Unpacking the Environmental Costs of E-Commerce: A System Dynamics Analysis of CO₂ Emissions in India

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ABSTRACT

The exponential growth of e-commerce has brought convenience and value-added services, but it has also led to a surge in CO2 emissions. A study using a system dynamics approach was conducted to investigate the impact of e-commerce on CO2 emissions in India. The study employed a rigorous methodology comprising a literature review, discussion with experts, and developing a conceptual causal-effect framework covering numerous exogenous variables and their feedback effects. Overall, the study reveals that e-commerce operates within a complex system of interdependent factors, and it is essential to consider these factors and their feedback effects when developing strategies to promote sustainable growth.

Keywords: E-Commerce Economy, System Dynamics, CO2 Emission, Causal-Effect Diagram, Feedback Effects

1. INTRODUCTION

The rapid growth of the e-commerce economy has fundamentally transformed the retail landscape, endowing consumers with unparalleled convenience and value-added services (Weidinger et al., 2019; Dey, 2017). Nevertheless, this growth has also engendered a considerable escalation in CO_2 emissions, necessitating a more nuanced understanding of the environmental impact of e-commerce (Cheba et al., 2021; Xie et al., 2023). Since India is a developing country, India's e-commerce economy relies on the transportation sector for its development, which is its backbone. Out of India's major modes of transportation, road transport has the largest energy consumption. Urban areas are responsible for over 70% of all global emissions, according to known data (Sanna et al., 2014). The transportation sector contributes to 90% of India's GHG (Greenhouse gas) emissions (Tracker C.A., 2020). This study, therefore, aims to investigate the effects of the e-commerce economy's growth on CO_2 emissions in India, thereby contributing significantly to the ongoing discourse on the sustainability of e-commerce practices.

Despite the burgeoning concern about the environmental impact of the e-commerce economy, the existing studies used limited variables and may not be able to capture complex feedback mechanisms comprehensively. There is a lack of research that explores the underlying causes and feedback mechanisms driving these emissions (Hidayatno et al., 2019). To address this gap, our study will conduct a thorough literature review accompanied by the Causal Loop Diagram (CLD) to identify the factors/variables to be considered and model the complex interactions of these multiple factors, respectively. As e-commerce continues to grow and evolve, new variables, such as consumer perception of sustainable packaging, must be considered. This timely study explores the impact of these newly added variables on the environmental performance of the e-commerce economy in India (Hidayatno et al., 2019; Xie et al., 2022). Finally, extant literature highlights a lack of a comprehensive conceptual flow diagram that integrates different factors and variables affecting the sustainability of e-commerce in India (Ariansyah et al., 2021). Our study will develop a CLD that incorporates various drivers and feedback mechanisms in the e-commerce supply chain and use it to analyze the impact of different interventions and policies.

In conclusion, the literature has primarily focused on a limited number of variables, failing to comprehensively capture the intricate ecosystem of the e-commerce economy (e.g., emissions Jaller and Pahwa, 2020; Prasertwit&Kanchanasuntorn, 2021). Consequently, there is a pressing need for more extensive research that considers a broader range of variables and feedback effects. This study aims to address this research gap by examining the impact of the e-commerce economy's growth on CO_2 emissions using a system dynamics approach. A conceptual causal-effect diagram is developed using the software Vensim PLE and refined after multiple discussions with academicians and industry experts, which encapsulates a broad range of variables and feedback effects. The study's approach enables the investigation of the feedback effects of various variables in the e-commerce system, providing a more sophisticated understanding of the complex interplay between different factors and their impact on CO_2 emissions. This study makes significant contributions to both academia and industry. Firstly, the study provides a more comprehensive

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understanding of the impact of the e-commerce economy by considering a wide range of variables and feedback effects. The study's findings can guide policymakers and industry leaders in developing sustainable strategies that balance economic growth with environmental responsibility, thereby creating a more sustainable e-commerce economy in India and beyond. Secondly, this study contributes to the broader literature on system dynamics and its application in studying complex systems. The study's approach enables the investigation of the feedback effects of various variables in the e-commerce system, providing valuable insights for researchers in system dynamics. Moreover, this study offers specific examples of the factors contributing to the growth of the e-commerce economy and CO_2 emissions in India, providing practical guidance for industry practitioners. The study's findings help companies focus on the factors that contribute to CO_2 emissions and design targeted strategies to mitigate their negative impact on the environment.

In conclusion, this study's system dynamics approach and comprehensive analysis of the e-commerce economy ecosystem's impact on CO_2 emissions provide valuable insights for researchers, policymakers, and industry leaders. The study's findings can inform the development of sustainable practices that balance the convenience of online shopping with the imperative to reduce greenhouse gas emissions. The study's contribution to the literature on system dynamics and using a wide range of variables and feedback effects in the analysis makes it a valuable addition to the field. Ultimately, this research aims to foster the development of a more sustainable e-commerce economy in India and beyond, with significant implications for the broader global economy. The study's findings are particularly relevant to companies and policymakers seeking to reconcile economic growth with environmental responsibility, as it provides a nuanced understanding of the economic costs and benefits of e-commerce practices. Overall, this study presents a sophisticated analysis of the impact of the e-commerce economy's growth in India, contributing to the ongoing discourse on the sustainability of e-commerce economy practices and providing valuable insights for future research and policy development.

2. METHODOLOGY AND SOFTWARE

System Dynamics (SD) is a powerful modeling technique that can be used to forecast the behavior of a system in the future (Forrester, 1961; Sterman, 2000). Real-world systems are often complex and difficult to comprehend, making it challenging to consider all the factors and analyze their interrelationships and effects on each other. However, SD can handle the nonlinear nature of the system (Sterman, 2000). With the help of the Causal Loop Diagram (CLD), an SD tool, it is possible to explore the causal relationships among different components of the system. This approach allows the identification of critical components and how they control the system's behavior. The CLD model consists of balancing and reinforcing loops, where balancing loops can reduce the impact of a change over time, while reinforcing loops can amplify the effects of a change, leading to significant impacts on the system over a period. The Vensim PLE software is used in this study to develop the CLD model, and experts (Table 1) were consulted to further refine the CLD.

Group	No. of experts	From	Profiles	Experience (years)
Group 1: Logistics Sector	1	Industry	Consultant	2
	1	Industry	Senior consultant	3
Group 2: E-commerce	1	E-commerce firm	Associate director (at an e- commerce company)	6
Group 3: Academia	3	Academia	Researcher	2

Table 1: Profile of Experts.

2.1 SCOPE OF MODELING

Here we intend to study how growth in the online retail market leads to an increase in carbon emissions in India. We investigate the problem through a system dynamics perspective. We consider the variables such as an increase in the number of people using online platforms for the purchase of products, i.e., an increase in the online retail sector which contributes to an increase in the number of vehicles due to an increase in e-commerce orders to be delivered. The issues of CO_2 emissions can vary in different places, here we particularly consider the issues in India.

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After identifying the issue of increasing carbon emissions through literature and multiple discussions with experts, Causal Loop Diagram (CLD) has been developed. Here we have used the software Vensim PLE (Personal Learning Edition) for the development of the CLD model. It can further suggest what policy measures can be taken by the e-commerce sector for reducing carbon emissions. The problem at hand has been studied in three phases (Figure 1):



Figure 1: Methodology adopted for the study.

Phase 1: Problem detailing: The problem has been identified by reviewing the literature. The variables/factors corresponding to the problem have been identified from the literature and the inputs from the experts. The factor/variable identified from the literature have been detailed in Table 2.

Factor/Variable	Explanations	Reference(s)	Factor/Variable	Explanations	Reference(s)
Consumer behaviour	Decisions and actions of people or households when they buy or use a product	(Sethuraman et al., 2019; Joshi et al., 2018; Kanchan et al., 2015)	Logistic transport cost	Transportation costs incurred to deliver the e- commerce orders	(Hidayatno et al., 2019)
Demand of offline and online market	The increase in consumption of products through online as well as offline	(Hidayatno et al., 2019)	Price of online products	At what price the product can be purchased online	(Gurtu, 2021)
Online retail sector	Selling of product(s) of various types in small	(Cheba et al., 2021; Khare et al., 2012; Kanchan et al., 2015)	Shipment volume per delivery	how much space cargo will take up on a truck which in turn decides the cost to transport	(Hidayatno et al., 2019)
e-commerce orders	Electronic transactions for the exchange of goods	(Cheba et al., 2021); Raman, 2014)	Logistics transport utilization (truckload factor)	Whether the trucks used for deliveries are fully utilized or	(Hidayatno et al., 2019)

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	and services, transfer of data or funds (primarily over the internet)			half utilized (full truckload (FTL) or half truckload (HTL)	
Packaging volume	The amount of space that material takes up. The internal size of the box used for packing the product(s)	(Chueamuangphan et al., 2019; Escursell et al. 2021; Hidayatno et al., 2019)	Space requirement	Space required to store the inventory (product(s))	(Gurtu, 2021)
CO ₂ emission	Emissions stem due to the consumption of solid, liquid, and gas fuels	(Xie et al., 2022; Awwad et al., 2018; Hidayatno et al., 2019)	Space utilization	Whether the space of a fulfillment center is efficiently utilized or not	(Li et al., 2021)
Consumer perception	The opinions, beliefs, and feelings customers	(Rao et al., 2021; Khare et al., 2012)	Automation (fulfillment centers)	Level of automation at fulfillment centers	Industry report
Number of deliveries	Number of orders delivered from source to end	Experts input	Customer service level	Quality of service provided to the customers	Experts input
Number of vehicles	Number of vehicles involved to deliver the e- commerce orders	(Awwad et al., 2018)	cost	The inventory holding cost of the product has the impacting the overall cost of the product	(Gurtu, 2021)

Phase 2: CLD development: For developing causal-effect relationships, suitable experts were identified, and their inputs were considered. Two consultants from the logistics industry from India were chosen for the study. In addition, an associate director of an e-commerce company was considered, and three academicians from a top business school in India were considered for the study. With the help of experts, balancing and reinforcement loops were identified in the causal loop diagram. In addition, the expert's input was considered in taking the variables the number of deliveries, automation (fulfilment centers), and customer service level. The details of the expert have been provided in Table 2. The growth of e-commerce and then the growth of CO2 emissions due to e-commerce is discussed. The growth of e-commerce has been discussed thoroughly in the previous section.

Phase 3: Validation and policy recommendation: Once the CLD has been developed, it is again validated by the experts to verify the relationships of the identified variables/factors. The conceptual model is then used to recommend the policy for sustainable e-commerce.

3. RESULT

Figure 2 depicts the conceptual model developed in Vensim PLE. It highlights the broad conceptual framework that includes the interaction of important variables. There are five loops: threebalancing loops and two reinforcing loops in the diagram. The loops in the diagram have been discussed further.

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Figure 2: Causal Loop Diagram (CLD).

3.1 REINFORCING LOOP 1 (R1)

The shift in consumer behavior towards online consumption has led to a surge in demand for products and services offered through online retail markets. This shift in consumer preferences has been attributed to the changing lifestyles of people, who now prefer to purchase goods and services online rather than through traditional brick-and-mortar retail stores (Sethuraman et al., 2019; Joshi et al., 2018; Kanchan et al. 2015). As a result, there has been a significant shift in consumer buying patterns, with a reduction in demand for the offline market and a corresponding increase in the online market (Hidayatno et al., 2019). This trend has been further accelerated by the widespread availability of high-speed internet connectivity, the proliferation of smartphones, and the increasing adoption of digital payment systems. As the demand for online retail markets continues to grow, there has been a significant increase in e-commerce orders creating a reinforcing effect, leading to an expansion of the online retail sector's market share (Cheba et al., 2021). This has resulted in a fundamental transformation of the retail landscape, with significant implications for both consumers and businesses alike. The continued growth of the e-commerce economy is expected to drive further changes in consumer behavior and purchasing patterns, leading to a continued shift towards online retail markets and a corresponding reduction in the offline market's share.

3.2 BALANCING LOOP 1 (B1)

The growth of the e-commerce industry has resulted in an increased demand for warehousing space to store inventory at various fulfillment centers, which has led to higher warehousing costs and, in turn, higher prices for online products (Gurtu, 2021). To meet customer demand for faster delivery, e-commerce companies are seeking to install fulfillment centers closer to their customers, which has implications for the cost and availability of suitable real estate. This, in turn, creates a balancing effect on the increased prices of online products. However, the adoption of automation technologies in warehouses has enabled e-commerce companies to optimize space utilization by installing mezzanine systems, which have reduced space requirements, resulting in cost savings and increased efficiency in warehouse operations (Li et al., 2021). This, in turn, has led to faster order fulfillment and improved customer service levels (experts' input), contributing to increased customer loyalty and higher sales volumes. Moreover, the increased adoption of automation technologies in the e-commerce industry is poised to drive further growth (industry report), with increased efficiency and cost savings reducing the impact of the balancing effect on higher prices for online products.

3.3 BALANCING LOOP 2 (B2)

The rise of e-commerce has led to an increase in packaging volume, resulting in a corresponding increase in CO_2 emissions because of the materials used in packing products (Chueamuangphan et al., 2019; Escursell et al., 2021; Hidayatno et al., 2019). As consumers become more aware of their purchasing decisions' environmental impact, they increasingly seek to purchase environmentally sustainable products. This shift in consumer preferences is leading to a loss of customer goodwill among online shoppers when purchasing products that are not environmentally friendly (Rao

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et al., 2021; Khare et al., 2012). Consequently, this shift in consumer perception can lead to a decrease in demand for online products and a corresponding shift towards offline purchases, resulting in a decline in the online retail sector. In turn, this can lead to an increase in the price of online products as e-commerce companies seek to offset the decline in demand, further exacerbating the decrease in consumer perception and leading to a further decrease in demand, creating a balancing effect. This complex interplay between consumer perception, pricing, and demand highlights the importance of developing sustainable practices in the e-commerce industry to mitigate the industry's environmental impact and maintain consumer goodwill and demand for online products. As such, e-commerce companies must proactively implement sustainable packaging practices and communicate these efforts to their customers to maintain consumer trust and meet their evolving expectations.

3.4 BALANCING LOOP 3 (B3)

With the rise of e-commerce, there has been a corresponding increase in the number of deliveries required to fulfill customer orders (expert input). This increase in demand for deliveries has led to a corresponding increase in the number of vehicles required to transport goods, which has led to an increase in the volume of CO_2 emissions generated by the logistics sector (Awwad et al., 2018). These increased emissions have imposed carbon taxes on vehicles, making logistics transport costlier (Hidayatno et al., 2019). As a result, there has been a corresponding increase in the price of online products, which can lead to a decrease in the demand for online products as consumers shift their preferences towards offline retail, creating a balancing effect. This shift in consumer behavior can have significant implications for the e-commerce industry, with decreased demand reducing the viability and profitability of online retail businesses.

Moreover, the increase in transport costs can lead to further increases in the price of online products, creating a feedback loop that can further exacerbate the decline in demand. Ultimately, the sustainability of the e-commerce industry relies on establishing a balance between the need for efficient and cost-effective logistics and the environmental impact of these operations, and this requires a comprehensive and integrated approach that considers the interplay between various factors. Such an approach must also consider consumers' evolving expectations and preferences, who are increasingly seeking environmentally sustainable products and services. As such, e-commerce companies must proactively develop sustainable logistics and supply chain practices that prioritize environmental sustainability while maintaining the affordability and accessibility of their products and services. This can involve investments in renewable energy, using low-emission transport options, and adopting circular economy principles to minimize waste and reduce the environmental impact of packaging.

3.5 REINFORCING LOOP 2 (R2)

The growth of the e-commerce industry has led to an increase in the volume of shipments required to fulfill customer orders, which has led to a corresponding increase in shipment volume per delivery (Hidayatno et al., 2019). E-commerce companies seek to transfer as many products as possible in a single shipment to optimize transport efficiency when shipping products from one fulfillment center to another. This increased shipment volume per delivery leads to increased logistics transport utilization, as the vehicle space is fully utilized. This, in turn, reduces the number of vehicles required to transport goods, resulting in a corresponding decrease in logistics transport costs and a reduction in CO_2 emissions. The decrease in logistics transport costs can lead to a decrease in the price of online products, making them more affordable and accessible to consumers and creating a reinforcing effect. This, in turn, can contribute to an increase in the share of the online retail sector, as consumers are more likely to choose online retailers over traditional brick-and-mortar stores due to the increased affordability of online products. However, to fully realize the benefits of increased shipment volume per delivery, e-commerce companies must adopt sustainable logistics practices, such as using low-emission transport options and optimizing delivery routes to reduce the environmental impact of their operations.

4. **DISCUSSION**

The causal loop diagram (CLD) model developed in this study highlights the complex interplay between various factors that impact the sustainability of the e-commerce industry. The model provides insights into the key drivers of increased CO_2 emissions and their implications for the online retail sector by analysing the cause-and-effect relationships between different variables. The study's findings suggest that policymakers and e-commerce companies can take specific actions to promote sustainable e-commerce practices and mitigate the industry's environmental impact.

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One critical insight from the CLD model is the importance of consumer behaviour in driving the growth of the online retail sector. As consumers increasingly shift their purchasing preferences towards online channels, there is a corresponding increase in the demand for e-commerce products and services. However, as the study highlights, consumer awareness of CO_2 emissions associated with online retail operations can have a negative impact on consumer perception and, in turn, the online retail sector. Thus, e-commerce companies must prioritize sustainable practices, such as using low-emission transport options and sustainable packaging materials, to maintain consumer trust and drive long-term growth.

Another key insight from the study is the importance of automation in fulfilment centres. The increasing automation of fulfilment centres can lead to faster delivery times and greater efficiency in warehouse operations, which can improve the customer experience and encourage repeat purchases. However, the study also highlights the cost implications of holding inventory in fulfilment centres, which can lead to increased prices for online products and, in turn, a decrease in the online retail sector. Thus, e-commerce companies must balance the benefits of automation with the need to maintain affordable prices for consumers.

The study also highlights the importance of effective transport utilization in reducing the environmental impact of the e-commerce industry. By optimizing transport routes and increasing shipment volume per delivery, e-commerce companies can reduce the number of vehicles required to transport goods, leading to a corresponding decrease in CO_2 emissions and transport costs. However, the study also highlights the potential negative impact of increased vehicle use on the price of online products, as carbon taxes and other emissions-related costs can be passed on to consumers.

Overall, the CLD model developed in this study offers valuable insights into the complex interplay between various factors impacting the sustainability of the e-commerce industry. By highlighting the key drivers of increased CO_2 emissions and their implications for the online retail sector, the model provides a basis for policymakers and e-commerce companies to develop sustainable practices that balance the needs of consumers, logistics efficiency, and environmental sustainability. This can involve the adoption of circular economy principles, the use of low-emission transport options, and the optimization of delivery routes, among other measures. Ultimately, by taking a comprehensive and integrated approach to sustainability, e-commerce companies can drive long-term growth and enhance their reputation as responsible corporate citizens. Based on the findings of the study, the following recommendations can be made to promote sustainable e-commerce practices:

4.1 CONSUMER:

The shift in consumer behaviour from offline to online purchasing requires a focus on consumer behaviour and perception when CO_2 emissions due to e-commerce are considered.

- Customers should be encouraged to buy more items in one order, thus increasing the basket size of the products. The emissions per item increase inversely with basket size.
- The type of packaging also plays an essential role in consumer perception. The perception of the consumer changes whether the packaging is corrugated or plastic.
- Efficient utilization of the space in the delivery package also leads to changes in consumer perception.
- Communicate sustainability efforts to consumers: E-commerce companies should be transparent about their sustainability efforts and communicate these efforts to consumers to build consumer trust and drive long-term growth. This can involve providing information on sustainable packaging materials, low-emission transport options, and other sustainability initiatives to consumers through marketing and communication channels.
- An environmental rating of the products regarding environmental sustainability can also lead to a perception change among consumers.
- Implement recycling and waste reduction programs to minimize waste and reduce the environmental impact of packaging.

4.2 INVENTORY:

• The location of fulfilment centers near the delivery location can lead to a reduction in distance travelled by the vehicle reducing CO₂ emission. In addition to this, there will also be a reduced holding cost of the inventory as the inventory will be delivered as soon as it gets stored in the nearby fulfilment centres.

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• Balance automation with affordability: While the automation of fulfilment centres can lead to faster delivery times and greater efficiency in warehouse operations, e-commerce companies must balance the benefits of automation with the need to maintain affordable prices for consumers. This can involve exploring alternative delivery models, such as click-and-collect or locker pick-up, to reduce the cost of logistics transport and minimize the environmental impact of their operations.

4.3 TRANSPORT:

- Use of electric vehicles: It has attracted much attention as Amazon India has already been working towards using an electric fleet of vehicles. Towards commitment to electric mobility in the country, the e-commerce giant has announced a collaboration with Mahindra Electric.
- Use of drones: For delivering lightweight items, drones can be used, thus reducing emissions and faster delivery of products.
- Optimize delivery routes: E-commerce companies should optimize delivery routes to reduce the number of vehicles required to transport goods, leading to a corresponding decrease in CO₂ emissions and transport costs. This can be achieved through the use of advanced data analytics and artificial intelligence tools to optimize delivery routes and minimize the environmental impact of transport operations.
- Additionally, e-commerce companies can leverage data analytics and artificial intelligence to optimize logistics operations, reduce delivery times, and minimize the environmental impact of their operations. By taking a holistic and proactive approach to sustainability, e-commerce companies can not only reduce their environmental impact but also enhance their brand reputation, build consumer trust, and drive business growth over the long term.

Collaborate with stakeholders: E-commerce companies should collaborate with stakeholders, such as policymakers, suppliers, and consumers, to drive sustainable practices and promote environmental sustainability in the industry. Invest in renewable energy: E-commerce companies can invest in renewable energy sources, such as solar or wind power, to power their operations and reduce their dependence on fossil fuels. This can help to reduce the environmental impact of their operations and build a reputation as environmentally responsible corporate citizens. The recommendation summarized and conclusion have been provided in Table 3.

 Table 3: Recommendations and conclusions.

	1.a Behaviour	1.b Perception
1.Consumer	The shift in consumers from offline to online purchases increases the online retail sector (+)	Awareness of CO_2 emissions due to different operations of online retailing leads to reduced perception thus reducing the online retail sector (-)
Recommendation	 Type of packaging: corrugate Efficient utilization of space Rating the products for envir 	ed or plastic in the delivery package conmental sustainability
	2.a Automation	2.b Holding cost
2.Inventory	An increase in automation of fulfilment centres leads to efficient operations which increases the online retail sector (+)	Inventory storage in different fulfilment centres leads to an increase in holding cost which leads to an increase in the price of online products, reducing online retailing (-)
Recommendation	 The location of fulfilment centres near delivery locations can lead to a reduction in the distance travelled by the vehicle leads to a reduction in CO₂ emissions. This will also reduce the holding cost of the inventory. 	
	3.a Utilization	3.b Number of vehicles
3.Transport	Effective utilization of vehicles leads to less transit time for	Increased number of vehicles for deliveries leads to an increase in CO_2 emissions which in turn imposes a carbon

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	products to be delivered leading to on-time delivery thus increasing the online retail sector (+)tax on vehicles increasing the price of online products and encouraging consumers to purchase offline thus reducing the online retail sector	Į
Recommendation	 Use of electric vehicles: Amazon has collaborated with Mahindra Electric towards the commitment to electric mobility in the country Use of drones: This is a future possibility that lightweight products can be delivered through drones to the consumers 	

5. Limitations and Scope for Future Work

Like other studies, this study also has its limitations. Causal loop diagrams are qualitative and do not provide a quantitative representation of the relationships among variables. It is difficult to determine the strength and direction of the relationships and to measure the impact of changes in one variable on the system. A quantitative analysis of the study can be done further. In the future, the research questions can be explored, as discussed in Table 4.

Table 4: Future Research Themes

Theme	Research question	Reference
E-commerce returns	How does the rate of e-commerce return in India affect CO ₂ emissions?	(Hjort, 2016)
Traffic congestion	How does traffic congestion affect CO_2 emissions from e-commerce in Indian cities and what solutions can be implemented?	(Peng, 2019)
Renewable energy	What is the potential for using renewable energy sources to power e-commerce operations and reduce CO_2 emissions in India, and what are the challenges and opportunities?	(Imran et al., 2023)

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