International Symposium on World Ecological Design
F. Ying et al. (Eds.)

doi:10.3233/FAIA240019

Based on the Carbon Emission Model Study Generated by the Application of Art Paper in Design

Qiushi HUANG[a] and Lu PENG [a,1]
[a]*School of Art and Design, Beijing Institute of Fashion Technology,China*

Abstract. With the increasing prominence of global environmental problems, low carbon emissions have become one of the focuses of social attention. As a widely used material, the carbon emissions in the production and use of art paper cannot be ignored on the environmental impact. This paper aims to explore a comprehensive model study of carbon emissions from production to design of art paper. The study adopts the Life Cycle Assessment (LCA) method to systematically evaluate the carbon emission energy that may be generated from paper production to subsequent design through data analysis of different art papers. Exploring multiple aspects, including the selection of materials and printing processes, the use of renewable energy, transportation conservation, and waste management, ultimately establishing a comprehensive assessment model for carbon emissions. It aims to provide practical and feasible solutions for sustainable development in design paper, providing a comprehensive framework for environmentally friendly paper for designers, while providing new ideas for environmental protection and sustainability.

Keywords. Art paper application, Carbon emissions, Sustainable design.

1. Introduction

With the growing global concern about environmental issues, all walks of life are working to reduce carbon emissions, and for designers, how to choose art paper for design is no exception. Art paper is a special paper widely used in books, albums, posters and other fields. However, its production process can generate significant carbon emissions. Therefore, controlling the carbon emissions generated by the application of art paper has become a priority.

This study adopts a comprehensive model study, the life cycle assessment model. First, a carbon footprint assessment was carried out to analyze the carbon emissions of different art paper production. From the designer's point of view, evaluate the carbon emissions generated by the design process. This leads to better control energy use, reduce resource waste, reduce carbon emissions, and achieve more environmentally friendly design practices.

[1] Corresponding Author: Lu PENG, Beijing Institute of Fashion Technology, Professor, No. A2, Cherry Blossom Garden East Street, Chaoyang District, Beijing, China; E-mail: 772596833@qq.com.

2. Theoretical research

2.1. Carbon emissions and sustainable design

There is a close relationship between carbon emissions and sustainable design, which aims to meet the needs of today without compromising the ability of future generations to meet their needs. Carbon emissions, which are the release of carbon dioxide and other greenhouse gases produced during the life cycle of a product, are one of the main causes of climate change. Therefore, by reducing carbon emissions, the goal of sustainable design is achieved. Adopt low-carbon measures and optimize design to reduce carbon emissions while driving sustainable development.

2.2. Sustainable design towards carbon neutrality

How much is it necessary to control carbon emissions to meet sustainable design requirements? Carbon emissions are a complex issue, as they are influenced by many factors, such as regional climatic conditions, industrial structure, and renewable energy utilization. The goal of sustainable design is to achieve social, economic and environmental development. Therefore, carbon emission standards may vary from industry to industry and region to region. However, "carbon neutrality" is a universal measure of carbon sustainability, which means that the carbon emissions of a particular system, process or activity are equal to or lower than the amount of carbon absorbed or offset through renewable energy and abatement measures, i.e. net carbon emissions are zero or negative. In summary, to meet the requirements of sustainable design, the goal is to achieve carbon neutrality or as close to carbon neutral as possible. That is to say, in the process of art paper from production to design, designers need to consider everything from paper selection to process design. Adopt practical emission reduction designs to achieve low carbon emissions and thus achieve a sustainable vision.

3. Art Paper applications produce carbon footprint assessments

The concept of "carbon footprint" is derived from the "ecological footprint", which mainly refers to the total amount of gases emitted by humans in the process of production and consumption related to climate change[1]. So far, though, there is no precise, academic definition of carbon footprint. However, scholars from various countries have different knowledge and understanding of it. The definition of a carbon footprint by the WRI (World Resources Institute)/WBCSD (World Business Council for Sustainable Development) covers three aspects [5]: first, it includes the institution's own direct carbon emissions; secondly, to cover emissions from the energy supply sector; Finally, direct and indirect carbon emissions throughout the supply chain life cycle. Defined by the Carbon Trust, a carbon footprint is an assessment of the total amount of CO2 emitted by a product over its life cycle (raw material extraction, processing and disposal of waste products). Therefore, combined with the above definition, carbon footprint refers to the total amount of greenhouse gases emitted by individuals, organizations or products over their life cycle, usually measured in carbon dioxide equivalents (CO2e, that is, the carbon equivalent of CO2). With the rise of carbon footprint evaluation and the improvement and maturity of evaluation standards, carbon footprint evaluation has gradually been introduced into the paper industry.

3.1. Objectives and scoping

This study mainly discusses the carbon emission energy that may be generated by paper from production to subsequent design, in addition to the three main process units of art paper production and printing process and post-process process, it also includes product transportation, excluding other production processes, final presentation, use and solid waste treatment of process units. Since China has not yet formed a sound waste paper recycling system, it is difficult to obtain waste paper recycling data, so waste paper generation and recycling are not within the scope of research [6].

3.2. Simplify evaluation

Based on the target scoping defined in 3.1, and taking into account the practical constraints of data acquisition, the following simplified explanations are made:

- Production and maintenance processes related to production equipment, building facilities, production water and packaging materials are not considered.
- The raw materials involved in this study require road freight, and the return carbon emissions and waste paper transportation process are not considered.

3.3. Data Collection

According to the defined goal and scope boundary, the carbon emission process generated by art paper in the design is divided into four process units: art paper production, printing process, post-production process (processing technology), post-transportation and data collection of carbon emissions in the process unit. The collection process proceeds in two steps.

- Primary activity level data. According to the research objectives and problems, data collection is carried out through research, factory provision, sampling and testing.
- Sub-activity level data. It is impossible to give accurate figures from the data obtained from the actual research process, such as different paper sources, different manufacturers, production conditions in different production areas, etc., so estimates are obtained based on some industry data. Or replace it with the Chinese life cycle basic database CLCD-China, the EU life cycle database ELCD 3.0, Ecoin- vent, the central commercial database Ecoinvent 2.2 Public or relevant scientific and technical literature data[10].

3.4. Carbon emissions from art paper production

First, the carbon footprint assessment of the life cycle of different art paper productions is carried out. Data on carbon emissions from different art paper production are collected and analysed in comparison. According to the European Paper Industry Association (CEPI), based on the production of one sheet of A4 size paper, Whiteboard paper produces about 0.33-0.45 kg of carbon dioxide equivalent carbon emissions; offset paper may produce about 0.2-0.4 kg of carbon dioxide equivalent carbon emissions; corrugated paper may produce about 0.2-0.5 kg of carbon dioxide equivalent carbon emissions; matte paper has an average carbon emission of about

0.45-0.6kg CO2eq; in general, the production of coated paper may require more energy and chemicals to produce than other papers, so its carbon emissions may be higher, and the carbon emissions of coated paper are about 0.5- 0.8kgCO2eq;According to the U.S. Environmental Protection Agency (EPA), it is roughly estimated that about 1.5 tons of carbon dioxide are emitted for every ton of paper produced. However, this is an average that includes various paper types, while newsprint is generally lighter and thinner and may be slightly reduced. A standard piece of newsprint (measuring approximately 11 inches x 22 inches) weighs about 0.006 pounds (about 2.7 grams). From this, we can get the following estimates: the carbon emissions of 1 piece of newsprint ≈ 0.006 pounds of paper × 1.5 tons of CO2 emissions / 1 ton of paper ≈ 0.009 pounds of CO2 emissions (about 4 grams), so the following estimates can be obtained: the carbon emissions of one sheet of A4 newsprint ≈ 0.33-0.44kgCO2eq; Kraft paper is usually made from waste paper, and the carbon emissions in the production process are relatively low because it does not require the extraction and processing of plant fibers. But there is still a need to consider energy consumption and carbon emitted from other production processes. The average carbon footprint of producing a sheet of A4 kraft paper is about 0.1-0.3 kg of carbon dioxide equivalent (CO2eq). The carbon emissions of different art paper production are shown in Table 1.

Table 1. Statistics on carbon emissions from different types of paper production.

Paper	Σ (kgCO2-eq/kg)
Kraft paper	0.1-0.3CO2-eq
Offset paper	0.2-0.4CO2-eq
Corrugated paper	0.2-0.5CO2-eq
Newsprint	0.33-0.44CO2-eq
Whiteboard paper	0.33-0.45CO2-eq
Matte paper	0.45-0.6CO2-eq
Coated paper	0.5-0.8CO2-eq

3.5. Carbon emissions from the subsequent design of art paper

For the subsequent design of art paper, the carbon emission part is mainly divided into the subsequent two parts, the designer chooses the printing process, and the subsequent processing technology, such as hot stamping process, convexity, concave process, etc.

We start by assessing the carbon footprint of the production of different printing processes. The study "The Impact of Printing on Paper Emissions" has estimated the carbon emissions of printed paper.A standard-size sheet of paper (A4,210 mm × 297 mm) can have carbon emissions ranging from 0.2 to 0.6 kg CO2e. This range covers variations in different paper types and printing conditions. The first is offset printing, a common printing process commonly used for high-quality printed materials such as books, magazines, brochures and posters.It uses inks and plates to transfer images to the printing medium, estimating that each A4 offset print may produce about 0.005-0.01 kg of CO2 emissions; digital printing uses digital technology and is suitable for small batch printing needs, such as personalized business cards, brochures, etc. Digital printing typically produces less scrap and chemicals than offset printing, potentially producing about 0.002-0.005 kg of CO2 emissions per sheet of A4 paper; old-fashioned lithography, a traditional printing process used to print simple text or images. Although this process has been used less, it produces a higher carbon footprint, with estimates that each sheet of A4 paper may produce about 0.01-0.02 kg of CO2

emissions; gravure printing is commonly used for packaging materials, printing banknotes, etc. It uses gravure to transfer ink onto the printing medium. It is estimated that about 0.01-0.02 kg of CO2 emissions may be generated per sheet of A4 gravure print; Since laser printing is a relatively new technology and is more energy efficient, it generally produces fewer carbon emissions than traditional offset or gravure printing. Therefore, laser printing is more energy-efficient than traditional printing processes, because it does not require the production of printing plates, and there is no ink mixing process. Therefore, laser printing per sheet of A4 paper printed may produce about 0.001-0.003 kg of CO2 emissions. Overall, laser printing has relatively low carbon emissions and is a relatively environmentally friendly printing option. These values are for reference only, and the actual emissions will vary depending on many factors, and according to the above estimates, we obtain the carbon emissions of different printing processes as shown in Table 2.

Table 2. Statistics on carbon emissions generated by different printing processes.

Pringting process	Σ (kgCO2-eq/kg)
Offset printing	0.005-0.01
Digital printing	0.002-0.005
Vintage lithography	0.01-0.02
Intaglio printing	0.01-0.02
Laser printing	0.001-0.003

In book design, designers usually use "riding pegs" to bind books. Riding nails are generally brushed with low carbon steel, and high carbon wire is used when binding books with large spine thicknesses. Referring to the relevant literature [3], the carbon emissions per kg of steel production are 6470kgCO2-eq/t. In this study, the carbon emission coefficient of steel replacing riding nails with steel is 6.470kgCO2-eq/kg.

After the multi-color offset printing process, powder spraying is generally used, and the two can usually be combined. Powder spraying with pure natural plants (such as corn) as raw materials, it is the current modern high-speed multi-color offset printing process indispensable process, its main role is to prevent the back of the print from dirty, improve printing efficiency and quality. Referring to the data in the relevant data [4], the carbon emission coefficient of maize is calculated to be 0.111kgCO2-eq/kg.

Hot stamping paper, commonly known as galvanized aluminum, is a special material used in the printing and binding process to add metallic texture and decorative effects. It consists of polyester film (PET) coated with multiple layers of chemistry. This polyester film is typically 12 microns thick. Based on the GHG emission levels of PET particles provided in the Ecoinvent database, the corresponding carbon emission factors can be calculated, as shown in Table 3.

Table 3. The carbon emission factor of PET.

	CO2 (kg/kg)	CH4 (kg/kg)	N2O (kg/kg)	Σ (kgCO2-eq/kg)
PET	1.6657	0.011783	0.003289	2.905

Print lamination is a decorative and protective treatment that adds a layer of film to the printed surface. Polypropylene and other plastic films are covered on the surface of the printed matter, heated with adhesive, pressurized and bonded together to form a paper-plastic integrated print. At present, the lamination process is widely used in

biaxially oriented propylene plastic film (BOPP), polypropylene film (PP), polyvinyl chloride film (PVC), polyethylene film (PE), etc. In the case of substrates for BOPP films, for example, the corresponding carbon emission factors can be calculated and replaced based on the GHG emission levels of PP particles and stretch blow molding processes available in the Ecoinvent database, as shown in Table 4.

Table 4. The Carbon emission factors of the BOPP film.

	CO2 (kg/kg)	**CH4 (kg/kg)**	**N2O (kg/kg)**	**Σ (kgCO2-eq/kg)**
PP	1.6657	0.011783	0.003289	2.940
Stretch blow molding	0.5108	0.000033	0.000723	0.727
	Carbon emission factor			3.667

Road transportation, with reference to the research results of China's motor vehicle environmental emission inventory, calculate the corresponding carbon emission coefficient, as shown in Table 5.

Table 5. Carbon emission parameters of automobile vehicles in China

Vehicle type		CO2	CH4	Σ (gCO2-eq/tkm)
Light vehicles	Gasoline cars<3.5t	209	0.06	210.5
	Diesel cars<3.5t	181	0.01	181.25
Mid-size car	Gasoline cars>3.5t	95.1	3.27E-02	95.9175
	Diesel cars3.5-7.5t	194	3.64E-03	194.091
Heavy vehicles	diesel fuel7.5-16t	123	6.67E-03	123.16675

3.6. Inventory analysis

Since the carbon emission data is replaced by the eFootprint system's own database or scientific literature data, and the environmental emissions are allocated to different process units, the energy impact of electricity is negligible in the product system. In this study, data analysis is carried out according to four processes: art paper production, printing process, post-process (processing technology), and post-transportation. Finally, the list result of printing and processing A4 paper as a functional unit is obtained, that is, the carbon emission data of the design and printing of an A4 paper in each process unit, the results are shown in Table 6.

Table 6. Aggregation of carbon emission data at each stage

	Type	Σ (kgCO2-eq/kg)
Art paper production	Kraft paper	0.1-0.3
	Offset paper	0.2-0.4
	Corrugated paper	0.2-0.5
	Newsprint	0.33-0.44
	Whiteboard paper	0.33-0.45
	Matte paper	0.45-0.6
	Coated paper	0.5-0.8
Pringting process	Offset printing	0.005-0.01
	Digital printing	0.002-0.005
	Vintage lithography	0.01-0.02
	Intaglio printing	0.01-0.02
	Laser printing	0.001-0.003
Back-end process	Riding spikes	6.470
	Dusting	0.111
	Foil stamping paper	2.905
	Lamination	3.667
	UV varnish	0.000042
Transport — Light vehicles	Gasoline cars<3.5t	0.2105
	Diesel cars<3.5t	0.18125
Transport — Mid-size car	Gasoline cars>3.5t	0.09592
	Diesel cars3.5-7.5t	0.194091
Transport — Heavy vehicles	diesel fuel7.5-16t	0.12317

3.7. Case study

Based on the carbon emission evaluation model generated by the application of art paper in the design, this paper calculates the carbon footprint of Mellow's packaging design according to the paper selection to printing and then to the back-end process, and for the later road transportation, this study selects a medium-sized diesel vehicle with a load of 3.5-7.5 as the means of transportation, and its carbon emission factor is 0.1941kgCO2-eq/tkm.

Table 7. "Mellow" packaging design carbon emission model

Type		Σ (kgCO2-eq/kg)
Paper	Kraft paper	0.1-0.3
	Coated paper	0.5-0.8
Pringting process	Offset printing	0.005-0.01
Back-end process	Lamination	3.667
Transport	Diesel cars3.5-7.5t	0.194091

Taking a chocolate packaging as a functional unit, the packaging is shown in Figure 1, Mellow company uses kraft paper for packaging, followed by the packaging covered with ingredient table stickers, the main component of this sticker is coated paper, that is, a chocolate packaging paper produces 0.6-1.1 kg CO2-eq/kg carbon emissions. According to several common printing processes listed in the model, it can be seen from the figure that there is only black in the packaging, and the chocolate packaging is mass-produced, that is, it is very likely that the offset printing method will produce carbon emissions of 0.005-0.01kgCO2-eq/kg. In the post-process, the sticker part adopts the lamination process, which produces about 3.667kgCO2-eq/kg carbon

emissions, and the carbon emissions of later road transportation are 0.1941 kgCO2-eq/tkm. In total, such a chocolate package produces about 4.7191 kg CO2-eq/kg of carbon emissions.

Figure 1. Mellow chocolate packaging design.

3.8. Results and discussion

The carbon emission model research of art paper production and post-application in design is of great significance to designers in sustainable design, and Table 6 can enable graphic designers to more intuitively consider the entire life cycle of output posters, books and packaging, so as to better choose printing methods and processes to control carbon emissions. Secondly, measures such as choosing low-carbon materials, optimizing product manufacturing processes, and improving energy efficiency can also help reduce carbon footprint.

4. Rational utilization of energy resources

In addition to the carbon emission model generated by the application of art paper in the design, designers can also reduce carbon emissions in other aspects, such as choosing environmentally friendly paper materials, ink materials, optimizing waste management and other measures can help reduce carbon footprint.

4.1 Eco-friendly paper material

Sustainable design emphasizes the efficient use of energy and resources. The use of renewable energy and resource-efficient materials can reduce carbon emissions by reducing dependence on fossil fuels. Designers may consider choosing environmentally friendly paper production materials to better achieve low carbon goals, such as using wood with sustainable forest management or recycled fiber.As shown in Figure 2, Pat Mangulabnan's "sprout" packaging, the wrapping paper is made of pineapple leaves, which is 100% biodegradable. Secondly, the "Sprout" packaging ink uses soy ink, which can further enhance its eco-friendliness, and it can be used with edible starch wrapping paper, which can provide more protection for cereal in the package during transportation. Choosing environmentally friendly paper materials and ink materials can better achieve the purpose of low carbon.

Figure 2. "Sprout" packaging design by Pat Mangulabnan.

4.2 Waste management

Effective disposal solutions, such as recycling or conversion into other valuable products. Proper waste management is also closely related to carbon emissions. The use of degradable or recyclable materials, as well as the reuse and recycling of waste, contribute to the overall carbon footprint.

Like recycled cotton paper, it is usually made from recycled cotton textile waste, such as T-shirts or jeans. Cotton textile waste is the main component in landfills, often takes hundreds of years to biodegrade naturally, recycled cotton paper made from it not only diverts millions of tons of waste from landfills every year, but also has a soft texture and rich color, banknotes, business cards, important documents printing paper and other paper products that need long-term preservation, so you can choose recycled cotton paper for design. In addition, the raw materials of the paper industry are mainly derived from plants, after the fiber is extracted from plants, the remaining part in the pulping process through alkali recovery, bark knots boiler, waste residue boiler and wastewater anaerobic treatment and other steps, through the biogas utilization device to efficiently convert the remaining organic matter into biomass energy, this way can not only greatly reduce the consumption of fossil energy, but also reduce greenhouse gas emissions. In Europe, paper mills consume more than 57% of non-fossil energy by converting organic matter from papermaking into biomass energy.

In addition to the applications of eco-friendly materials and waste management mentioned above, designers can also reduce carbon emissions in later transportation, optimize transportation modes and routes to reduce carbon emissions in logistics.

5. Results and Discussion

Research based on comprehensive models shows that in art paper application design, it is feasible and effective for designers to adopt the carbon emission model generated by art paper application for a series of low-carbon emission measures. Through the selection of environmentally friendly materials and printing processes, life cycle carbon emissions can be reduced and controlled. In addition, the use of renewable energy and the optimization of transport modes play a role in reducing the carbon footprint. At the

same time, improvements in waste management can also provide new ideas for reducing the environmental burden.

The comprehensive model proposed in this study provides a comprehensive guide for designers to select materials to achieve low carbon emissions. By increasing awareness and understanding of low-carbon products among designers and consumers, and encouraging them to choose environmentally friendly art papers, the industry will move towards a more sustainable direction.

6. Conclusions

The exploration based on the comprehensive model of this study provides an important reference for low carbon emissions in art paper design. By comprehensively considering the carbon footprint assessment generated by paper printing, the selection of environmentally friendly materials, the use of renewable energy, waste management and other measures, a comprehensive carbon emission assessment model is finally established, which provides specific operational guidelines for the sustainable development of designer paper. It will help to further enhance the environmental awareness of designers and consumers, and promote the development of the entire industry in a more environmentally friendly and low-carbon direction, providing new ideas for environmental protection and sustainable development, and contributing more to environmental protection.

References

[1] WANG Wei, LIN Jianyi, CUI Shenghui. Review of carbon footprint analysis methods[J].Environmental Science and Technology,2010, 33(1):71-78.
[2] YU Xiaodi, Dong Dahai, Zhang Xiaofei. Product carbon footprint and its development status at home and abroad[J].Economic Research Guide,2010, 93(19):182-183.
[3] SHANG Chunjing, CHU Chenglong, ZHANG Zhihui. Comparison of carbon emissions in the life cycle of different structures[J].Building Science,2011,27(12):66-70.
[4] SHI Leigang, CHEN Fu, KONG Fanlei, et al. Study on carbon footprint of winter wheat-summer maize planting mode in North China Plain[J].Chinese Journal of Mouth, Resources and Environment,2011,21(9):93-98.
[5] Duan Xiaoxue, "Dairy Carbon Footprint Accounting Methods and Case Studies" Source: China Excellent Master's Thesis Full-text Database (2018): 01 Hubei University of Technology
[6] MA Qianqian, LU Baorong, ZHANG Qingwen. Carbon Footprint Assessment Method of Paper Products Based on Life Cycle Assessmen[J]. China Pulp & Paper, 2012,31(9):57-62.
[7] MA Qianqian, LU Baorong, ZHANG Qingwen. Carbon footprint evaluation and its application in papermaking industry[J].China Papermaking,2011,30(11):64-69.
[8] ZHAO Guojie, YOU Yajie, HUANG Qishuai. Carbon footprint evaluation of corrugated base paper products based on life cycle assessment[J].China Papermaking Journal,2021,40(08):40-44.
[9] Justin Bousquin, Eni Gambeta, Marcos Esterman, Sandra Rothenberg.Journal of Industrial Ecology 1 (16), S195-S205, 2012
[10] HAN Y L. Life Cycle Analysis of Water Consumption, Energy Con-sumption, and GHG Emissions and Sustainable Production Path- ways Investigation for Papermaking Industry in China[D]. Guang-zhou:South China University of Technology, 2019.