EAI Endorsed Transactions
on Energy Web
Research Article EAI.EU

Life Cycle Assessment and Model Optimization for Sustainable Energy Cross-Border E-Commerce

Hongli Liu[1,*] and Ruiling Cui[1]

[1] School of Humanities and Management, Xi' an Traffic Engineering Institute, Xi'an 710065, Shannxi, China

Abstract

INTRODUCTION: In an in-depth study of the application of sustainable energy in cross-border e-commerce, a comprehensive assessment and model optimization of its life cycle are conducted to promote the practical application of sustainable development in e-commerce. With the increasing global concern for renewable energy and environmental protection, e-commerce, as an international business model, has attracted much attention in terms of the environmental and social impacts of its sustainability.
OBJECTIVES: The aim is to provide scientific assessment methods and effective model optimization strategies to promote the feasibility and sustainability of cross-border e-commerce for sustainable energy.
METHODS: A comprehensive life cycle assessment (LCA) model was constructed using the system life cycle assessment (SLCA) methodology by collecting data from various aspects of sustainable energy cross-border e-commerce. The model considers the entire life cycle process from energy production, logistics, transportation, and product manufacturing to final consumption and integrates various factors such as resource utilization, environmental emissions, and social responsibility. Based on the assessment, a series of model optimization strategies are proposed, including suggestions for improving supply chain efficiency, promoting green energy applications, and strengthening social responsibility.
RESULTS: This study achieved significant life cycle assessment and model optimization results. In terms of energy use, promoting the application of renewable energy significantly reduces carbon emissions; in terms of supply chain management, optimization leads to an overall efficiency improvement and a reduction in resource wastage; and in terms of social responsibility, the enterprise strengthens employee training and community involvement, which enhances its social image. These results show that sustainable energy cross-border e-commerce can better achieve sustainable development goals through systematic assessment and optimization.
CONCLUSION: Life cycle assessment and model optimization provide scientific assessment methods and practical suggestions for sustainable energy cross-border e-commerce. In global sustainable development, the e-commerce industry should actively adopt sustainable energy and minimize its negative impacts on the environment and society by optimizing production and supply chain management. Future research can continue to expand the assessment model and deeply explore the potential of sustainable energy in e-commerce to provide more precise guidance for the industry's sustainable development.

Keywords:sustainability, E-commerce, life cycle assessment, energy consumption

Received on 21 March 2024, accepted on 21 April 2024, published on 23 April 2024

Copyright © 2024 H. Liu *et al.*, licensed to EAI. This is an open access article distributed under the terms of the CC BY-NC-SA 4.0, which permits copying, redistributing, remixing, transformation, and building upon the material in any medium so long as the original work is properly cited.

doi: 10.4108/ew.5493

*Corresponding author. Email: 201904020924@stu.zjsru.edu.cn

1. Introduction

With the rising global interest in sustainable development and positive changes in energy architecture, applying sustainable energy in business is becoming a global concern(Prado & Chikezie, 2021). In this global change environment, cross-border e-commerce, as one of the significant forms of business operations, has attracted extensive research interest in terms of its energy demand and environmental impacts(Nogueira et al., 2021). This study focuses on "Life Cycle Assessment and Model Optimization of Sustainable Energy Cross-border E-commerce," aiming to study this complex and essential area in depth to provide scientific theoretical support and practical guidance to promote the e-commerce industry towards a more environmentally friendly and socially responsible direction(Roy et al., 2021). Globally, sustainable energy, one of the key factors driving economic growth, provides new development opportunities for the business sector and offers viable alternatives for solving the environmental problems caused by traditional energy sources(Lin & Jiang, 2021). In particular, cross-border e-commerce, an increasingly globalized business, has become an urgent issue with its vast energy demand and associated environmental footprint. Therefore, through an in-depth study of the life cycle of sustainable energy in cross-border e-commerce, the author provides the industry with a comprehensive assessment and effective model optimization to drive this industry toward a more sustainable and responsible direction.

A systematic study of life cycle assessment and model optimization to explore maximizing sustainable energy use in e-commerce can effectively reduce energy consumption and environmental impact(Rai et al., 2023). To provide innovative solutions for the e-commerce industry by encouraging companies to adopt renewable energy, optimize production processes and supply chain management, and emphasize the importance of social responsibility(Wang et al., 2022). This endeavor is expected to promote the e-commerce industry in a more environmentally friendly, efficient, and socially responsible direction and provide practical and feasible ways to achieve the Sustainable Development Goals (SDGs). The global nature of e-commerce makes its energy consumption and environmental impact non-negligible(Siegfried et al., 2021). The problems caused by the overuse of traditional energy sources, ecological emissions, and the dire global climate change situation have prompted an urgent need to apply sustainable energy in e-commerce(Havrysh et al., 2021). Therefore, understanding and optimizing the life cycle of sustainable energy cross-border e-commerce has become an inevitable choice to achieve a win-win situation for economic growth and environmental protection.

An in-depth study of the life cycle of sustainable energy cross-border e-commerce is expected to provide the industry with innovative solutions that will lead to more active adoption of renewable energy, optimization of the supply chain, enhancement of social responsibility, and ultimately, the achievement of the goal of sustainable development(Byun et al., 2022). This study aims to lead the e-commerce industry in a more environmentally friendly, efficient, and socially responsible direction, laying a solid foundation for future economic sustainability.

2. Related work

Life cycle assessment (LCA) is a systematic way to evaluating the environmental, social, and economic implications of a product, service, or activity over its life cycle (Degen & Schuette, 2022). The methodology examines numerous factors, including resource utilization, energy consumption, trash generation, and environmental emissions (Xie et al., 2021). The life cycle is the whole process of a product, service, or activity, from the extraction of raw materials, manufacture, transportation, and use to its final disposal or recycling (Torkayesh et al., 2022). This includes all the links associated with that product or activity, involving multiple stages and various activities. At the beginning of the LCA, the objectives and scope of the evaluation need to be defined(Kumar & Tewary, 2021). This includes defining the purpose of the evaluation, designating the specific type of product or activity, and defining the timeframe and geographic scope of the review (Ashutosh et al., 2021). For example, they evaluate the entire life cycle of an electronic product, from the excavation of raw materials to the manufacturing, transportation, use, and disposal of the product. The core phase of LCA is Life Cycle Analysis (LCA). In this phase, data related to the product or activity is collected and analyzed. These data include information on the collection of raw materials, the manufacturing process, transportation, the use phase, and disposal(Cheng et al., 2022). Typically, LCA considers environmental aspects such as energy consumption, greenhouse gas emissions, water use, soil pollution, and other indicators and may also view social factors such as employee welfare and community impact(Xu et al., 2021). After completing the LCA, the results are interpreted to identify where the product or activity has had significant environmental and social impacts. Recommendations for improvement are then made, which may include optimizing the production process, reducing energy consumption, using environmentally friendly materials, or promoting more sustainable supply chain management.

Life cycle assessment aims to provide decision-makers and stakeholders with comprehensive information that enables them to weigh environmental, social, and economic aspects more fully throughout the life cycle of a product or activity(Li et al., 2021). This helps advance sustainable development goals by enabling industries to manage their impacts responsibly, leading to more sustainable production and consumption.

Sustainable energy cross-border e-commerce refers to using renewable energy sources and adopting sustainable business models in e-commerce activities to facilitate international trade and cross-border exchanges while minimizing negative impacts on the environment(Atmaca et al., 2021). In sustainable energy cross-border e-commerce, emphasis is placed on using renewable energy sources, such as solar, wind, and water, to meet the energy needs in e-commerce activities(Liao et al., 2021). This can reduce carbon emissions by using renewable energy in data centers, warehouses, and logistics centers and reduce reliance on non-renewable energy sources, thus making the entire supply chain more environmentally friendly(Haryanti & Subriadi, 2021). Sustainable energy cross-border e-commerce emphasizes green supply chain management, including renewable energy sourcing, supplier selection, and optimization of logistics and transportation(Atmaca et al., 2021). Companies can reduce their overall environmental impact by selecting suppliers that employ sustainable business practices, reducing the carbon footprint in transportation, and optimizing logistics processes (Cui & Shao, 2023). By integrating sustainable energy principles into e-commerce activities, sustainable energy cross-border e-commerce aims to provide companies with a viable and environmentally friendly business model while driving global trade in a more sustainable and environmentally friendly direction.

3. Research Methodology

3.1 Life cycle assessment

Life Cycle Assessment (LCA) is an internationally defined approach that helps assess the environmental pressures, environmental benefits, gains and losses, and areas for improvement connected with any product or service across its full life cycle.LCA is made up of two parts: the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA), which collects and analyzes data on environmental interventions associated with a specific product. The Life Cycle Inventory (LCI) is an essential component of the LCA, tasked with collecting and assessing environmental data for a specific product or service. These statistics include information about raw material extraction, manufacture, and consumption, as well as final disposal options such as recycling, reuse, and energy recovery. Life cycle inventories address a variety of environmental issues, including air and water pollutants, waste generation, and resource use.

Based on life cycle inventories, life cycle impact assessment (LCIA) collects and assesses data to quantify the environmental impacts of a product or service.LCIA takes into account areas of effect such as human health, ecosystem loads, resource depletion, and so on, and gives decision-makers with the information they need to make sustainable decisions while designing, manufacturing, and using a product or service. LCIA delivers an integrated approach from an entire lifecycle perspective, enabling businesses, policymakers, and consumers to understand and fully assess a product's or service's environmental impacts. Through Life Cycle Inventory and Impact Assessment, LCA provides scientific tools and guidance to promote sustainable development, optimize production processes, and motivate consumers and businesses to make greener choices. Life Cycle Impact AssessmentLife Cycle Impact Assessment (LCA) is the estimation of environmental stress indicators in the form of, e.g., climate change, photochemical smog, acid rain, human health impacts, etc., linked to ecological interventions that can be traced over the life cycle of a product. The data used in LCA must be consistent and of good quality and reflect the industrial process chain. The methodology used should reflect the most commonly accepted current practices.

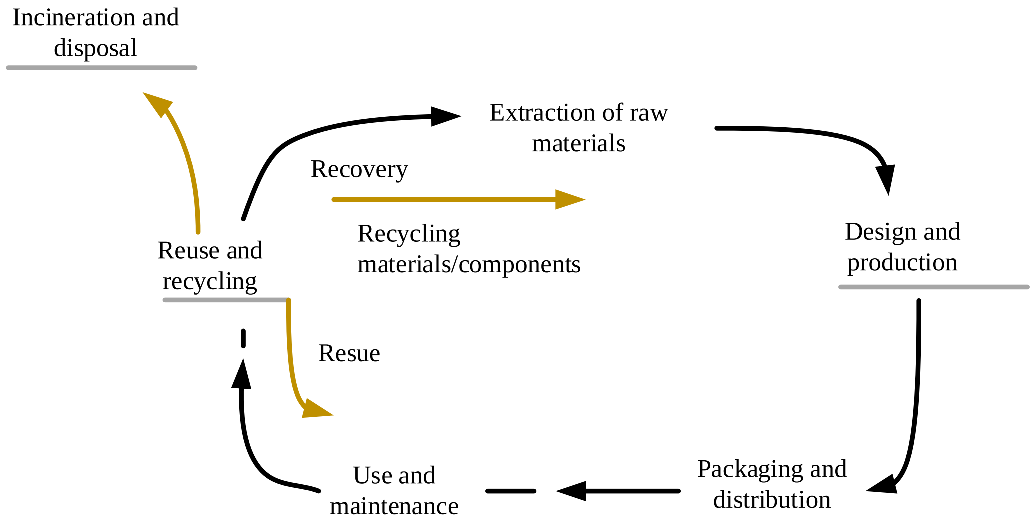

Figure 1 Life cycle evaluation framework

Many businesses and enterprises have long applied the theory of life cycle management to the context of sustainable development, and LCA is increasingly being used in industry to reduce the environmental impact of the entire range of products and services, as well as to improve the competitiveness of a company's products and to communicate with government departments. LCA is used to improve product design when making decisions about raw material selection, process selection, specific design needs, recycling, etc. LCA can also be applied to selecting the "orange" system and to purchasing decisions, technology investment, and innovation.

The advantage of life cycle analysis is that it allows for a single means of synthesizing upstream and downstream environmental pressures, human health, and resource consumption. This macro view complements other social, economic, and ecological assessments. Life cycle thinking can also be used in interest group consultations and policy operations in public services. This approach ensures a significant perspective, policy-oriented ecological assessment considering upstream and downstream interests and gains and losses. Life Cycle Analysis (LCA) effectively provides companies with information about the environmental performance of their products and services to develop a product strategy that meets the requirements of long-term sustainable development. The Life Cycle Scale can analyze the environmental performance of production and consumption patterns at different levels.

LCA methodology for sustainable social development

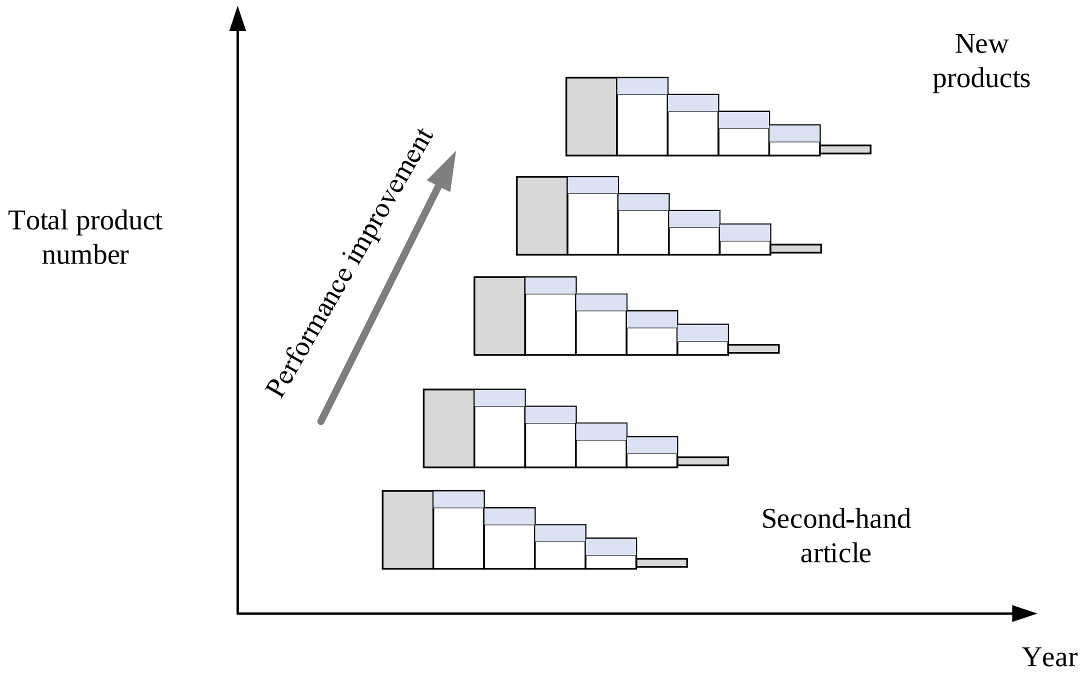

Figure 2 LCA approach to sustainability

Change in the quantity of energy e-commerce products in year t:

$$\Delta N_{use}(t) = N_{in}(t) - N_{out}(t) \tag{1}$$

$$\Delta N_{use}(t) = N_{use}(t) - N_{use}(t-1) \tag{2}$$

Assuming that the lifetime distribution of energy e-commerce products is $g(a)$ and a denotes years, the

$$N_{out}(t) = \sum_{a=0}^{a_{\max}} N_{in}(t-a)g(a) \tag{3}$$

$$N_{use}(t) = N_{use}(t_0 - 1) + \sum_{x=t_0}^{t}[N_{in}(t) - \sum_{a=0}^{a_{\max}} N_{in}(t-a)g(a)] \tag{4}$$

It t_s is imported, then

$$N_{use}(t) = \sum_{x=t_0}^{t} N_{in}(t) - \sum_{x=t_0}^{t}[\sum_{a=0}^{a_{\max}} N_{in}(x-a)g(a)] = \sum_{x=t_s}^{t} N_{in}(t)[1 - \sum_{a=0}^{t-x} g(a)] \tag{5}$$

Although existing lifecycle-based environmental assessment methods for transportation modes and packaging have yielded some results, the differences and complexity of the transportation structure, mode of transportation, energy supply, and data involved cause the results of the environmental assessment of cross-border e-commerce logistics modes to be non-uniform, with temporal and spatial variability. There is also a scarcity of data on the full-lifecycle cross-border e-commerce evaluation logistics modes. The overall life cycle assessment of the cross-border e-commerce logistics model is even more ambiguous. As a result, this project first develops a full life cycle model for two types of cross-border e-commerce logistics (direct distribution and consolidation), from raw material production to cross-border transportation to waste disposal, and then conducts a comparative analysis of the environmental benefits of the two types of cross-border e-commerce.

3.2 Energy across e-commerce

Energy cross-border e-commerce refers to using e-commerce platforms and digital technologies to buy, sell, and trade energy products through cross-border trade. Developments in this area are mainly driven by globalization, digitalization, and the liberalization of energy markets. Cross-border e-commerce platforms provide an online marketplace for buyers and sellers to find potential trading partners quickly. These platforms typically offer services such as online payments, digital contracts, and logistics, and the use of digital technologies such as blockchain, the Internet of Things, and big data analytics can improve the transparency, traceability, and efficiency of energy transactions. Blockchain technology is capable of ensuring the security and trustworthiness of energy transactions. The liberalization of energy markets has led to the rise of cross-border e-commerce. Energy producers, distributors, and consumers can choose their suppliers and purchasing methods more freely and are no longer constrained by traditional geographic and industry limitations, and cross-border e-commerce must comply with national and regional regulations and standards. The specific nature of the energy sector may require special compliance measures, such as tax policies and environmental restrictions on energy trading, which can facilitate the international trading of renewable energy. The different climatic conditions and distribution of energy resources between countries make cross-border trading of renewable energy an attractive option, contributing to sustainable global energy development. Cross-border e-commerce involves legal, currency, and market risks in countries and regions. Participants need to take measures to manage these risks, such as using financial instruments for exchange rate risk management, and have also given rise to energy finance markets, including energy derivatives and financing instruments, to meet the funding needs of participants in cross-border transactions.

Energy cross-border e-commerce provides broader market opportunities for the energy industry and promotes the efficient allocation of global energy resources and sustainable development. However, due to the complex regulatory, technical, and market conditions, participants must carefully consider and adequately address the various challenges.

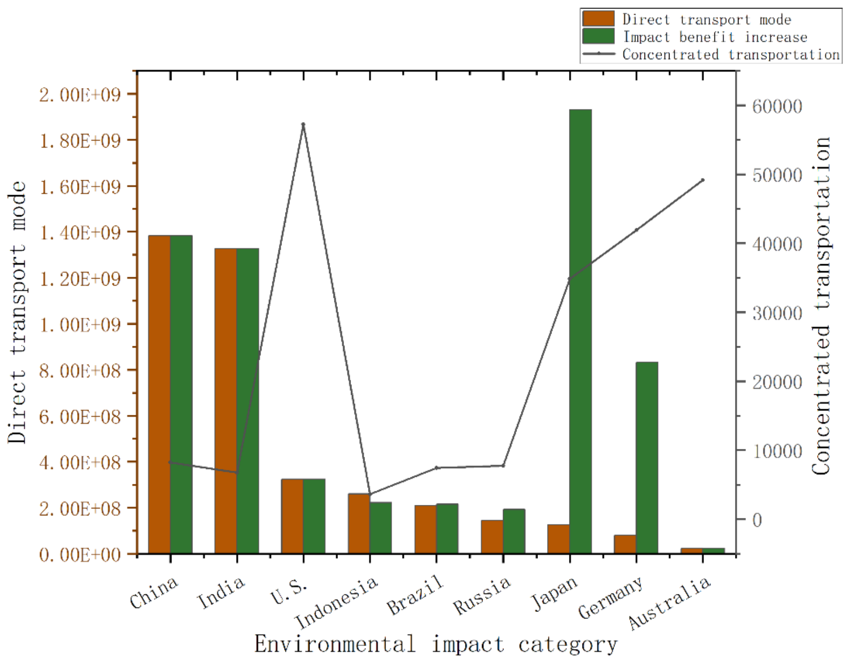

Figure 3 Environmental impact categories

Figure 3 provides a comparative analysis of the processes of the direct and consolidated transport modes, characterizing the results for each impact category. Conducting energy cross-border e-commerce between different countries may involve other environmental impacts and benefits, which are mainly influenced by the energy structure of each country, environmental regulations, the level of renewable energy use, and transportation costs. The energy structure of different countries varies considerably, with some countries relying mainly on fossil fuels and others preferring to use renewable energy. If energy cross-border e-commerce prompts more renewable energy exchanges, it may positively impact global emissions reduction targets, with different environmental regulations and standards between countries, which relate to environmental standards for energy production and use and carbon emissions control. The benefits of cross-border e-commerce may vary depending on the differences in regulations of the countries involved. Energy cross-border e-commerce may lead to the export of clean energy to other countries from countries with higher renewable energy capacity. This can help to promote renewable energy globally but may have some economic benefits for the exporting country. Cross-border e-commerce may involve the transportation of energy over long distances, which may increase transportation costs and carbon emissions. However, if energy sources are more efficient or cleaner, it may reduce the overall carbon footprint globally. Cross-border e-commerce may create jobs in the energy sector, but in some cases, it may also harm the energy industry in other countries. It may also affect social and economic sustainability and lead to cross-border technology and innovation transfer. If this helps improve the efficiency and viability of clean energy, it will positively impact the global environment. Environmental impacts and benefits depend on a combination of factors. In advancing this area, emphasis should be placed on cooperation, information transparency, and sustainable development to ensure that environmental benefits are maximized and potential negative impacts are minimized.

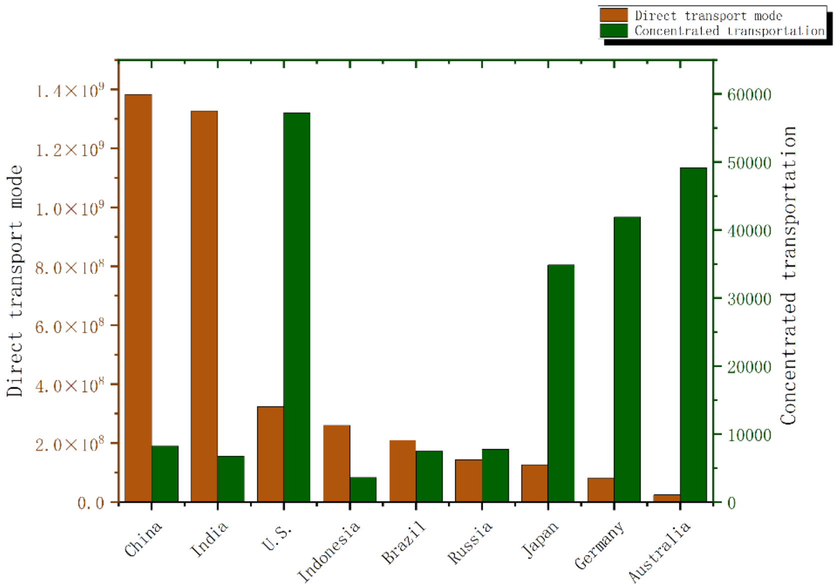

Figure 4 Comparison of environmental impact contribution of cross-border logistics

The environmental impacts of cross-border logistics are multifaceted, including transportation emissions, packaging waste, energy consumption, etc. Cross-border logistics usually requires long-distance transportation, including air, road, rail, and sea transport. Greenhouse gas emissions from these modes of transportation can harm climate change. Air transportation is usually the most emission-intensive mode, while maritime transportation is more environmentally friendly. Goods in cross-border logistics often require packaging to ensure they are not damaged during transportation. The production and disposal of packaging materials can lead to waste of resources and environmental problems. Excessive packaging and using non-sustainable materials can increase the burden on the environment. The means of transportation, equipment, and storage facilities used in logistics all require energy. There are differences in the energy efficiency of different modes of transportation and equipment, resulting in additional environmental impacts, and logistics infrastructure requires large amounts of land, including warehousing, transportation hubs, and parking lots. This can lead to land-use change, ecosystem damage, and biodiversity loss, and the logistics process can generate pollutants, such as oil and chemical spills. These pollutants may cause pollution to the surrounding environment and waters. Logistics activities may lead to traffic congestion, increasing vehicle idling time in congested conditions, increasing energy consumption and emissions, and to some extent, community inconveniences, such as noise, traffic congestion, and land use changes, which can negatively affect residents' quality of life. When comparing the environmental impacts of cross-border logistics, there is a need to consider different modes of transportation, regional characteristics, and adopted sustainable practices. At the same time, promoting sustainability in logistics and adopting measures such as greening transportation, reducing packaging waste, and improving energy efficiency can reduce the negative environmental impacts of cross-border logistics.

4. Life Cycle Assessment Model Optimization

4.1 Empirical evidence of life cycle assessment results

The cross-border transfer type of China's electric power enterprises refers to the domestic market as the primary form of electric power enterprises, in the continuous improvement of their international competitiveness at the same time, but also the expansion of the domestic market, the domestic and foreign markets in a two-pronged approach to cross-border e-commerce business, so that it can be better integrated into the domestic macrocycle as the primary form of the domestic and international double cycle of the new development of the mutual promotion of the domestic and international double cycle. The reasons for the changes in the type of cross-border transfer are manifold. On the one hand, the e-commerce giants have a significant market share, the product homogenization is severe, the domestic home appliance enterprises in the domestic market are very competitive, the development of the domestic market has encountered a bottleneck, and the beauty of the United States has constrained the cross-border e-trade in our country. On the other hand, enterprises must expand the scale of production, expand the international market, and improve the company's global visibility. At the same time, the state must create a favorable policy environment for the cross-border transformation of e-commerce.

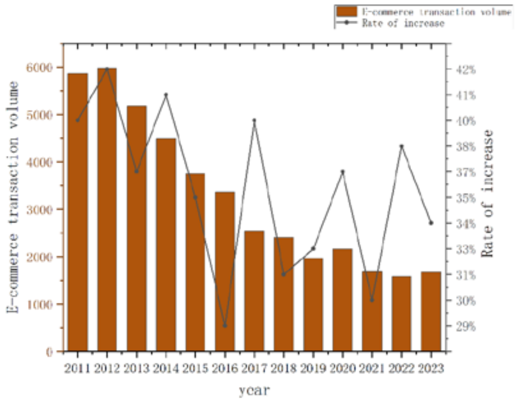

Figure 5 Energy Cross-Border E-Commerce Transactions and Growth Rate, 2011-2023

Although the scale of foreign exchange transactions of China's e-commerce companies has continued to grow, the growth rate of their foreign exchange reserves has declined in recent years and has gradually shown a lack of incremental growth and insufficient growth. On the one hand, there are large e-commerce companies like Alibaba and Jingdong, both of which are well known in the country and have a high market share, and other small and medium-sized e-commerce enterprises want to occupy a place in this piece of cake, whether it is the marketing model or the platform operation, and it is not easy to have too much innovation. On the other hand, due to the poor supervision of e-commerce enterprises, the severe homogenization of products, and the increasingly prominent problem of counterfeit goods, logistics, payment, and after-sales service, many problems result in the decreasing trust of consumers in the power supply companies. Based on this, the traditional cross-border transfer mode is not the best choice. The profound development of the domestic Internet and improving the channels and policies of third-party payment provide technical support for transforming China's foreign trade companies into cross-border e-commerce.

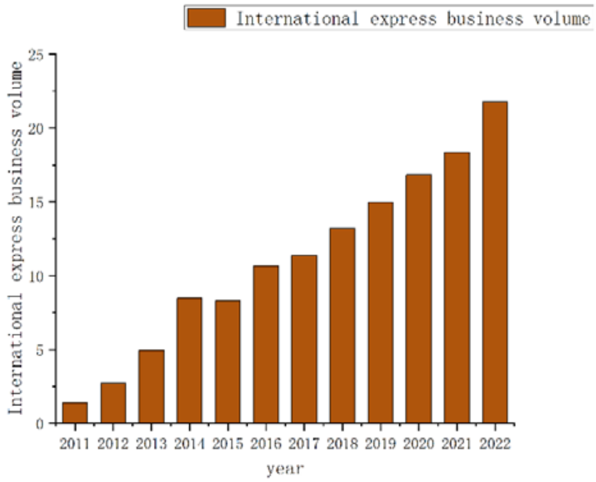

Figure 6 Volume of express delivery business

The volume of express business is an important indicator of the degree and level of development of China's logistics industry, as well as a key role in boosting cross-border enterprise operations. As shown in Figure 6, over the past 2023 years, China's international, Hong Kong, Macao, and Taiwan express business volume has increased more than tenfold, demonstrating the rapid development of the cross-border logistics industry in the past decade. However, the cross-border logistics industry still accounts for less than one percent of China's total logistics, indicating that there is still much room for growth. In theory, the larger the scale of the express delivery industry, the higher its logistics turnover rate, the shorter the time for goods or services to reach the customer, the higher the conversion rate of logistics, and therefore, the rapid development of cross-border logistics industry will have a considerable pull effect on the logistics industry's cross-border logistics, according to the previous study, the volume of express business between countries and Hong Kong, Macao, Taiwan, and its proportion in the overall import and export trade is positively correlated.

Conducting a life cycle assessment of energy cross-border e-commerce requires careful consideration of multiple stages, including energy production, logistics, and e-commerce platform operations. Due to the complexity of this area and the numerous aspects involved, an LCA can give the carbon footprint of energy cross-border e-commerce activities, i.e., the GHG emissions generated from energy production and logistics to e-commerce platform operations. This helps to understand the potential contribution of this business model to climate change. Considering that energy cross-border e-commerce involves the production, transportation, and sale of energy products, an LCA can provide the amount of energy used throughout the entire lifecycle stage, thus revealing the extent of its dependence on the resource. Since cross-border e-commerce involves the international transportation of commodities, logistical emissions are an essential factor to consider. The assessment can include factors such as mode of transportation, transportation distance, and logistics efficiency to understand the impact of the logistics phase on the environment. The appraisal can also consider the energy efficiency of the e-commerce platform and the energy consumption of the data center to understand the impact of the e-commerce operation phase on the overall environment. The impact of energy cross-border e-commerce on employment opportunities, community relations, socio-economic benefits, etc., can also be considered in the life cycle assessment. This helps to provide a comprehensive understanding of its social sustainability, and the LCA can also evaluate other environmental externalities associated with energy CBT, such as impacts on water resources, land use changes, etc. The assessment results could also consider the positive ecological impacts of technological innovations, such as improving the efficiency and sustainability of energy transactions through digital technologies and intelligent means.

These empirical results provide essential guidance for developing improvement strategies that can help reduce negative environmental impacts while increasing social and economic benefits in the energy cross-border e-commerce sector. However, it is worth noting that the accuracy and comparability of LCAs are directly affected by the methodology and data quality; therefore, care needs to be taken when conducting them.

In pursuing the goal of minimizing environmental impacts, ensuring the scientific validity and transparency of life cycle assessment methodologies is crucial. Using authoritative data sources, accurate measurement techniques, and transparent model parameterization can enhance the credibility of assessment results. In addition, establishing appropriate boundaries and considering differences across geographies and markets are essential for comparing and interpreting LCA results. To fully understand and address the environmental aspects of energy cross-border electricity generation, the industry should promote data sharing and collaboration to ensure consistent assessment methodologies across different entities. Such collaboration can improve the comparability of assessment results and help develop more integrated and accurate insights that can drive the industry in a more sustainable direction. In addition, LCA results should be incorporated into the decision-making process and shared with stakeholders to enable a concerted effort to move the energy cross-border electricity sector in a more sustainable and environmentally friendly direction. A scientific and transparent assessment can provide vital support to the industry to achieve a balance between economic growth and environmental protection.

4.2 Sustainable energy cross-border e-commerce

Cross-border payments for sustainable energy cross-border e-commerce face specific risks related to the nature of cross-border transactions and the different countries, currencies, and regulations involved. Cross-border payments apply to currencies of other countries so that exchange rate fluctuations may impact the transaction. Exchange rate fluctuations may result in changes in the value of the payment amount in the local currency, which may affect transaction costs and profits. Processing speeds and processes of banks and financial institutions in different countries and regions may differ, leading to delays and uncertainty in cross-border payments. Other countries have clear regulations, including preventing money laundering (AML) and combating terrorist financing (CFT). Failure to comply with these regulations can result in payments being rejected or facing legal issues, and cross-border payments involve online transactions and, therefore cybersecurity and fraud risks. This can include issues such as theft of payment information and credit card fraud.

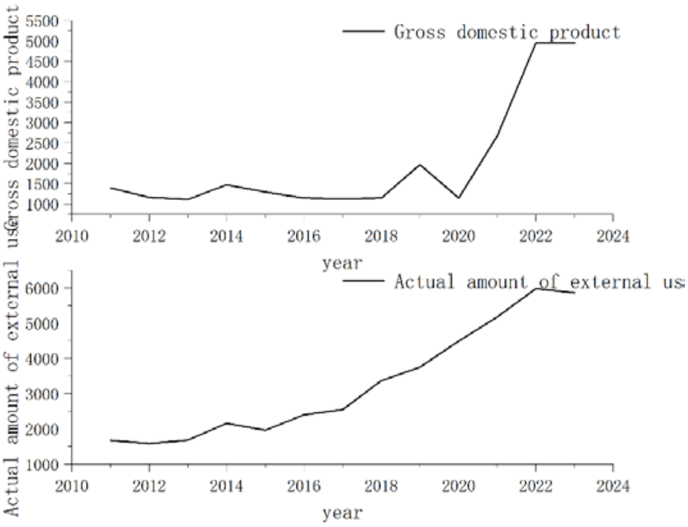

Figure 7 Cross-border payment risks

Sustainable energy cross-border e-commerce may face several barriers in international trade, which may stem from various political, legal, economic, cultural, and other factors. Different countries may have different policies and regulations for the trade of energy products and e-commerce, including tariffs, quotas, licenses, etc., different countries and regions may have different technical standards and certification requirements, which may increase the complexity of selling sustainable energy products in the international market, products that meet the standards of one country may need to be adjusted for the market of other countries, and exchange rate fluctuation that exists between countries may have an impact on the pricing and costs of sustainable energy cross-border e-commerce, and currency fluctuations may increase transaction uncertainty, especially for complex transactions involving multiple national currencies. Cultural and language barriers, which may affect aspects such as market understanding, advertising strategies, and customer service, as well as political instability, geopolitical tensions, and conflicts, may adversely affect cross-border e-commerce activities. This may make market access more complex and even interrupt transactions in some cases, and intellectual property protection may be inadequate in some countries, creating sustainable energy technologies and innovations vulnerable to infringement and piracy. Cross-border e-commerce may be limited by differences in financial systems and payment services in different countries, and some countries may have restrictions on specific payment methods, foreign exchange management, etc., which may affect the smooth running of transactions.

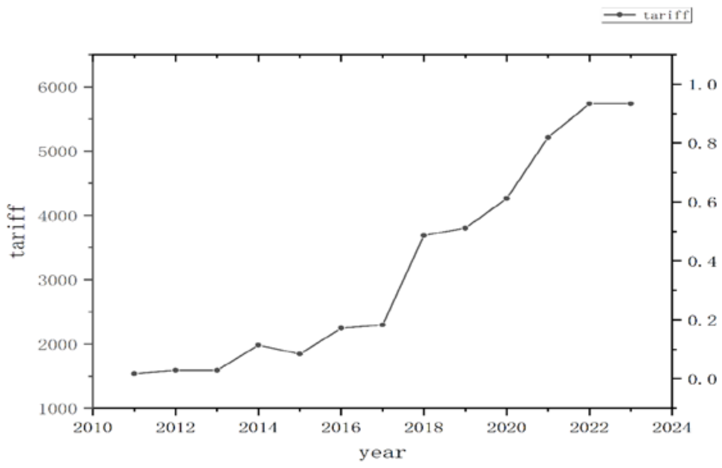

Figure 8 Consumption tariffs for the population, 2011-2023

In sustainable energy cross-border e-commerce, the percentage of recycled packaging, the rate of recyclable packaging usage, and the rate of product returns are essential indicators of environmental friendliness and sustainability.

Packaging recovery ratio: A measure of how much packaging material a business uses is recycled. A high packaging recovery ratio helps reduce the burden of waste on the environment, reduces resource waste, and promotes a circular economy. Businesses can increase their packaging recovery ratio by adopting recyclable materials, providing recycling facilities, or cooperating with social and governmental organizations.

Recyclable Packaging Utilization Rate: This refers to how much packaging material companies use is recyclable. Recyclable packaging helps reduce the environmental impact of single-use packaging. Enterprises can choose to use biodegradable materials, recyclable materials, or recycled packaging designs to increase the rate of recyclable packaging utilization.

Product return and exchange rate: This is the percentage of products purchased by customers that are returned or exchanged. A lower product return rate usually indicates higher product quality, customer satisfaction, and less unnecessary shipping and packaging waste. Companies can reduce product return rates by providing accurate product information, excellent customer service, and effective return policies.

These metrics are essential in sustainable energy cross-border e-commerce because they reflect how much a company cares about the environment and is committed to sustainability in its operations. When developing and implementing sustainable strategies, companies should consider how to maximize the percentage of recycled packaging, increase the use of recyclable packaging, and, at the same time, reduce the rate of product returns. These measures will help companies fulfill their social responsibility, enhance their brand image, and meet consumer demand for environmental protection and sustainability.

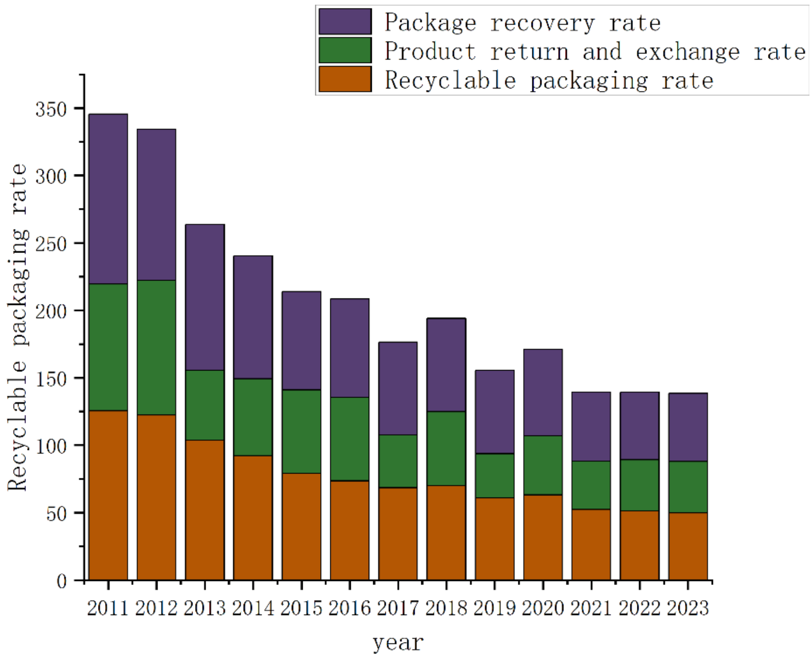

Figure 9 Share of packaging recovery ratio, recyclable packaging utilization rate, and product return rate

5. Conclusion

An in-depth study of this area was conducted to understand the environmental and economic impacts of this business activity. The life cycle assessment led to many critical conclusions regarding sustainable energy cross-border e-commerce: firstly, it was found that this business area is showing a fast-growing trend globally. Sustainable energy cross-border e-commerce plays a crucial role in facilitating clean energy exchanges and promoting green technology innovation. However, some potential environmental and economic challenges were identified as the business scaled up. Life cycle assessment reveals data on various aspects such as carbon footprint, energy consumption, and logistical impacts generated at different stages. This data provides business participants with robust information to help them identify potential improvement opportunities, reduce environmental impacts, and increase resource efficiency. The study further highlights the importance of model optimization in sustainable energy cross-border e-commerce. By adopting more efficient and environmentally friendly production and logistics models, businesses can minimize carbon emissions and resource wastage and thus achieve more sustainable operations. This includes innovations such as adopting clean energy, optimizing supply chains, and promoting green packaging. However, it is also recognized that environmental, social, and economic interests need to be balanced when implementing sustainable strategies. While pursuing ecological protection, the business must maintain financial soundness and social sustainability. This requires collaboration between various stakeholders, including governments, businesses, social organizations, and consumers. Overall, this paper emphasizes the urgency of implementing sustainable practices in the challenging cross-border e-commerce sector of sustainable energy, which is full of opportunities and challenges. Through in-depth analysis and innovative model optimization, it is expected to steer the industry in a more environmentally friendly and economically viable direction, making a positive and lasting contribution to global clean energy and sustainable development goals. The core insights emphasize the balance between the environment and the economy, calling on the business sector to pay close attention to reducing carbon footprints and resource wastage while promoting clean energy exchanges and fostering green technology innovation. The insightful study of Life Cycle Assessment and Model Optimization provides business players with clear direction on how to more effectively implement sustainable practices and improve the overall environmental sustainability of their business. This research calls for collaboration between business communities and stakeholders, emphasizing the need for sustainability in sustainable energy cross-border e-commerce. Governments, businesses, social organizations, and consumers should work together to develop and adhere to clear sustainability standards, promote the use of renewable energy, drive innovative packaging solutions, reduce return and exchange rates, and create a sustainable ecosystem that supports economic growth while minimizing environmental impact. This paper provides practical and strategic advice for the industry and sets an example for the SDGs. By promoting innovation, collaboration, and sustainable practices, it is hoped that together, the author can build a greener, cleaner, and more economically viable future.

Reference:

[1] Ashutosh, A., Mishra, H., Nandivardhan, G., & Acharjee, A. (2021). *Life cycle analysis and design for sustainability of a sustainable renewable energy system*. 56–78.

[2] Atmaca, N., Atmaca, A., & Zetin, A. H. (2021). The impacts of restoration and reconstruction of a heritage building on life cycle energy consumption and related carbon dioxide emissions. *Energy and Buildings*, *253*, 111507-. https://doi.org/10.1016/j.enbuild.2021.111507

[3] Byun, J., Kwon, O., Kim, J., & Han, J. (2022). Carbon-negative food waste-derived bioethanol: A hybrid model of life cycle assessment and optimization. *ACS Sustainable Chemistry & Engineering*, *14*, 10. https://doi.org/10.1021/acssuschemeng.1c08300

[4] Cheng, H., Huang, Y. T., & Huang, J. (2022). The application of DEMATEL-ANP in livestream e-commerce is based on consumer shopping motivation research. *Scientific Programming*, *2022*, 1–15.

[5] Cui, Q., & Shao, F. (2023). Comparison of life cycle assessment for laminating and glazing processes based on simapro. *Pigment & Resin Technology*, 88–99. https://doi.org/10.1108/PRT-09-2021-0116

[6] Degen, F., & Schuette, M. (2022). Life cycle assessment of the energy consumption and GHG emissions of state-of-the-art automotive battery cell production. *Journal of Cleaner Production*, *Jan.1*, 330.

[7] Haryanti, T., & Subriadi, A. P. (2021). E-commerce acceptance in the dimension of sustainability. *Journal of Modelling in Management*, *ahead-of-print*(ahead-of-print), 1–24.

[8] Havrysh, V., Kalinichenko, A., Brzozowska, A., & Stebila, J. (2021). Life cycle energy consumption and carbon dioxide emissions of agricultural residue feedstock for bioenergy. *Applied Sciences*, *11*(5), 2009. https://doi.org/10.3390/app11052009

[9] Kumar, D., & Tewary, T. (2021). Techno⸗conomic assessment and optimization of a standalone residential hybrid energy system for sustainable energy utilization. *International Journal of Energy Research*, *2*, 67–84.

[10] Li, B., Jiang, X., Bai, D., Zhang, Y., Zheng, N., Dong, X., Liu, L., Yang, Y., & Li, D. (2021). *Full-cycle energy consumption benchmark for low-carbon computer vision*. 1–34.

[11] Liao, H., Li, C., Nie, Y., Tan, J., & Liu, K. (2021). Environmental efficiency assessment for remanufacturing end-of-life machine and multi-objective optimization under carbon trading mechanism. *Journal of Cleaner Production*, *Jul.25*, 308.

[12] Lin, C., & Jiang, F. (2021). Research of multidimensional optimization of LEACH protocol based on reducing network energy consumption. *Journal of Electrical and Computer Engineering*, *2021*(1), 1–9.

[13] Nogueira, G. P. M., de Assis Rangel, J. J., & Shimoda, E. (2021). Sustainable last-mile distribution in B2C e-commerce: Do consumers care? *Cleaner and Responsible Consumption*, 4364. https://doi.org/10.1016/j.clrc.2021.100021

[14] Prado, J. C. D., & Chikezie, U. (2021). A decision model for an electricity retailer with energy storage and virtual bidding under daily and hourly CVaR assessment. *IEEE Access : Practical Innovations, Open Solutions*, *PP*(99), 1–1.

[15] Rai, Heleen. B., Touami, Sabrina., & Dablanc, Laetitia. (2023). Not all e-commerce emits equally: Systematic quantitative review of online and store purchases' carbon footprint. *Environmental Science & Technology*, *57*(1), 708–718. https://doi.org/10.1021/acs.est.2c00299

[16] Roy, A. M., Venkatesan, R. P., & Shanmugapriya, T. (2021). Simulation and analysis of a factory building's energy consumption using eQuest software. *Chemical Engineering & Technology*, *44*, 567–584.

[17] Siegfried, P., Michel, A., Tnzler, J., & Zhang, J. J. (2021). Analyzing sustainability issues in urban logistics in the context of the growth of e-commerce. *MPRA Paper*, 13–25.

[18] Torkayesh, A. E., Rajaeifar, M. A., Rostom, M., Malmir, B., Yazdani, M., Suh, S., Heidrich, O., & Kazmerski, L. (2022). Integrating life cycle assessment and multi-criteria decision making for sustainable waste management: Key issues and recommendations for future studies. *Renewable and Sustainable Energy Reviews*, 566–588. https://doi.org/10.1016/j.rser.2022.112819

[19] Wang, Q., Han, X., & Zhao, L. (2022). Sustainable retroft of industrial utility system using life cycle assessment and two-stage stochastic programming. *ACS Sustainable Chemistry & Engineering*, 34–58.

[20] Xie, J., Wang, Z., Wang, F., Wu, S., Chen, Z., & Yang, C. (2021). The life cycle energy consumption and emissions of asphalt pavement incorporating basic oxygen furnace slag by comparative study. *Multidisciplinary Digital Publishing Institute*, *8*, 8.

[21] Xu, S., Li, Z., & Yang, Q. (2021). Comparative life cycle assessment of energy consumption, pollutant emission, and cost analysis of Coal/Oil/Biomass to ethylene glycol. *ACS Sustainable Chemistry & Engineering*, *47*, 9. https://doi.org/10.1021/acssuschemeng.1c05454