims to compare Chinese interior wall decorative products. Thus, the LCIA method should better be designed for Chinese context to make the assessment result relevant.

BEPAS is an LCA-based environmental impact assessment model for construction processes (Zhang et al., 2006). It was endorsed by the Ministry of Housing and Rural-Urban Development of China and was adopted as a standard for sustainability assessment of building project. BEPAS is suitable for comprehensive comparison between products because it combines midpoint and endpoint methods in the impact assessment phase. BEPAS considers the impact of three main environmental aspects of buildings: facilities, materials, and surroundings. The environmental impacts are then allocated to two safeguard areas, namely, ecosystem damage and resource depletion, which are further divided into 11 detailed categories. The data are characterized and weighed on the basis of the principle of the social willingness to pay (WTP) to integrate the environmental impacts of different categories into a single value.

3.2 Health impact assessment

Air pollution and climate change is a transboundary phenomenon with global, regional, national, and local sources, thereby leading to large differences in the geographical distribution of human exposure (Im et al., 2018). BHIAS developed three regional dispersion models for globe, city, and room. This part presents the definition of territorial scopes of emissions and consideration about the respiratory effect ignored by BHIAS.

The source and incidence of emissions are illustrated in Fig. 2. Emissions associated with an interior wall decorative product come from manufacturing processes of the supply chain and use phase. The emissions are classified into four classes according to their damage effect: emissions leading to global warming and causing global warming-related diseases, emissions causing respiratory effects and circulatory effects, emissions causing carcinogenesis, and non-air transmitted emissions such as COD and oil that will not cause significant damage effect to human body. Manufacturing emissions consist of all the four categories, whereas use phase emissions are carcinogenic substances, such as formaldehyde and benzene.

The concentration of manufacturing emissions makes no distinction of indoor air and outdoor air because they are

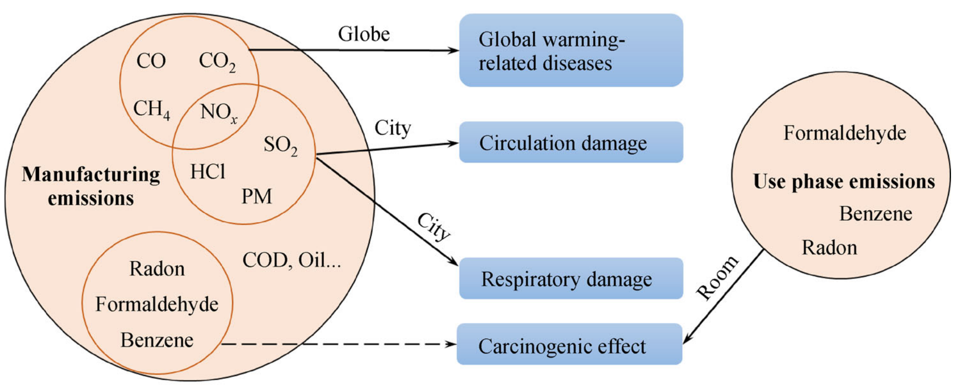

Fig. 2 Sources and territorial scopes of emissions

released into the air and contribute to the background concentration. Thus, the territorial scope of non-toxic substances is set as the globe or a city. Emissions of toxic substances are slowly released from the interior decorative products to the room in use phase. The total discharge of these substances may be minor, but they can have a significantly higher impact on human health than outdoor emissions (Skaar and Jorgensen, 2013) partly due to their higher concentrations (Sexton et al., 2004). Another reason is that people spend the majority of their time indoors, which results in the percentage as high as 85% (Brasche and Bischof, 2005; Tian et al., 2009). The incremental portion of indoor concentration brought by manufacturing emissions is very small that it can be ignored compared with the part brought by use phase emissions. Thus, the territorial scope of toxic substances is set as a room.

Respiratory effect is a hygiene term ignored by BHIAS, which indicates that a substance causes health damage only if its concentration is above a certain value. BHIAS assumes that all of the substances do not have threshold effect. For carcinogenesis with no threshold effect, the influence scope is a room and the impact on human body is based on toxicological works. According to toxicological studies, global warming-related diseases and respiratory and circulatory effects should consider threshold effect. However, the impact scope in BHIAS is the globe or a city, and the impact on human body is based on statistical results of incidents caused by the excess harmful substances. Thus, BHIAS carefully avoids the problem of threshold effect.

3.3 Integration

Previous research (Li et al., 2017) has confirmed the feasibility of integrating BEPAS and BHIAS. They both use LCA methodology and cause-effect chain analytical pathway and share the same research scope and emission inventory. Although emissions are classified to different categories and analyzed by dissimilar influence path methods, BEPAS and BHIAS use monetization method (WTP for BEPAS, DALY for BHIAS), which enables them to transform impact of different safeguard areas to the same unified unit and facilitate comparison with each other. Figure 3 shows the integrated assessment model for interior wall decorative products.

In addition to emissions listed in Fig. 3, interior wall decorative products may contain other carcinogenic substances, such as methylbenzene and other heavy metals, including lead. The International Agency for Research on Cancer (IARC) assessed 834 substances and divided them into five levels according to their clarity of causal relationship with human carcinogenesis. Formaldehyde, benzene, and nickel are first-level carcinogenic substances on the IARC list, which indicates they have

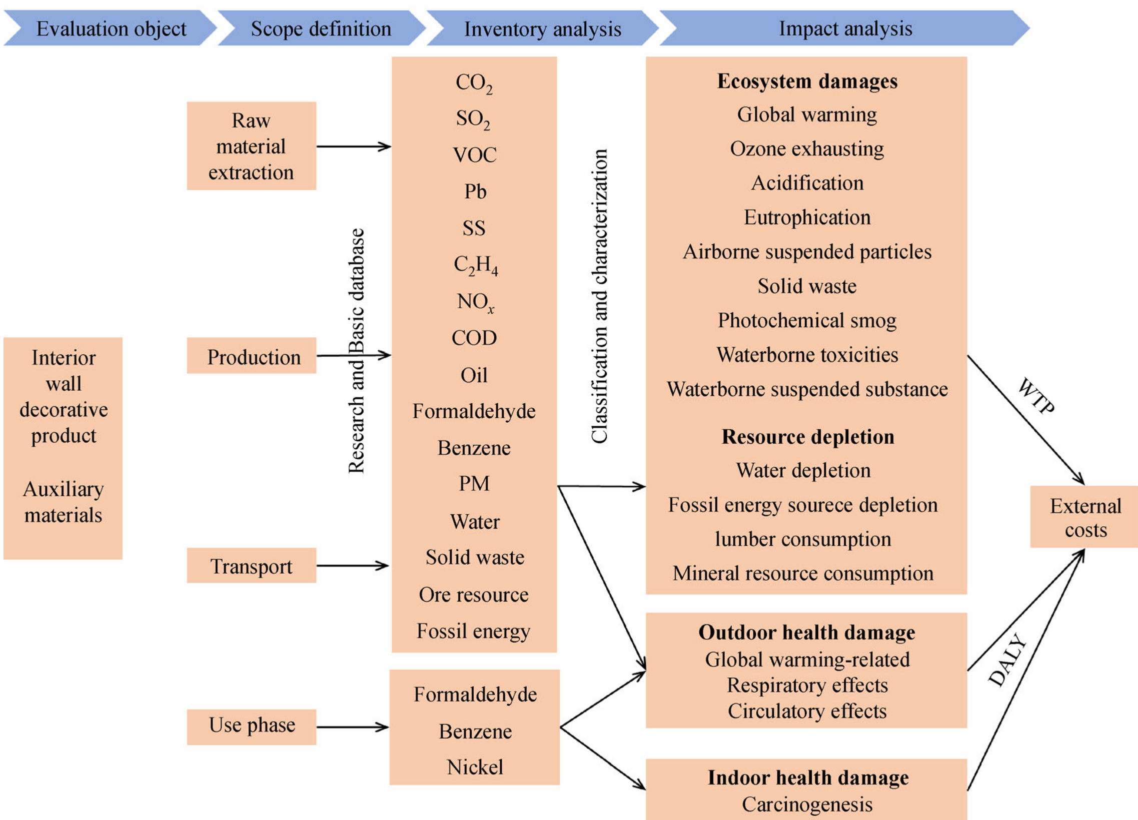

Fig. 3 Integrated assessment model for interior wall decorative products

definite carcinogenesis. The carcinogenesis of substances such as methylbenzene and lead are not definite, and the epidemiological studies about them are insufficiently mature to support the health impact assessment. Thus, this research only considers substances in the emission list.

The final external cost is the sum of environmental and health impact assessments. People may place higher weight on health impact than environmental impact when choosing an interior wall decorative product because individual health is their primary consideration compared with social responsibility. However, this research stands at social perspective instead of individual and ignores functionality of products or personal value preferences. WTP and DALY represent social wtp for environmental and health impacts, respectively. Environmental and health impacts are weighed under the same social value orientation. Thus, no secondary weights are applied in the integration.

4 Materials and assessment

This research aims to rank the superiority of interior latex and wallpaper in terms of environmental and human health impacts. Interior latex can be divided into water-based interior latex, water soluble paint, solvent-based interior latex, and universal latex paint, among which universal latex paint is suitable for different levels of consumers and has the largest market share. The most commonly used wallpapers are PVC, pure paper, and non-woven wallpapers, among which non-woven wallpapers are mainstream products and the most environmentally friendly wallpapers. This research defines the assessment target as universal latex paint and non-woven wallpapers. Considering the possible differences in raw material ratio and production facilities, two Chinese leading latex paint manufacturers are surveyed. The wallpaper industry has relatively simple production procedures, long history, and stability of product quality in the market. We survey one Chinese leading wallpaper manufacture because it can represent the market average. The life span of interior latex product 1 (IL1), interior latex product 2 (IL2), and non-woven wallpaper are 8, 10, and 8 years. Considering the confidentiality requirement of manufactures, this research does not show the raw material ratio of products.

More than 98% of the total mass of raw materials for manufacturing are assessed, and the remaining 2% are not assessed due to their low dosage and unavailability of manufacturing data. The supply chains and auxiliary products include acrylic emulsion and coalescing agents for universal latex paint and acrylic paint, basement membrane, and paste powder for non-woven wallpapers. Data of supply chains and auxiliary products are also provided by the aforementioned manufacturers. The core manufacturing processes refer to universal latex paint include production, cleaning operation, waste gas treatment, and sewage treatment. For non-woven wallpapers, the core manufacturing processes include production and cleaning operation. Transportation of raw materials to factories and finished products to customers is excluded because it varies among manufacturers and does not affect the industrial average. Target products include intermediate and auxiliary products and their derived emissions and resource consumption (including waste treatment performed by manufacturers and the part handed over to waste treatment plants). However, emission and resource consumption data from manufacturers always refer to some other products or by-products, and only a part of data correspond to production line that produces single product. An allocation approach is needed to associate the environmental burdens to each functional input or output of a multiple-function system that fulfills more than one function (ISO, 2006a). This research applies mass allocation approach to address this problem, that is, the derived emissions and resource consumption are distributed to each product or by-product according to their mass ratio.

E-Balance database developed by IKE (a Chinese leading company) is chosen as basic database because of its Chinese background and large variety of intermediate products. Fate factors of regional dispersion and population data for national and indoor models are retrieved from previous research (Kong, 2010) and Chinese national statistics (National Bureau of Statistics of China, 2017), whereas fate factors and population data for city level model are calculated using statistics of the city where the manufactures are located (Shanghai Bureau of Statistics, 2017). Exposure-response functions data are provided by US Environment Protect Agency (US EPA, 2008). Epidemiologic data and population age structure for DALY calculation are from previous research (Kong, 2010) and Chinese national statistics (National Bureau of Statistics of China, 2017). WTP for environmental impact is based on carbon trading prices, emission charge, resource price, and tax. The value of a statistical life year used for monetizing human health impact is from previous research (Li et al., 2010).

5 Results and analysis

Table 1 shows the external costs of the assessed products. Tables 2, 3, and 4 show the detailed external costs of various impact sources of IL1, IL2, and non-woven wallpaper, respectively.

5.1 Comparison between interior latex and non-woven wallpaper

Table 1 shows that the integrated impact values of interior latex products are lower than those of non-woven wallpaper. No significant difference is found in the

Table 1 External costs of safeguard areas

Impact categories	External costs (CNY/functional unit)		
	Interior latex product 1	Interior latex product 2	Non-woven wallpaper
Ecological damage	0.42	0.71	0.86
Resource depletion	0.12	0.20	0.20
Human health impact	0.28	0.30	0.21
Integrated impact	0.82	1.20	1.27

Table 2 External costs (yuan/functional unit) of impact sources of interior latex product 1

Safeguard areas	Raw material acquisition							Total
	Coarse whiting	Kaolin	Titanium dioxide	Coalescer	Styrene-acrylic emulsion	Water	Talcum powder	
Ecological damage	4.45E−02	8.13E−02	1.78E−01	1.37E−02	9.05E−02	0.00E+00	0.00E+00	4.08E−01
Resource depletion	2.28E−02	1.40E−03	7.37E−02	1.73E−03	1.26E−02	3.79E−03	1.62E−05	1.16E−01
Human health impact	5.23E−03	1.65E−01	9.01E−02	2.78E−03	1.82E−02	0.00E+00	0.00E+00	2.81E−01
Integrated impact	7.25E−02	2.48E−01	3.42E−01	1.82E−02	1.21E−01	3.79E−03	1.62E−05	8.06E−01
Proportion	8.79%	30.07%	41.53%	2.21%	14.71%	0.46%	0.00%	97.77%

Safeguard areas	Manufacturing				Total	Use phase
	Electricity	Solid waste treatment	Cleaning	Sewage treatment		
Ecological damage	6.45E−03	1.60E−05	8.84E−06	2.47E−03	8.95E−03	1.09E−05
Resource depletion	4.64E−03	4.74E−04	1.05E−03	−5.34E−04	5.63E−03	1.51E−03
Human health impact	1.94E−03	4.32E−06	0.00E+00	2.37E−04	2.18E−03	7.85E−05
Integrated impact	1.30E−02	4.95E−04	1.05E−03	2.17E−03	1.68E−02	1.60E−03
Proportion	1.58%	0.06%	0.13%	0.26%	2.03%	0.19%

Table 3 External costs (yuan/functional unit) of impact sources of interior latex product 2

Safeguard areas	Raw material acquisition							Total
	Coarse whiting	Kaolin	Titanium dioxide	Coalescer	Styrene-acrylic emulsion	Water	Talcum powder	
Ecological damage	1.43E−02	2.80E−02	3.46E−01	1.41E−01	1.71E−01	0.00E+00	0.00E+00	7.00E−01
Resource depletion	7.30E−03	4.84E−04	1.43E−01	1.77E−02	2.38E−02	1.31E−03	5.95E−04	1.94E−01
Human health impact	1.68E−03	5.68E−02	1.75E−01	2.84E−02	3.43E−02	0.00E+00	0.00E+00	2.96E−01
Integrated impact	2.32E−02	8.53E−02	6.63E−01	1.87E−01	2.29E−01	1.31E−03	5.95E−04	1.19E+00
Proportion	1.93%	7.09%	55.08%	15.51%	19.03%	0.11%	0.05%	98.80%

Safeguard areas	Manufacturing					Total	Use phase
	Electricity	Solid waste treatment	Cleaning	Sewage treatment	PM		
Ecological damage	3.88E−03	2.11E−05	1.32E−05	2.09E−03	1.77E−05	6.02E−03	1.09E−05
Resource depletion	7.82E−04	6.24E−04	1.66E−03	−4.52E−04	0.00E+00	2.61E−03	1.51E−03
Human health impact	1.16E−03	5.68E−06	0.00E+00	2.00E−04	4.63E−05	1.42E−03	7.85E−05
Integrated impact	5.83E−03	6.51E−04	1.67E−03	1.84E−03	6.40E−05	1.01E−02	1.60E−03
Proportion	0.48%	0.05%	0.14%	0.15%	0.01%	0.83%	0.19%

proportional distribution of safeguard areas among three products, all of them bring the largest damage to the ecological environment (51%–68%), followed by human health (16%–34%) and resource depletion (15%–16%). Although IL1 has the lowest resource depletion value, IL2 and non-woven wallpaper have the same resource deple-

Table 4 External costs (yuan/functional unit) of impact sources of non-woven wallpaper

Safeguard areas	Raw material acquisition			Total
	Non-woven paper	Crylic	Water	
Ecological damage	3.03E−01	8.40E−02	0.00E+00	3.87E−01
Resource depletion	9.77E−02	3.87E−03	3.49E−02	1.36E−01
Human health impact	6.39E−02	1.78E−02	0.00E+00	8.17E−02
Integrated impact	4.64E−01	1.06E−01	3.49E−02	6.05E−01
Proportion	36.48%	8.30%	2.74%	47.53%

Safeguard areas	Manufacturing			Total	Use phase
	Electricity	Solid waste treatment	Sewage treatment		
Ecological damage	2.95E−01	1.15E−04	4.93E−02	3.44E−01	1.30E−01
Resource depletion	6.41E−02	3.41E−03	−1.07E−02	5.68E−02	9.58E−03
Human health impact	9.54E−02	3.11E−05	4.73E−03	1.00E−01	2.75E−02
Integrated impact	4.54E−01	3.56E−03	4.34E−02	5.01E−01	1.67E−01
Proportion	35.67%	0.28%	3.41%	39.35%	13.12%

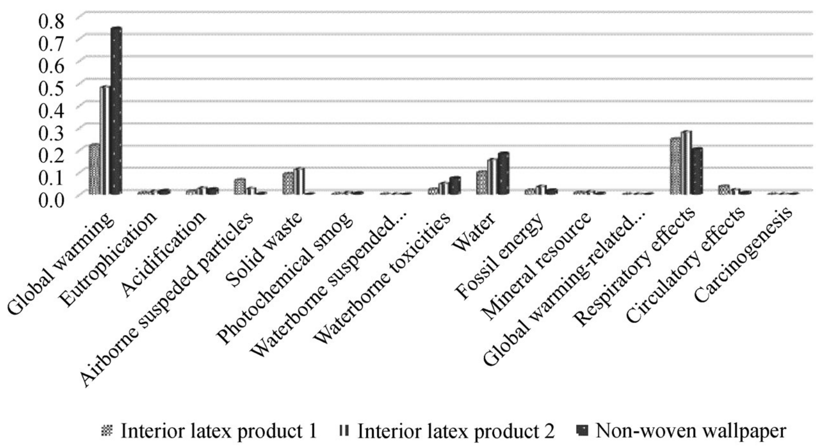

Fig. 4 External costs of categories

tion value. The difference between interior latex and non-woven wallpaper lies primarily in ecological damage and human health impact. The ecological damage caused by interior latex can be 17%–51% lesser than that of non-woven wallpaper, whereas the human health impact caused by interior latex can be 33%–43% more than that of non-woven wallpaper. This result is inconsistent with the common sense that high ecological damage will lead to high human health impact. The main reason is that global warming distributes most to the ecological damage (Fig. 4) due to large emission of greenhouse gases, whereas the human health impact brought by global warming-related diseases is quite low because of large territorial scope of greenhouse gases as the globe. Acidification and airborne suspended particles contribute much less to the ecological damage. However, the associated respiratory and circulatory effects are extremely high.

Figure 4 shows the external costs of categories. Global warming is the most impacted category among the three safeguard areas because it contributes 27%–59% to the integrated impact of three products. The primary generating way of carbon emission is burning of fossil fuels. Electricity, which is a kind of secondary energy, is partly generated by burning coal, thereby making electricity consumption a source of carbon emission. Compared with non-woven wallpaper, the advantage of interior latex on global warming comes from the low electricity use in its manufacturing process. Interior latex production involves mixing at room temperature, whereas non-woven wallpaper production is energy intensive because every square meter of wallpaper requires many energy-consuming processes, such as drying and hot rolling.

Carcinogenesis caused by indoor emissions in the use phase accounts for a very small proportion (less than 0.1%) of the total human health impact. By contrast, much emphasis should be given to respiratory effect, which is the largest health issue caused by the products and the second impacted category. Acidification and airborne suspended particles can lead to respiratory effect. No significant difference is observed in acidification between interior latex and non-woven wallpaper, but airborne suspended particles caused by interior latex is higher than those by non-woven wallpaper. As shown in Table 2 interior latex manufacturers greatly reduce the discharge amount of dust during manufacturing by using dust catchers. However, the airborne suspended particles caused in raw material acquisition are much higher than those of non-woven wallpaper. As a result, interior latex has higher impact on respiratory effect than non-woven wallpaper.

5.2 Comparison between two interior latex products

IL1 uses large quantities of water as liquid ingredients with styrene-acrylic emulsion weighing about one-fifth by mass of water and a tiny amount of coalescer. For solid part, IL1 uses coarse whiting and kaolin. IL2 uses titanium dioxide, coarse whiting, and talcum powder as solid part and much more styrene-acrylic emulsion and coalescer as liquid ingredients, weighing the same and a half by mass of water. In terms of raw material ratio, IL2 has higher quality than IL1 and thus has longer life span. Tables 2 and 3 show that nearly all the external costs of interior latex are associated with raw material acquisition. The most impact-intensive raw materials are titanium dioxide, kaolin, coalescer, and styrene-acrylic emulsion. IL2 uses more coalescer and styrene-acrylic emulsion than IL1 and replaces coarse whiting and kaolin with more impact-intensive titanium dioxide. In general, IL1 has no quality superiority but causes lesser environmental and human health impacts than IL2.

6 Conclusions

This study carries out an integrated environmental and human health impact assessment to quantify the superiority of interior latex paint and wallpaper. The environmental and human health impact assessments are performed using BEPAS and BHIAS models, which are based on LCA methodology and impact-pathway chain, respectively. The assessment scope, associated emissions, and territorial scope of various emissions are defined to facilitate the comparison study of interior wall decorative products. Data of one non-woven wallpaper product and two universal latex paint products of different raw material ratios are collected and transformed into input and output inventories. The environmental impact is allocated to ecological damage and resource depletion with eight and three categories, respectively. Health impact is divided into four categories. The impacts of categories are calculated and monetized using WTP and DALY and summarized as an integrated external cost of environmental and human health impacts.

From the assessment results, the main findings are as follows: 1) The integrated impact of interior latex is lower than that of non-woven wallpaper, but interior latex can cause more human health damage than non-woven wallpaper. 2) The most impacted safeguard is ecological damage, followed by human health and resource depletion. 3) Respiratory effect as the major health issue associated with interior wall decorative products should be given more attention than carcinogenesis caused by indoor emissions in the use phase. 4) The hotspot of interior latex production is material acquisition. Thus, manufactures who aim to provide green products should find balance between quality and environmental and human health impact because raw material ratio that guarantees high product quality and long life span also leads to high integrated impact of per unit function of products.

Nevertheless, this research needs further improvement. The assessment scope excludes transportation of raw materials, which can be considered in future research for comprehensive comparison. This research ignores 2% of raw materials by mass because of their low dosage and unavailability of manufacturing data. This insufficiency can be improved by overall investigation of the total supply chain and the development of a basic database.

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