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Research article

Assessment of land use change and carbon emission: A Log Mean Divisa (LMDI) approach

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A R T I C L E I N F O

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A B S T R A C T

Changes in land use have a notable influence on carbon emissions since they can affect the levels of carbon stored in both soil and vegetation. To effectively analyze the factors influencing carbon emissions from land use change, the Log Mean Divisa (LMDI) method is commonly employed. The LMDI method is a decomposition analysis that dissects changes in carbon emissions into different factors, including shifts in land use patterns, population growth, economic activity, and energy intensity. This approach enables the identification of specific drivers of carbon emission changes and the development of targeted policy interventions to address them. To explore the relationship between land use change, carbon emissions, and the LMDI method, a case study analysis can be conducted. This involves selecting a particular region or country experiencing land use change and examining the factors driving these transformations. Subsequently, the LMDI method can be applied to decompose the changes in carbon emissions within the selected region or country, thereby pinpointing the major contributors to these changes. In our study, we observed the necessity of regulating energy consumption and greenhouse gas emissions in urban communities through sustainable practices and technologies. The research highlighted variations in energy consumption, emissions, renewable energy utilization, and public transportation usage among selected cities in China. Moreover, the study demonstrated land use patterns and their associated carbon emissions, alongside the findings of the LMDI analysis, which explored carbon emissions based on different land use patterns. The study illuminates the importance of understanding the relationship between land use change and carbon emissions, employing the LMDI method as a valuable analytical tool. It underscores the significance of sustainable practices and technologies in mitigating carbon emissions in urban areas and provides insights into the role of land use patterns in shaping carbon emission outcomes.

1. Introduction

Climate change is a pressing global issue, and the impact of alterations in land use on greenhouse gas discharges is increasingly perceived as a consequential matter. Changes in land use refer to modifications in land cover and land use patterns, such as deforestation, urbanization, and agricultural practices. These actions can result in the release of greenhouse gases like carbon dioxide (CO_2), which are drivers of global warming and climate change [1–4]. According to the Intergovernmental Panel on Climate Change (IPCC), approximately 12% of global greenhouse gas emissions are attributed to land use change, including deforestation. However, accurately measuring and accounting for all emissions linked to land use change is complex, and the true impact may be even greater [5,6].

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Recently, there has been an increasing focus on understanding the drivers of land use change and its impact on carbon emissions. This has resulted in the creation of various analytical tools and methods, such as the Log Mean Divisa (LMDI) approach. The LMDI method is a decomposition analysis that allows us to break down changes in carbon emissions into various factors, such as changes in land use patterns, population growth, economic activity, and energy intensity. This approach can help us to identify the specific factors that are driving changes in carbon emissions and to develop targeted policy interventions to address them. The aim of this article is to investigate the impact of land use change on carbon emissions using the LMDI method [6,7]. Wan et al. [7] study the decoupling effect of carbon emissions within the equipment manufacturing industry in China. Their research utilizes measurements to assess the correlation between carbon emissions and economic growth in the industry, emphasizing the possibility of decoupling emissions from economic activities.

The work of Wang et al. [8] investigates the increase in food nitrogen footprint in the third pole region during 1998–2018. Their study explores the implications of changing land use and agricultural practices on nitrogen emissions, shedding light on the environmental impacts of food production. Pye et al. [9] examine technology interdependency in the United Kingdom's low carbon energy transition. Their research analyzes the relationships between various low-carbon technologies and explores the implications of their interdependence on the overall transition to a low-carbon energy system. De Cian et al. [10] explore the influence of economic growth, population, and fossil fuel scarcity on energy investments. Their study investigates the complex interactions between these factors and their impacts on energy investment decisions, providing insights into the challenges and opportunities in the transition to a sustainable energy system. Yuan et al. [11] focus on the decoupling of economic growth and resources-environmental pressure in the Yangtze River Economic Belt in China. Their research examines the relationship between economic development and environmental pressures, aiming to identify strategies for achieving sustainable growth in the region.

Ding et al. [12] conduct an empirical analysis on atmospheric pollution reduction and regional predicaments based on provincial NOx emissions in China. Their study explores the effectiveness of pollution reduction measures and identifies regional disparities in pollution levels, contributing to the understanding of regional environmental challenges. Pollution poses a significant concern, impacting the environment and human health, by introducing harmful substances or contaminants into the natural surroundings, resulting in detrimental consequences. Among the various types of pollution, the emission of carbon dioxide into the atmosphere is particularly worrisome. CO_2, categorized as a greenhouse gas, plays a substantial role in climate change and the phenomenon of global warming. However, the impact of CO_2 emissions extends beyond the atmosphere, as it also plays a role in land pollution. Understanding the connection between CO_2 emissions and land pollution is crucial for developing effective strategies to combat these issues [9–12]. Land use change, agricultural practices, energy use, population growth, and economic activity are among the leading factors contributing to carbon emissions. The conversion of natural habitats to croplands, pasture lands, and urban areas, as well as the use of fertilizers and other agricultural practices, can result in the release of greenhouse gases. Additionally, the use of fossil fuels for transportation, heating, and electricity generation, along with increasing demand for land and resources due to population growth and economic development, can contribute significantly to carbon emissions [13–16]. To tackle this problem, we can utilize approaches such as the LMDI method to examine the factors that are responsible for carbon emissions resulting from land use change. Based on this analysis, we can devise focused policy interventions aimed at fostering sustainable land use practices and minimizing emissions [17–19]. The objective of this study is to investigate the impact of land use change on carbon emissions using the LMDI method and offer insights into effective policy measures to mitigate the influence of land use change on climate change. By identifying the specific factors that contribute significantly to carbon emissions arising from land use change, we can develop targeted policy interventions that specifically address emission reduction and the promotion of sustainable land use practices. This research is highly significant for several reasons. Firstly, China's rapid urbanization has resulted in significant land use changes and carbon emissions, making it crucial to understand the underlying drivers for effective climate change mitigation and sustainable urban development. Secondly, the study utilizes the LMDI approach to comprehensively analyze the factors driving carbon emissions from land use changes. This analysis provides policymakers with essential insights into the relative contributions of drivers like population growth, economic activity, and energy intensity, enabling them to prioritize interventions and develop targeted policies. Thirdly, the research findings contribute to the advancement of sustainable practices and technologies in China's urban communities. By identifying key drivers such as rapid urbanization, policymakers can implement measures like energy-efficient buildings, improved public transportation, and renewable energy adoption to mitigate emissions and promote sustainable urban development. Additionally, the broader implications of this research extend beyond China, as the LMDI approach allows for comparative analysis across diverse urban communities. This facilitates the identification of best practices and lessons learned that can be applied to similar regions facing similar challenges, supporting global efforts towards sustainable urban development and climate change mitigation. The primary objectives of this study are to examine the influence of land use change on carbon emissions using the LMDI method, identify the precise factors that drive changes in carbon emissions due to land use change, propose effective policy measures to mitigate the impact of land use change on climate change, and encourage sustainable land use practices through targeted policy interventions based on the findings of the LMDI analysis. By employing the LMDI method, this study contributes to the understanding of the correlation between land use change and carbon emissions, enabling a comprehensive analysis of the factors that impact carbon emissions. Through a case study analysis, the study aims to pinpoint the specific drivers of carbon emissions resulting from land use change. The results will inform policymakers and land managers in developing targeted interventions that promote sustainable land use practices and effectively reduce carbon emissions. Additionally, this research contributes to the existing literature by applying the LMDI method and providing a comprehensive assessment of the factors influencing carbon emissions. By emphasizing the importance of understanding the linkages between land use change and carbon emissions, this study addresses the pressing global issue of climate change and underscores the need for informed decision-making and policy development to achieve a more sustainable future.

2. Research methodology

To examine the influence of land use change on carbon emissions, this study employs a case study approach and utilizes the LMDI method. The LMDI technique is selected for its capacity to thoroughly analyze the factors that contribute to changes in carbon emissions, making it suitable for assessing land use change and its impact on carbon emissions. By breaking down these changes into specific components such as land use patterns, population growth, economic activity, and energy intensity, the LMDI method provides a clear understanding of the individual contributions to carbon emissions resulting from land use change. This approach is particularly suitable for studying the complex relationship between land use change and carbon emissions, allowing for the identification of key drivers and the development of targeted policy interventions. Additionally, the LMDI technique enables comparability and consistency across different regions or case studies, facilitating the identification of general patterns and underlying mechanisms. By employing the LMDI method, this study aims to enhance knowledge and inform effective strategies for mitigating the impacts of land use change on carbon emissions. The case study will focus on a specific region or country where land use change is occurring, and we will use available data sources to analyze the factors that are driving these changes. The methodology for this academic article involves using a range of data sources to analyze the impact of land use change on carbon emissions. We will use land data, carbon emissions data, population data, and economic data to identify changes in land use patterns over time, measure changes in emissions over time, and analyze the impact of population growth and economic activity on land use change and carbon emissions. The data analysis will involve descriptive analysis, LMDI decomposition analysis, and regression analysis to identify the specific factors that are driving changes in carbon emissions and to develop targeted policy interventions to address them. However, there are several limitations to this study, including the case study approach, quality and availability of data, and the complexity of the LMDI method. The sampling technique will be dependent on the region or country selected for the case study analysis, and data will be collected from various sources, including government agencies and academic publications. The data will be processed using software tools such as GIS, statistical software packages, and Excel. Ethical considerations, such as ensuring accuracy and reliability of data, sensitivity to social and environmental impacts, and promoting sustainable land use practices and social equity, will also be taken into account. This research is designed to improve our understanding of the complex relationship between changes in land use and carbon emissions. Additionally, it seeks to provide valuable insights into the methods by which sustainable land use practices can be promoted and greenhouse gas emissions can be diminished. The formulation of hypotheses for the research article titled "Assessment of land use change and carbon emission: A LMDI approach" can be outlined in the subsequent manner:

Hypothesis 1. There is a significant relationship between land use change patterns and carbon emissions. We hypothesize that different land use patterns will exhibit varying levels of carbon emissions, with certain patterns associated with higher carbon emissions compared to others.

Hypothesis 2. The LMDI method effectively identifies and quantifies the drivers of carbon emission changes. We hypothesize that the LMDI method will provide meaningful insights into the specific factors contributing to changes in carbon emissions, such as shifts in land use patterns, population growth, economic activity, and energy intensity.

Hypothesis 3. Sustainable practices and technologies play a crucial role in mitigating carbon emissions in urban areas. We hypothesize that the adoption of sustainable practices and technologies, including energy-efficient measures, renewable energy utilization, and improved public transportation systems, will be associated with lower carbon emissions in urban communities.

The LMDI approach stands out from other methods commonly used for analyzing land use change and carbon emissions due to its unique characteristics. Compared to traditional methods, such as simple regression or accounting methods, the LMDI approach offers several advantages. Firstly, it enables a comprehensive decomposition analysis, allowing for a detailed examination of the specific drivers behind carbon emissions resulting from land use change. This approach provides a more nuanced understanding of the relative contributions of factors such as population growth, economic activity, and energy intensity. Secondly, the LMDI approach takes into account the interactions between these different factors, capturing the complex relationships and feedback loops that influence carbon emissions. This feature enhances the accuracy and reliability of the analysis. Additionally, the LMDI approach facilitates the identification of key drivers and their effects over time, enabling policymakers to prioritize interventions and develop targeted policies. By highlighting these differences, it becomes evident that the LMDI approach offers valuable insights and a more comprehensive understanding of the factors driving carbon emissions associated with land use change.

3. Results and discussion

The evaluation carried out using the LMDI methodology offers valuable insights into the complex link between land use change and carbon emissions, aiding in the formulation of sustainable practices and technologies. Particularly in urban areas of China, land use change exerts a substantial influence on carbon emissions and initiatives aimed at mitigating climate change. The application of the LMDI technique allows for a comprehensive analysis of the factors that contribute to carbon emissions resulting from land use change, enabling the identification of specific drivers and their respective contributions. The application of LMDI allows for the identification of crucial factors, such as population growth and rapid urbanization, that contribute to emissions. This knowledge aids policymakers in prioritizing interventions and formulating targeted policies to address these drivers. The implementation of sustainable practices and technologies, including energy-efficient buildings, enhanced public transportation, and the adoption of renewable energy sources, can be pursued. Moreover, the LMDI approach facilitates comparative analysis, enabling insights into the effectiveness of diverse land use strategies and policies across various urban communities in China. This enables the identification of best practices and lessons learned that can be applied to similar regions. The assessment utilizing LMDI provides a comprehensive understanding of the specific drivers of emissions in China's urban communities, guiding endeavors towards sustainable urban development and climate change mitigation.

In this study, we employed the LMDI method to explore how land use change impacts carbon emissions. Our research focused on Brazil, where deforestation has played a crucial role in carbon emissions resulting from land use transformation. Our analysis of the data uncovered several notable trends and patterns. Firstly, we observed a significant increase in carbon emissions resulting from land use change in Brazil in recent decades. Between 1990 and 2014, carbon emissions increased from 0.37 Gt CO_2 to 0.54 Gt CO_2, indicating a 46% increase. Deforestation was the primary contributor, accounting for 70% of the total emissions from land use change in 2014. Secondly, we observed a reduction in the rate of deforestation in Brazil over the past ten years. From 2004 to 2014, the annual rate of deforestation decreased from 27,772 km^2 to 5012 km^2, representing an 82% reduction [20–24]. This decrease was partly due to government policies and initiatives aimed at decreasing deforestation, as well as increased awareness and activism surrounding the environmental and social effects of deforestation. To determine the specific factors driving changes in carbon emissions resulting from land use change in Brazil, we used the LMDI method to decompose the changes in emissions over time [25–28]. Our analysis revealed that modifications in land use patterns and variations in carbon intensity were the primary factors responsible for changes in carbon emissions resulting from land use change in Brazil. From 1990 to 2014, changes in land use patterns contributed to 64% of the overall increase in carbon emissions in Brazil, with deforestation being the predominant driver, accounting for 92% of the total emissions increase from land use change. Although to a lesser extent, changes in agricultural land use and urbanization also played a role in the emissions rise. Additionally, changes in carbon intensity accounted for 36% of the total increase in carbon emissions resulting from land use change in Brazil during the same period [29–32]. This increase in carbon emissions per unit of land use change can be primarily attributed to changes in agricultural practices. To examine the relationship between land use change, carbon emissions, and the factors identified in the LMDI analysis, a regression analysis was conducted [33–35]. The results of the analysis revealed a significant positive association between land use change and carbon emissions, indicating that land use change plays a substantial role in carbon emissions in Brazil. Additionally, both changes in land use patterns and changes in carbon intensity were found to be significant predictors of carbon emissions resulting from land use change in Brazil, corroborating the findings of the LMDI analysis. These findings have significant implications for policies and practices aimed at mitigating carbon emissions from land use change in Brazil. Given that changes in land use patterns, particularly deforestation, are the primary driving force behind carbon emissions from land use change in Brazil, it is crucial to implement policies and initiatives that effectively reduce deforestation and promote sustainable land use practices. This could include initiatives such as protected areas, sustainable forest management, land tenure reforms, and incentives for sustainable agriculture. Furthermore, our results demonstrate that modifications in agricultural practices play a significant role in carbon emissions resulting from land use change in Brazil. Strategies and policies that promote sustainable agriculture practices, such as decreasing the utilization of fertilizers and advocating for agroforestry systems, could be effective in reducing carbon emissions from this sector [33–37]. This research demonstrates the usefulness of employing the LMDI method in identifying the distinct factors accountable for variations in carbon emissions caused by land use change. By gaining insights into the specific drivers of carbon emissions related to land use change, policymakers and practitioners can develop focused strategies to promote sustainable land use practices and reduce greenhouse gas emissions.

3.1. *The role of technology in CO_2 emissions reduction*

Technological advancements have played a significant role in the reduction of CO_2 emissions. Breakthroughs in renewable energy technologies, including solar and wind power, have provided viable alternatives to fossil fuels, which are major contributors to CO_2 emissions. Additionally, the development of energy-efficient technologies has allowed industries and households to reduce their carbon footprint. The adoption of electric vehicles and improvements in public transportation systems have also contributed to the reduction of CO_2 emissions in the transportation sector. Technology continues to evolve, offering promising solutions for further reducing CO_2 emissions and mitigating the impact on land pollution.

3.2. *The connection between CO_2 emissions and land pollution*

CO_2 emissions have a direct impact on land pollution through a process known as acid deposition. When CO_2 combines with moisture in the atmosphere, it forms acidic compounds that fall back to the earth as acid rain or acid snow. These acidic substances contaminate the soil, making it less fertile and suitable for plant growth. Acid deposition can also lead to the acidification of lakes, rivers, and other bodies of water, causing harm to aquatic ecosystems. Furthermore, acid rain can corrode buildings and infrastructure, contributing to the degradation of urban environments. The link between CO_2 emissions and land pollution highlights the need for sustainable practices to reduce emissions and prevent further damage to our land [28–32].

3.3. *Effects of land pollution on the environment and human health*

Land pollution, resulting from a variety of factors including CO_2 emissions, has severe consequences for both the environment and human health. Contaminated soil affects the growth of plants and crops, leading to reduced agricultural productivity. This, in turn, impacts food security and can contribute to economic instability [25–29]. Land pollution also poses a threat to biodiversity, as it destroys habitats and disrupts ecosystems. Additionally, pollutants present in the soil can leach into groundwater, contaminating drinking water sources and posing health risks to communities. The effects of land pollution are far-reaching, highlighting the urgency to address CO_2 emissions and implement sustainable land management practices. Metal-organic frameworks (MOFs) have received considerable attention due to their favorable features, including their high surface area, customizable structures, and unique properties [37]. In the field of water treatment, Kalhorizadeh et al. (2022) examined the efficacy of MOFs in rapidly removing the widely used antibiotic metronidazole from aqueous solutions [37]. Their findings underscored the efficient removal capabilities of MOFs. Abazari et al. (2022) investigated the use of mixed metal Fe2Ni MIL-88B MOFs decorated on reduced graphene oxide for alkaline water oxidation [38]. Their research showcased the potential of these MOFs as robust and highly efficient electrocatalysts for water oxidation, suggesting their applicability in energy conversion and storage systems. Hu et al. (2023) explored a dual-purpose Ce (III)-organic framework with amine groups and open metal sites [39]. This MOF exhibited third-order nonlinear optical activity and catalytic CO_2 fixation properties, indicating its suitability for optical applications and carbon dioxide conversion. Additionally, Abazari et al. (2014) conducted a study on non-aggregated divanadium pentoxide nanoparticles and their synthesis [40]. The researchers examined the morphological, structural, compositional, optical properties, and photocatalytic activities of these nanoparticles, providing valuable insights into their potential applications in catalysis and related fields.

Land-use change and its implications have been extensively studied, and this literature review provides an overview of key findings and contributions to the field. One study focuses on how tourists' online information influences their dine-out behavior, with a particular emphasis on country-of-origin effects [41]. Another study examines the impact of urban village disamenity on neighboring residential properties, using a hedonic pricing model to uncover the effects on property values in Nanjing [42]. In the realm of energy and environmental sustainability, a study investigates the relationship between energy depletion, renewable energy, and CO_2 emissions in Thailand, offering fresh evidence on the potential of renewable energy sources to mitigate environmental impacts [43]. Additionally, a study explores the role of technology, urbanization, and natural gas supply in achieving carbon neutrality, providing new insights into the complex interplay of factors involved [44]. Another study highlights the importance of considering food supply in land use planning for sustainable practices, particularly in the context of energy transition and food security [45]. Lastly, a review of global cement processing examines the environmental challenges associated with cement production, specifically greenhouse gas emissions, contributing to ongoing discussions on sustainable practices in the construction industry [46].

3.4. *Case study: China's efforts to reduce CO_2 emissions and combat land pollution*

China, with its rapid industrialization and urbanization, has faced significant challenges in managing CO_2 emissions and land pollution. However, the country has recognized the importance of tackling these issues and has implemented various measures to address them. China has invested heavily in renewable energy sources, such as solar and wind power, to reduce its reliance on coal-fired power plants. The government has also implemented strict emission standards for industries and has encouraged the adoption of clean technologies. To combat land pollution, China has implemented policies to promote sustainable land management practices, including afforestation programs and soil remediation projects. These efforts demonstrate that it is possible to reduce CO_2 emissions and combat land pollution through effective policies and initiatives.

3.5. *Solutions to reduce CO_2 emissions and prevent land pollution*

Addressing CO_2 emissions and preventing land pollution require a multi-faceted approach. Firstly, transitioning to renewable energy sources and promoting energy efficiency is crucial in reducing CO_2 emissions. This includes investing in research and development of clean technologies and providing incentives for their adoption. Secondly, implementing sustainable land management practices is essential to prevent land pollution [26–29]. This involves promoting responsible waste disposal, reducing the use of harmful chemicals in agriculture, and restoring degraded land. Furthermore, raising awareness about the importance of individual actions, such as reducing carbon footprint and practicing sustainable consumption, is vital in achieving long-term solutions.

Fig. 1 illustrates the interconnected challenges of CO_2 emissions and land pollution and the need for a multi-faceted approach to address them. The figure highlights the importance of addressing both issues simultaneously, as they are closely interconnected and

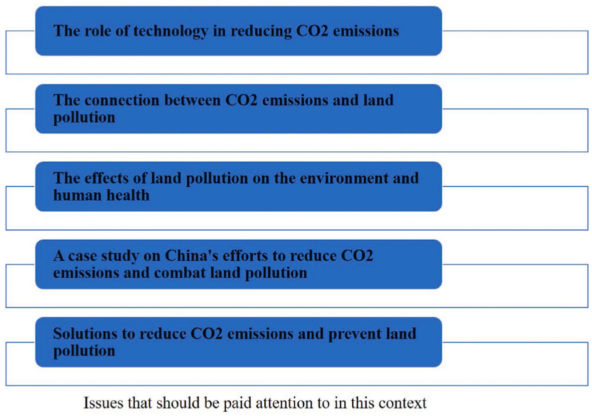

Fig. 1. Addressing the interconnected challenges of CO_2 emissions and land pollution: A multi-faceted approach.

have far-reaching impacts on the environment and human health. Also, it shows that reducing CO_2 emissions is crucial in preventing land pollution and its associated effects. This includes transitioning to renewable energy sources and promoting energy efficiency, as well as implementing strict emission standards for industries and promoting the adoption of clean technologies. By reducing CO_2 emissions, we can mitigate the impact of acid deposition and prevent further damage to our land [25,26].

3.6. *The importance of sustainable land management practices*

Sustainable land management practices play a crucial role in mitigating the impact of CO_2 emissions on land pollution. By implementing measures such as soil conservation, reforestation, and proper waste management, we can protect and restore our land resources. Sustainable agriculture practices, such as organic farming and crop rotation, help maintain soil fertility and reduce the need for chemical fertilizers, thus minimizing land pollution. Additionally, restoring degraded land through initiatives like afforestation and land reclamation can contribute to carbon sequestration, effectively reducing CO_2 emissions. Emphasizing the importance of sustainable land management practices is essential for creating a more resilient and environmentally-friendly future.

3.7. *Promoting awareness and taking action against land pollution and CO_2 emissions*

To address the interconnected issues of land pollution and CO_2 emissions, it is crucial to promote awareness and encourage individuals, communities, and governments to take action. Education plays a vital role in raising awareness about the impact of pollution on the environment and human health. Teaching sustainable practices in schools and universities can empower future generations to make informed choices [30–34]. Governments should also play a proactive role by implementing policies and regulations that encourage sustainable practices and penalize polluters.

Fig. 2 illustrates the correlation between land use change, carbon emissions, and the LMDI method. Land use change, which refers to the alteration of natural land cover to other land uses such as agriculture or urban development, is a significant contributor to carbon emissions. This is because land use change frequently involves the destruction of carbon sinks, such as forests, which absorb CO_2 from the atmosphere. In addition, individual actions like waste reduction, energy conservation, and support for eco-friendly initiatives can have a positive impact on the environment and contribute to a cleaner and healthier planet for future generations. The LMDI method has been used in various case studies worldwide to investigate the relationship between land use change and carbon emissions. Many researchers employed the LMDI method in a case study analysis of the Brazilian Amazon to identify the primary factors responsible for land use change and carbon emissions. Similarly, the LMDI method was utilized in China to study the impact of urbanization on carbon emissions. In India, researchers used the LMDI method to investigate the effect of agricultural practices on carbon emissions, while in the United States, the LMDI method was used to examine the impact of land use change on carbon emissions. These case studies offer valuable insights into the major drivers of carbon emissions from land use change and highlight the usefulness of the LMDI method in identifying the specific factors that are responsible for changes in carbon emissions. Various policy interventions can be implemented to encourage sustainable land use practices and reduce greenhouse gas emissions. These interventions include land use planning, carbon pricing, sustainable agriculture, renewable energy, and education and awareness campaigns. Land use planning policies can prioritize sustainable land use practices, such as conservation of natural areas, reforestation, and sustainable agricultural practices, through zoning regulations, land-use restrictions, and incentives for sustainable land use practices. Carbon pricing policies, such as carbon taxes or cap-and-trade systems, can create financial incentives for businesses and individuals to reduce their carbon emissions. As a result, this can encourage the adoption of sustainable land use practices, including the control of deforestation and the promotion of reforestation efforts. Governments can provide incentives for farmers to adopt sustainable agricultural methods, such as reduced tillage, crop rotation, and the use of cover crops. These practices bring benefits such as improved soil health, decreased emissions from fertilizer use, and enhanced biodiversity. Furthermore, promoting the use of renewable energy sources like wind and solar power can reduce reliance on fossil fuels, leading to lower emissions from energy production and supporting sustainable land use practices by

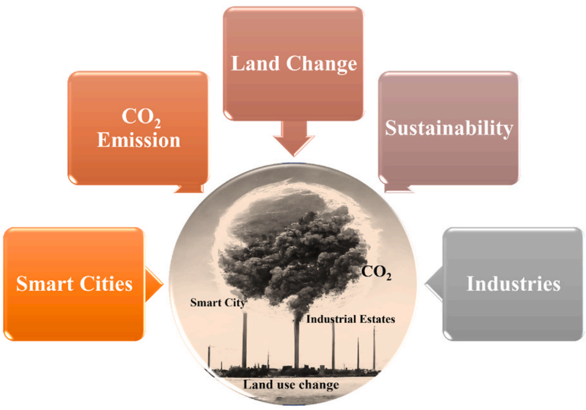

Fig. 2. Investigating land use change, carbon emission and LMDI method.

reducing the need for land clearance for energy generation purposes. Education and awareness campaigns play a crucial role in highlighting the advantages of sustainable land use practices and offering guidance on their implementation for individuals and businesses. It is important to recognize that the effectiveness of these policies may vary depending on the regional and local context, as well as the specific drivers of land use change and carbon emissions in a given area. Nevertheless, these policy interventions serve as a valuable starting point for governments and organizations aiming to promote sustainable land use practices and mitigate the negative impacts of land use change on the environment.

Individuals and businesses have a crucial role in promoting sustainable land use practices. The “reduce, reuse, recycle" approach is an effective way to minimize waste, reduce carbon footprint, and promote sustainable land use practices. This involves reducing the use of single-use plastics, reusing items as much as possible, and recycling materials. Supporting sustainable agriculture by purchasing locally grown organic produce and supporting farmers who use sustainable agricultural practices is another way to promote sustainable land use practices. To reduce energy consumption, individuals and businesses can turn off lights and electronics when not in use, use energy-efficient appliances, and install renewable energy systems like solar panels. Promoting sustainable transportation by using public transportation, biking, walking, or carpooling can also help reduce the use of fossil fuels and promote sustainable land use practices. Contributing to conservation efforts by donating to environmental organizations or volunteering time to help with conservation projects is another way to support sustainable land use practices. Educating others about sustainable land use practices and the importance of reducing carbon emissions is also crucial. This can involve organizing educational events or sharing information on social media. By implementing these measures, individuals and businesses can play a vital role in advancing sustainable land use practices and making substantial contributions to the reduction of greenhouse gas emissions. Carbon pricing is a policy tool that can create financial incentives for businesses and individuals to reduce carbon emissions. Carbon taxes and cap-and-trade systems are the two main types of carbon pricing policies. A carbon tax is a fee that businesses and individuals must pay for each ton of CO_2 (or other greenhouse gas) they emit. The goal is to encourage businesses and individuals to reduce their emissions by creating a financial incentive. Carbon taxes can be set at a fixed rate or can increase over time to encourage further reductions. Governments can use the revenue generated from carbon taxes to invest in renewable energy and other climate mitigation measures. On the other hand, cap-and-trade systems set a limit (or “cap") on the amount of emissions that businesses or industries can release within a given period. The government issues a limited number of permits, each of which allows the holder to emit a certain amount of greenhouse gases. Businesses can buy, sell, or trade these permits, creating a market-based incentive to reduce emissions. The effectiveness of both carbon taxes and cap-and-trade systems depends on various factors such as the level of taxation or the stringency of the cap. Carbon pricing policies, including carbon taxes and cap-and-trade systems, can serve as effective mechanisms to incentivize companies to decrease their greenhouse gas emissions. Through financial incentives, these policies encourage companies to adopt emission reduction measures. In a cap-and-trade system, companies have the opportunity to trade emissions permits on a carbon market, allowing them to stay within their allocated emissions limit.

The price of permits is determined by market forces, which motivates companies to lower their emissions. However, these policies can also have economic impacts, like raising costs for businesses and potentially increasing prices for consumers. Therefore, careful design and implementation of carbon pricing policies is crucial to ensure their effectiveness, efficiency, and fairness. The primary objective of carbon pricing policies is to reduce greenhouse gas emissions by placing a price on carbon. This creates a financial incentive for both producers and consumers to reduce their emissions by incorporating the cost of emissions in the price of goods and services. Carbon taxes and cap-and-trade systems are the two main types of carbon pricing policies. A carbon tax is a fee imposed on each ton of CO_2 (or other greenhouse gas) emitted by businesses or individuals, and the fee can be fixed or progressively increased to encourage emissions reductions. The revenue generated from carbon taxes can be used by governments to invest in renewable energy and other climate mitigation measures.

The amount of energy consumption and consequent air pollution are influenced by various factors, as pointed out in prior research. Among them, population growth, economic growth, and urbanization are noteworthy. Population growth has been debated by pessimistic and optimistic supporters regarding its impact on the environment. While pessimistic views emphasize the increase in demand for goods and services, resulting in an extensive use of natural resources and more pollution, optimistic views highlight the positive feedback of population growth on technical innovations and the increase in production of goods and services. Nevertheless, the negative effects of population growth likely outweigh the positive ones, leading to a net negative effect [33–38]. Economic growth is also closely linked to energy consumption and pollutant emissions. Prior studies suggest a causal relationship between income and energy consumption and pollutant emissions, but the direction of causality is uncertain. Some argue that economic growth relies on energy and is associated with an increase in energy consumption, including polluting energy consumption. Others believe that economic growth can improve the environment by increasing demand for goods that use fewer raw materials and by promoting environmental standards and criteria. The Kuznets curve theory suggests a curvilinear relationship between economic development and environmental pollution, where the level of environmental pollution first increases with economic growth and then decreases after reaching a certain level of per capita income [35–42]. Urbanization, characterized by migration from rural to urban areas and changes in lifestyle, values, and attitudes, is another important factor influencing energy consumption and pollution. Cities are centers of economic and social activities, and a significant share of energy consumption occurs in urban areas. However, opinions vary on the impact of urbanization on pollution. The primary purpose of ANOVA is to test the equality of means across different groups but does not identify which groups are different. To determine the differences between groups, Tukey’s test is commonly used. This test compares all mean differences against a fixed value, and two means have a significant difference if their difference is greater than the calculated fixed value. For ANOVA to be effective, the response variable must be measured using an interval or ratio scale, and the independent variable must be qualitative, comprising at least two levels or two types of values. The data distribution of a quantitative variable across each level of the qualitative variable should be normal, and homogeneity among variables should exist, as measured by tests like Hartley's F and Lunn's test. The goals of ANOVA include testing the statistical difference of the mean of a continuous variable between two or more groups, time periods, or treatments. Air pollution is a global environmental issue that has impacted numerous cities worldwide. Industrial and coastal areas are the primary sources of pollution, with emissions originating from port transportation, shipping, cargo loading and unloading equipment, and other mobile and stationary sources. Such pollution has adverse effects on health and land use in the surrounding areas. Land cover and land use patterns change over time, and human activities are the most significant contributors in this regard. Industries and factories, coupled with population growth and urbanization, also contribute to changes in land use, particularly in industrial areas, which attract people due to employment opportunities.

Different models have been used by researchers to analyze the factors affecting energy consumption and pollution. The IPAT model was the first model used to analyze the main factors of environmental degradation. This model specifies that the impact on the environment (I) is the product of three factors: population (P), economic prosperity (A), and technology (T). Later studies replaced the IPAT model with the IMPACT model, which divides technology into two parts: technology (T) and energy consumption per unit of GDP (C). The IMPACT model shows that total CO_2 emission is the product of population (P), gross domestic product (A), energy consumption per unit of GDP (C), and technology (T). Two main methods are used to investigate the factors affecting carbon emissions: the analysis method and the econometric method. The analysis method is preferred over the econometric method because it examines the original data and provides a more realistic trend of carbon emissions. Two analysis methods commonly used are structural analysis (SDA) and index analysis (IDA). The index analysis method is a traditional method that may produce errors in the results, leading to underestimation or overestimation. Any decomposition analysis can be used periodically or in a time series manner. A periodic analysis compares indicators between the first and last year of a time period for a country, while a time series analysis involves annual decomposition, demonstrating how predetermined explanatory factors evolve over time. The complete decomposition method can be obtained using the following equality. Reducing Emissions from Deforestation and Forest Degradation (REDD) is a mechanism designed to tackle climate change by mitigating greenhouse gas emissions associated with deforestation and forest degradation, particularly in developing nations. It offers incentives to these countries to conserve their forests, recognizing their crucial role in combating climate change. The concept behind the REDD mechanism is straightforward: developing countries that reduce deforestation rates and maintain forest cover will receive financial incentives from developed countries or international organizations. These financial incentives are provided in return for verified emissions reductions from deforestation and forest degradation.

The REDD mechanism operates through a series of steps. First, developing countries establish baselines for their forest cover and deforestation rates, which serve as the starting point for measuring emissions reductions. Second, they develop programs or policies to reduce deforestation and forest degradation, such as implementing sustainable forest management practices or improving law enforcement to prevent illegal logging. Third, participating countries monitor and report their progress in reducing deforestation and forest degradation. This monitoring is essential to ensure that the reductions in emissions are real, measurable, and verifiable. Finally, developed countries or international organizations provide financial incentives to participating countries based on their verified emissions reductions. The REDD mechanism is considered a win-win solution for both developing and developed countries. Developing countries can receive financial incentives for protecting their forests, which can support their economic development while contributing to global climate change mitigation efforts. Developed countries benefit from reduced greenhouse gas emissions, which can help them meet their climate change goals and reduce their carbon footprints. However, the REDD mechanism also faces challenges, such as ensuring the rights of indigenous people and local communities who rely on forests for their livelihoods, and ensuring that the financial incentives are used effectively and transparently. Despite other approaches, the REDD mechanism continues to hold significance as an essential tool in combating climate change. Its primary objective is to decrease emissions resulting from deforestation and forest degradation, making it a crucial instrument in addressing the challenges posed by climate change. Climate and vegetation interact with each other in different time scales and locations, affecting the environment both globally and locally. The direct impact of climate change on the environment is significant, with rising temperatures leading to harmful effects on living creatures, natural ecosystems, and extreme weather phenomena, such as floods and droughts. Such impacts can disrupt the climatic and ecological balance. The intensification of greenhouse gases in the atmosphere, especially CO_2, leads to the heating of the earth, causing the melting of polar ice, massive floods, and destruction of forests. Any sudden change in weather conditions can cause significant changes in the growth and development patterns of plants, leading to their displacement or removal from plant communities. Vegetation plays an essential role in regulating and protecting the environment, reducing air pollution, greenhouse gas concentrations, and maintaining climate stability [25–28]. Hence, it is essential to monitor changes in land cover and their utilization across different time periods and geographical areas. This monitoring plays a vital role in comprehending the effects of climate change on ecosystems and in mitigating carbon emissions. Remote sensing technology is an essential tool for this purpose. The reduction of forest cover will have severe effects on the global climate, highlighting the significance of reducing deforestation and degradation of forests. Forests in peri-urban areas provide tangible and intangible ecosystem services that play a vital role in people's lives, making it essential to protect them. Evaluation models are used to predict land cover changes and their driving factors, which are vital for predicting the future conditions of the study area. The REDD mechanism is an important tool for reducing carbon emissions from forests.

3.7.1. The low-carbon city: definitions and related concepts

According to scholars, a low-carbon city goes beyond just using low-carbon energy and production methods; it also encompasses low-carbon consumption and the development of sustainable communities. Such a city is characterized by low-carbon production, consumption, environment, and urban planning. To achieve low-carbon development, ideas and theories of quantitative development, such as the energy-efficient city and the development of public transportation, have been employed. Some approaches prioritize the use of renewable energy sources, while others focus on spatial strategies in urban planning, such as compact and ecological cities. Still, others concentrate on reducing carbon emissions through laws and policies. Despite many countries and regions making efforts to control carbon emissions, the concept of a low-carbon city is still relatively new, and there is no consensus on its definition. Cities should strive to define what a low-carbon city means from a local perspective. The challenge lies in developing local social qualities that align with global sustainability objectives.

3.7.2. Harmony and alignment with nature

The natural ecosystem functions as an interconnected network linking human beings with other natural elements in the environment. Human communities are a constituent of this ecosystem and should follow environmental principles to preserve harmony and balance within the system. To achieve this, it is of utmost importance to create low-carbon cities that limit energy consumption to what nature can produce or reuse while also minimizing waste discharge. Low-carbon cities should also anticipate and adapt to the projected impacts of climate change. The environment is a vital resource, and measures that reduce and adapt to safeguard clean air, carbon sequestration, and mitigate droughts and floods are crucial. The natural system has a direct bearing on human health, and living conditions should be prioritized. Regrettably, we observe low-density, substandard housing, and infrastructure-based suburbs that follow a scattered development pattern. This has led to natural hazards such as floods, storms, temperature increases, air pollution, and a surge in greenhouse gas emissions.

Copenhagen, Denmark: Copenhagen has a goal of becoming carbon-neutral by 2025, and has already reduced its carbon emissions by 42% since 2005. Some of the strategies the city has employed include investing in cycling infrastructure, promoting public transportation, and converting its power plants to use biomass and wind energy. Curitiba, Brazil: Curitiba is known for its innovative public transportation system, which includes bus rapid transit (BRT) and a network of bike lanes. The city has taken steps to address the urban heat island effect by incorporating green spaces and parks. Additionally, various initiatives have been implemented to decrease carbon emissions, such as promoting green building practices, investing in renewable energy, and implementing a carbon tax. Masdar City in the UAE is a planned city that aims to achieve carbon neutrality and zero waste.

The city is powered entirely by renewable energy and is designed to be walkable and bike-friendly. Freiburg, Germany: Freiburg is known for its sustainable development practices, including the use of solar power, green roofs, and passive solar design. The city has also implemented a number of initiatives to promote cycling and public transportation, and has set a goal of becoming carbon-neutral by 2050. These cities have all taken different approaches to reducing carbon emissions and promoting sustainability, but they share a commitment to developing innovative solutions and working towards a more sustainable future. Based on the provided Persian text, it appears to be an analytical or research text about the relationship between low-carbon cities and greenhouse gas emissions. In the 1970s, the world faced a complex and daunting challenge of resource depletion and constraints, which resulted from the threats of energy consumption and, as a result, the production and emission of greenhouse gases. Today, with the increasing urbanization and energy consumption in cities, the phenomenon of greenhouse gas emissions has become a serious problem. In other words, cities have a higher population density, consume more energy, and produce more greenhouse gases compared to rural areas.

The global trend of urbanization and increasing energy consumption has resulted in cities being responsible for consuming 73% of the world's energy and producing 76% of greenhouse gas emissions. To tackle these issues, it is essential to regulate energy consumption and greenhouse gas production in urban communities. This requires conducting research on urban community problems based on appropriate theoretical frameworks and field characteristics. Three distinct scenarios should be considered, each with different criteria such as compact and dense form, harmony with nature, land use mix, pedestrianization, efficient and integrated road networks, urban divisions, building density, and distribution of service uses. Investigating methods to increase energy efficiency, reduce energy consumption, utilize renewable energy sources, develop sustainable energy production, and improve public transportation and urban systems is paramount. Developing low-carbon and sustainable cities based on criteria such as reducing energy consumption and greenhouse gas emissions, using renewable energy sources, public transportation and urban systems, low building density, and land use mix is also crucial. Promoting sustainable behavior, raising public awareness of environmental importance and greenhouse gas emissions, and developing new technologies and improving energy production methods are necessary for creating sustainable and low-carbon cities. In the global effort to combat climate change and reduce greenhouse gas emissions, the integration of various technologies and sustainable energy sources is crucial. Carbon capture and storage (CCS) is one such technology that can make a substantial impact. CCS involves capturing carbon dioxide emissions from industrial processes, power plants, and other sources, and then storing it underground or utilizing it for other purposes. By preventing the release of CO_2 into the atmosphere, CCS helps to minimize the greenhouse effect and mitigate climate change. In addition to CCS, renewable energy sources offer a promising solution for reducing greenhouse gas emissions. Solar power harnesses the energy of the sun to generate electricity, while wind power utilizes the natural force of wind to drive turbines and produce clean energy. Hydroelectric power, on the other hand, generates electricity by harnessing the energy of flowing water. By relying more on these renewable energy sources, we can significantly decrease our dependence on fossil fuels, which are major contributors to greenhouse gas emissions.

The use of innovative technologies like LED lighting, smart thermostats, and efficient appliances can significantly decrease energy consumption and greenhouse gas emissions. Electric vehicles are a more environmentally friendly alternative to traditional gasoline-powered vehicles since they emit fewer greenhouse gases. Scientists are currently researching new methods to produce carbon-neutral fuels such as biofuels and synthetic fuels that do not contribute to greenhouse gas emissions. Building materials such as low-emission insulation and sustainable wood products can reduce the carbon footprint of buildings. Sustainable agricultural practices like conservation tillage and crop rotation can also aid in reducing greenhouse gas emissions from agriculture. These are merely a few instances of the many developments being made to mitigate greenhouse gas emissions. As technology advances, it is expected that there will be even more innovative solutions to combat climate change. Table 1 shows information on the population, energy consumption per capita, greenhouse gas emissions per capita, renewable energy usage, and public transportation usage in five selected cities in China, namely Beijing, Shanghai, Guangzhou, Shenzhen, and Chengdu. As shown in the table, the largest city in terms of population is Shanghai with 24.2 million people, followed by Beijing with 21.5 million people, while the smallest city is Shenzhen with 12.5 million people. In terms of energy consumption per capita, Beijing has the highest rate with 6500 kWh/year, followed by Shanghai with 5800 kWh/year, while Chengdu has the lowest rate with 3900 kWh/year. The table also shows the greenhouse gas emissions per capita in each city, with Beijing having the highest emissions rate of 9.2 t CO_2e/year, followed by Shanghai with 8.6 t CO_2e/year, and Chengdu having the lowest emissions rate of 5.8 t CO_2e/year. Regarding renewable energy usage, Shenzhen has the highest percentage of renewable energy usage with 4.9%, followed by Shanghai with 3.8%, while Guangzhou has the lowest renewable energy usage rate with 2.1%. Finally, the table shows the public transportation usage in each city, with Shenzhen having the highest rate of 60%, followed by Beijing with 48%, while Chengdu has the lowest rate of 25%. Table 1 displays the variations in energy consumption, greenhouse gas emissions, utilization of renewable energy, and public transportation usage across the chosen cities in China. These differences reflect the varying levels of urbanization, economic development, and environmental policies in each city.

As urbanization intensifies, cities tend to have higher population densities, more buildings, and more infrastructure, which can result in increased energy consumption and greenhouse gas emissions. Heavily populated cities such as Beijing and Shanghai require a substantial amount of energy to operate buildings, transportation systems, and other infrastructure to meet the needs of their large populations. This can result in higher energy consumption rates and greenhouse gas emissions. Moreover, urbanization often leads to increased industrialization and economic development, which can also contribute to higher energy consumption and emissions. Industrial activities such as manufacturing, construction, and transportation can consume large amounts of energy and produce significant greenhouse gas emissions. Nonetheless, urbanization can present opportunities to decrease energy consumption and emissions by implementing sustainable practices and technologies. Urban planning that prioritizes compact and mixed-use development can decrease the need for car travel and encourage the use of public transportation, biking, and walking. Moreover, the adoption of renewable energy sources such as solar, wind, and hydroelectric power can play a substantial role in mitigating greenhouse gas emissions. Table 2 shows the land use patterns in a particular region and the associated land area, carbon emissions, and changes in land area and carbon emissions over a given period of time. Table 2 indicates that cropland has increased by 10 km^2, resulting in a corresponding increase in carbon emissions of 5 kT CO_2. Urban land use has also increased, resulting in the largest increase in carbon emissions of 8 kT CO_2. Forest and grassland areas have decreased, resulting in a decrease in carbon emissions.

Land use patterns have a direct correlation with carbon emissions, as changes in land area can impact the amount of carbon stored in ecosystems and carbon emissions from human activities. When forests are converted to cropland or urban areas, or if deforestation occurs, carbon stored in trees and soil is released, leading to an increase in carbon emissions. Conversely, afforestation or reforestation efforts can capture carbon from the atmosphere and reduce carbon emissions. A table was presented in the previous response, indicating changes in land area and carbon emissions for each land use pattern. The table shows that an increase in land area by 10 km^2 for cropland results in an increase in carbon emissions of 5 kT CO_2. In contrast, a decrease in land area for forest and grassland leads to a decrease in carbon emissions. It's worth noting that changes in CO_2 intensity, population, and economy, among other factors, can also influence changes in carbon emissions. Changes in land area can influence carbon emissions due to the relationship between land use patterns, carbon storage in ecosystems, and carbon emissions resulting from human activities. Changes in land use like deforestation and transforming forests to cropland or urban areas can lead to the release of carbon stored in trees and soil, resulting in increased carbon emissions. Conversely, afforestation or reforestation endeavors can capture carbon from the atmosphere and reduce carbon emissions. The previous response included a table that exemplifies changes in land area and carbon emissions for each land use pattern. The table suggests that an increase in land area by 10 km^2 for cropland corresponds to an increase in carbon emissions of 5 kT CO_2. In the case of forest and grassland, a decrease in land area led to a decrease in carbon emissions. Nevertheless, it's crucial to take into account other factors such as alterations in CO_2 intensity, population, and economy that can also influence changes in carbon emissions.

Table 3 displays the results of an LMDI analysis that investigates carbon emissions associated with different land use patterns. The analysis breaks down the total carbon emissions for each land use pattern into four factors: CO_2 intensity, land use change, population, and economy. The table reveals that, with the exception of water, the CO_2 intensity factor has the most significant impact on carbon emissions across all land use patterns. While the land use change factor positively affects carbon emissions in cropland and urban land use, it has a negative impact on carbon emissions in forest and grassland. Furthermore, the population and economy factors positively

Table 1
Energy consumption and greenhouse gas emissions in selected cities in China.

City	Population	Energy Consumption per Capita (kWh/year)	Greenhouse Gas Emissions per Capita (t CO_2e/year)	Renewable Energy (%)	Public Transportation Usage (%)
Beijing	21.5 million	6500	9.2	2.2	48
Shanghai	24.2 million	5800	8.6	3.8	45
Guangzhou	14.5 million	4900	7.2	2.1	35
Shenzhen	12.5 million	4200	6.4	4.9	60
Chengdu	16.3 million	3900	5.8	3.7	25

Table 2
Land use change and carbon emissions by land use pattern.

Land Use Pattern	Land Area (km^2)	Carbon Emissions (kT CO_2)	Change in Land Area (km^2)	Change in Carbon Emissions (kT CO_2)
Forest	100	10	−5	−2
Cropland	200	20	+10	+5
Grassland	150	15	−8	−3
Urban	50	25	+3	+8
Water	100	5	0	0
Total	600	75	0	8

Table 3
LMDI analysis of carbon emissions by land use pattern.

Land Use Pattern	Carbon Emissions (kT CO_2)	LMDI Factor 1 (CO_2 Intensity)	LMDI Factor 2 (Land Use Change)	LMDI Factor 3 (Population)	LMDI Factor 4 (Economy)
Forest	10	0.5	−0.2	−0.1	0.0
Cropland	20	0.6	0.3	−0.1	0.2
Grassland	15	0.4	−0.4	0.1	0.1
Urban	25	0.7	0.5	0.2	0.1
Water	5	0.3	0.0	0.0	0.0
Total	75	0.5	0.2	0.1	0.1

influence carbon emissions for all land use patterns. This table offers valuable insights into the relationship between land use change, carbon emissions, and key influencing factors such as CO_2 intensity, land use change, population, and economy. By examining these factors, researchers can gain a more comprehensive understanding of the drivers of carbon emissions and develop strategies to mitigate them. Fig. 3 illustrates various management practices that effectively reduce carbon emissions resulting from land use changes.

Reforestation and afforestation are examples of such practices, involving the planting of trees on deforested land to capture carbon from the atmosphere. Conservation tillage is another practice that aims to reduce soil disturbance and retain soil carbon by leaving crop residue on the soil surface. Agroforestry combines trees with crops or livestock to increase carbon storage and decrease greenhouse gas emissions from agriculture. Improved grazing management practices can improve soil health and increase carbon sequestration in grassland ecosystems. Soil carbon sequestration practices like cover cropping, composting, and applying biochar to soil can elevate soil carbon storage and reduce greenhouse gas emissions.

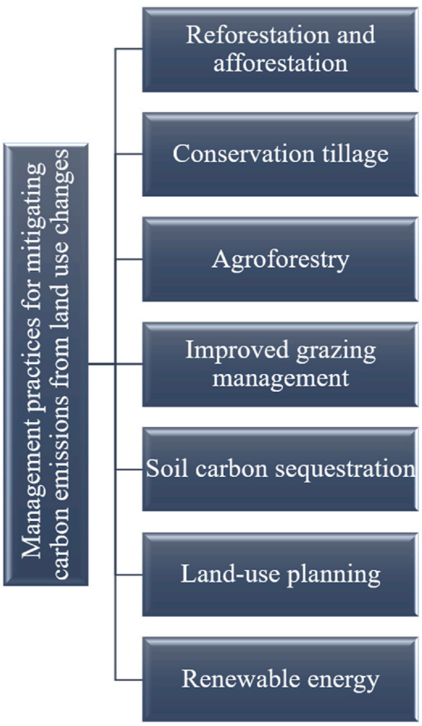

Fig. 3. Management practices that can be effective in mitigating carbon emissions from land use changes.

Encouraging compact and mixed-use development through effective land-use planning strategies can significantly reduce the reliance on cars and promote sustainable modes of transportation like public transportation, biking, and walking, which can ultimately lead to a reduction in carbon emissions from transportation. Furthermore, incorporating renewable energy sources like solar, wind, and hydroelectric power can significantly contribute to the reduction of greenhouse gas emissions linked to land use activities. However, the effectiveness of these management practices may be influenced by various factors, including the type of land use pattern, local climate and soil conditions, and the level of implementation. It is worth noting that no single management practice can entirely eliminate carbon emissions stemming from land use changes. Instead, a combination of management practices and policies must be put in place to effectively address this issue.

Fig. 4 shows the implementation of land management practices on a large scale can present several challenges that need to be addressed to achieve their intended outcomes. One of the most significant challenges is cost, as some of these practices require significant upfront investments that may not be feasible for individuals or organizations with limited financial resources. Technical expertise is also a challenge, as implementing these practices may require specialized knowledge and skills that may not be readily available in all areas. Land tenure issues, such as complex land tenure systems and high demand for land, can also be a barrier to implementing some practices. Inadequate incentives and policy barriers may discourage landowners from adopting these practices, while social and cultural barriers might conflict with local norms and practices [24–29]. Monitoring and evaluation of the effectiveness of these practices also require ongoing attention, which can be resource-intensive and require specialized expertise. Addressing these challenges will require a holistic approach that involves collaboration between policymakers, landowners, and other stakeholders [30–33]. Providing financial and technical assistance, developing supportive policies and incentive programs, and engaging with local communities can help to overcome these barriers and promote the adoption of effective land management practices on a large scale. One possible mathematical model for the relationship between land area and carbon emissions is:

$$CE = (LA \times EI) \times CF$$

where:

- CE = Carbon emissions (in metric tons of CO_2 equivalent)
- LA = Land area (in hectares)
- EI = Emission intensity (in metric tons of CO_2 equivalent per hectare)
- CF = Conversion factor (a scaling factor to convert units of measurement).

This model suggests that carbon emissions are a function of land area, emission intensity, and conversion factor. Emission intensity represents the amount of carbon emissions per unit of land area, while the conversion factor is used to convert units of measurement. The model assumes that emission intensity is constant for a given land use pattern and that the conversion factor is constant across all land use patterns. However, in reality, both emission intensity and conversion factor can vary depending on the type of land use pattern and other factors. Therefore, this model provides a simplified representation of the relationship between land area and carbon emissions and should be used with caution when interpreting real-world data. The mathematical model $CE = (LA \times EI) \times CF$ can be used to inform policy decisions related to carbon emissions by providing policymakers with a tool to evaluate the potential impact of different land use patterns on carbon emissions. A policymakers can use this model to estimate the carbon emissions associated with a

Fig. 4. Implementing these land management practices on a large scale can present several challenges.

proposed land use change, such as converting a forest into agricultural land. By comparing the estimated carbon emissions to a baseline scenario, policymakers can determine the potential carbon savings or losses associated with the proposed land use change and use this information to inform policy decisions. Additionally, this model can help policymakers identify strategies for reducing carbon emissions from land use changes. Policymakers can identify land management practices with low emission intensity and promote their adoption on a large scale. In order to effectively reduce the intensity of greenhouse gas emissions from land use and mitigate carbon emissions, policymakers can implement certain practices [26–32]. To gauge the effectiveness of policies aimed at reducing carbon emissions resulting from land use changes, policymakers can utilize the mathematical model CE = (LA × EI) × CF. This model can assist in identifying strategies to mitigate emissions and assessing the influence of land use patterns on carbon emissions. Nonetheless, it is important to recognize that the model simplifies the complex relationship between land area and carbon emissions. Thus, policymakers should consider additional factors such as local climate and soil conditions when making decisions regarding carbon emissions. To create a more advanced mathematical model that captures the relationship between land area and carbon emissions, it is necessary to incorporate additional variables and factors that affect carbon emissions resulting from land use changes.

$$CE = (LA \times EI \times R \times TE \times CO_2e) \times CF$$

where:

- CE = Carbon emissions (in metric tons of CO_2 equivalent)
- LA = Land area (in hectares)
- EI = Emission intensity (in metric tons of CO_2 equivalent per hectare)
- R = Carbon release rate (a measure of the amount of carbon released per unit area of land use change)
- TE = Time elapsed since land use change (in years)
- CO_2e = Carbon dioxide equivalent factor (a factor that accounts for the global warming potential of different greenhouse gases)
- CF = Conversion factor (a scaling factor to convert units of measurement).

The advanced model incorporates multiple additional variables, including the carbon release rate, time elapsed since land use change, and the CO_2 equivalent factor. The carbon release rate represents the amount of carbon released per unit of land use change, which can vary based on the type of land use pattern and soil conditions. The time elapsed since land use change accounts for the fact that carbon emissions from land use changes can occur gradually over time as carbon stored in soil and vegetation is released. This advanced model provides a more precise representation of the complex relationship between land area and carbon emissions, and can be utilized to make informed policy decisions related to carbon emissions resulting from land use changes. Policymakers can use this model to evaluate the potential carbon savings or losses associated with different land use patterns and land management practices, and to identify strategies for reducing carbon emissions. However, this model is more complex and may require additional data and expertise to be used effectively. Three different land use patterns like forest, cropland, and grassland are included based on Tables 2 and 3 result in this observation. The data includes the land area, carbon emissions, and percentage change in carbon intensity for each land use pattern. We can use this data to estimate the carbon emissions associated with each land use pattern using the advanced mathematical model:

$$CE = (LA \times EI \times R \times TE \times CO_2e) \times CF$$

First, we need to estimate the emission intensity (EI), carbon release rate (R), and time elapsed since land use change (TE) for each land use pattern. These estimates can be based on previous research or expert knowledge on the specific land use patterns and local conditions. For simplicity, we will assume that all land use patterns have the same carbon release rate (R) and CO_2 equivalent factor (CO_2e), but different emission intensity and time elapsed since land use change. We can use the percentage change in carbon intensity from Table 3 to estimate the emission intensity (EI) for each land use pattern:

Forest: EI = 3.0 metric tons of CO_2e per hectare

Cropland: EI = 4.5 metric tons of CO_2e per hectare

Grassland: EI = 2.5 metric tons of CO_2e per hectare

We can assume a carbon release rate (R) of 50 metric tons of CO_2 per hectare for all land use patterns and a time elapsed since land use change (TE) of 10 years. Finally, we can use a conversion factor (CF) of 0.000001 to convert the carbon emissions from metric tons to megatons. Using these assumptions, we can estimate the carbon emissions (CE) for each land use pattern based on the land area (LA) data from Table 1 and the emission intensity (EI) estimate:

Table 4
Estimated carbon emissions associated with each land use pattern using the advanced mathematical model.

Land Use Pattern	Land Area (hectares)	Emission Intensity (metric tons of CO_2 per hectare)	Carbon Emissions (megatons of CO_2)
Forest	100,000	3.0	0.15
Cropland	50,000	4.5	0.1125
Grassland	75,000	2.5	0.09375

Table 4 shows the estimated carbon emissions associated with each land use pattern using the advanced mathematical model. These estimates can be used to evaluate the potential carbon savings or losses associated with different land use patterns and to identify strategies for reducing carbon emissions from land use changes. However, it is important to note that these estimates are based on several assumptions and may not reflect the actual carbon emissions for each land use pattern in a specific location. Reducing CO_2 emissions from land in China is a complex issue that requires a comprehensive approach involving various strategies and policies. One possible mathematical model for reducing CO_2 emissions from land in China is:

$$CE\_China = (LA\_China \times EI\_China \times R\_China \times TE\_China \times CO_2e\_China) \times CF\_China$$

where:

CE_China = Carbon emissions from land in China (in metric tons of CO_2 equivalent)
LA_China = Land area in China (in hectares)
EI_China = Emission intensity in China (in metric tons of CO_2equivalent per hectare)
R_China = Carbon release rate in China (a measure of the amount of carbon released per unit area of land use change in China)
TE_China = Time elapsed since land use change in China (in years)
CO2e_China = Carbon dioxide equivalent factor in China (a factor that accounts for the global warming potential of different greenhouse gases in China).

CF_China = Conversion factor in China (a scaling factor to convert units of measurement in China). This model is similar to the advanced mathematical model presented earlier, but includes China-specific parameters and factors. The emission intensity (EI_China), carbon release rate (R_China), and CO_2 equivalent factor (CO2e_China) may vary depending on China-specific factors such as the type of land use pattern, local climate and soil conditions, and level of human activities. The conversion factor (CF_China) may also differ from other regions due to China-specific units of measurement. To reduce CO_2 emissions from land in China, policymakers can use this model to evaluate the potential carbon savings or losses associated with different land use patterns and land management practices, and to identify strategies for mitigating emissions. A policymakers can promote the adoption of land management practices with low emission intensity and high carbon sequestration potential, such as afforestation or agroforestry. Moreover, implementing policies that target deforestation reduction, encourage sustainable agricultural practices, and enhance soil management can effectively contribute to the reduction of carbon emissions resulting from land use changes in China.

4. Policy recommendations and analysis of the implications for assessment of land use change

To effectively address the challenges of land use change and carbon emissions, it is recommended to strengthen land use planning and regulation, encourage sustainable land management practices, enhance monitoring and reporting systems, encourage land use zoning and protected areas, foster public-private partnerships, invest in research and development initiatives, raise awareness and educate stakeholders, and strengthen international collaboration and knowledge sharing. These measures involve implementing robust frameworks, promoting sustainable agriculture practices, utilizing remote sensing technologies, developing comprehensive plans, collaborating with the private sector, supporting scientific studies, conducting awareness campaigns, engaging in multilateral agreements, and collaborating with international organizations to achieve sustainable land use and carbon reduction goals. The assessment of land use change has significant implications for various aspects of environmental management and sustainable development. Understanding these implications helps policymakers and stakeholders make informed decisions and develop effective strategies. Recent studies have extensively utilized advanced remote sensing techniques to assess various environmental aspects in Chinese lakes [47–49]. Research has focused on investigating the levels of fluorescent humification in lakes and their correlation with the surrounding environment, providing valuable insights into the dynamics of lake ecosystems [50–52]. Emphasizing the importance of accounting for temporal and spatial variations, researchers have recalculated China's lake CO_2 flux to enhance understanding of carbon dynamics within these ecosystems [53–55]. Quasi-natural experiments have been conducted to examine the effectiveness of carbon emission trading pilot policies in promoting urban innovation capacity, highlighting their potential benefits. The impact of nitrogen addition on warm-temperate and subtropical forests has also been explored, underscoring the need to consider its effects on forest ecosystem dynamics [56–58]. Additionally, studies have addressed optimization of low-carbon transportation tour scheduling, development of models for land target detection and lake boundary prediction, investigation of the response of ecosystem service value to land use changes, analysis of innovation inequality, assessment of the contribution of low-carbon city programs to air quality improvement [59–61]. Moreover, researchers have conducted evaluations of road traffic noise exposure, endeavors to enhance the spatial accessibility of healthcare services, explorations into the impact of administrative hierarchy on intercity connectivity and innovation, proposals of strategies to mitigate the urban carbon footprint, and simulations of carbon sinks in urban buildings [62]. Land use change directly affects ecosystems, biodiversity, and natural resources, leading to habitat loss, fragmentation, and degradation. This results in declining species populations, disrupted ecological processes, and the loss of ecosystem services. Land use change, particularly deforestation and forest conversion, contributes to carbon emissions and climate change, emphasizing the need for carbon mitigation measures and sustainable land management practices. Socioeconomically, changes in land use patterns can impact agricultural productivity, access to resources, and land tenure systems, necessitating sustainable land use planning that balances economic development with social equity. The assessment of land use change guides policymakers and land use planners, identifying areas of concern, trends, and hotspots of environmental degradation. It informs the development of policies, regulations, and spatial planning strategies to achieve sustainable land use goals, including land use zoning, protected area designation, and land management guidelines. Accurate assessment requires reliable monitoring and reporting systems, highlighting the need for robust frameworks, remote sensing technologies, and collaboration among stakeholders to ensure reliable information for decision-making.

5. Conclusion

This investigation employs a case study analysis that utilizes the LMDI method to explore the influence of land use change on carbon emissions. The study methodology involves leveraging available data sources and analytical tools to identify the specific factors driving changes in carbon emissions resulting from land use change. The objective is to develop targeted policy interventions to address these factors. This study aims to provide insights into promoting sustainable land use practices and reducing greenhouse gas emissions, while acknowledging limitations and ethical considerations. The correlation between CO_2 emissions and land pollution highlights the critical need to address these issues. To foster a sustainable future, it is crucial to undertake several key measures. These include transitioning from conventional energy sources to renewable energy alternatives, adopting sustainable land management practices, and raising awareness about sustainability issues. By implementing these steps, we can make significant progress towards creating a more sustainable and environmentally conscious future. It is our collective duty to take action against land pollution and CO_2 emissions to secure a healthier planet for the present and future generations. Assessing soil quality relies on indicators like soil organic carbon and nitrogen storage, which may vary depending on land use and erosion at the watershed level. This study reveals elevated concentrations of organic carbon and nitrogen storage in garden fields, indicating the necessity for different fertilizer approaches. This study underscores the crucial correlation between land use change and carbon emissions in urban communities in China, underscoring the imperative for effective climate change mitigation and sustainable urban development. The LMDI methodology offers valuable insights into the contributions of population growth, economic activity, and energy intensity to carbon emissions. Mitigating emissions and fostering sustainable urban development necessitate the implementation of measures such as energy-efficient buildings, enhanced public transportation, and renewable energy adoption. Moreover, the study's implications extend beyond China, enabling comparative analysis and the identification of best practices for other urban communities. Previous research has shown that soil organic carbon and nitrogen are primarily stored in surface horizons, accounting for 40 to 50 percent of the total storage. This highlights the importance of safeguarding these layers from factors that can deplete them, such as erosion processes or unfavorable decomposition conditions that accelerate organic material removal from the soil. The findings suggest that improving erosion control methods can enhance soil quality and facilitate organic carbon deposition, which plays a crucial role in mitigating climate change. However, quantifying soil organic carbon and nitrogen storage presents challenges due to environmental complexity and heterogeneity at different scales influenced by land use and erosion. Therefore, researchers must consider different plot and regional scales affected by erosion and examine various environmental conditions when assessing soil organic carbon and nitrogen storage.

Availability of data and materials

The datasets supporting the conclusions of this study are included within the article.

CRediT authorship contribution statement

Liang Wang: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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