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RESEARCH ARTICLE

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Do changes in land use and climate change overlap? An analysis of the World Bank Data

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Abstract

Land use change (LUC), including deforestation, agriculture, and urbanization, is a major contributor to climate change (CC). This change in land use has impacts on food, water, and energy systems, creating a complex interconnected web of issues. This study aimed to investigate the global link between LUC and CC from 1990 to 2012. Using time-series data from the World Bank, LUC was represented by irrigated land, arable lands, and forest areas, while CC was represented by CO_2 emissions. Moreover, the relationship between economic growth in high-income and low-income countries and LUC and CC was examined in this study. Based on the findings of this study, in low-income countries, the intensity of LUC is higher in comparison with high-income countries. Meanwhile, CO_2 emissions are increasing in middle-income and high-income countries. Economic growth is closely related to CO_2 emissions in countries with different levels of income. The study indicated that managing land use is of high importance to mitigate CO_2 emissions globally. According to the findings, recent LUC has shown more obvious effects on ecological variables than CC. Although LUC is not inherently directly related to CC, humans change land use, especially in terms of land management, to adapt to CC, and these changes will inevitably bring many environmental impacts. This study contributes significantly to advancing the understanding of the complex relationship between CC and LUC, emphasizing the need for integrated approaches in policy development. These measures are crucial to achieving resilience and meeting global CC reduction targets.

KEYWORDS
CO_2 emissions, economic growth, gross domestic product, land management, land use change

1 | INTRODUCTION

Land use change (LUC) and climate change (CC) are two major environmental challenges. The interconnected role of food, water, and energy is crucial in understanding the complex relationship between these two issues (Karabulut et al., 2018). This is what was discussed in COP28, the 28th annual United Nations (UN) climate meeting, where governments discuss how to limit and prepare for future CC (UNCC, 2024). During the negotiations from November 30 to December 13, representatives from 198 countries worked on important decisions impacting the world's response to climate crisis. Key achievements included an agreement to shift away from fossil fuels, establishing a fund to assist vulnerable countries in paying for climate-related damage, and releasing a significant assessment of the world's progress in addressing CC (UNCC, 2024). LUC, such as deforestation and agriculture, impacts the carbon cycle and contributes to CC. CC also affects security on food and water by changing precipitation patterns, increasing temperatures, and causing droughts and floods

(Akbar et al., 2023). Weather patterns have an influence on renewable energy sources such as solar and wind power (H. Li, Li, et al., 2023; C. Li, Smith, et al., 2023). In addition, humans use the land for agricultural, industrial, recreational, and residential purposes, which have significant impacts on CC (Buck et al., 2021; D. Wei et al., 2020) and land use encompasses all CC-related issues. The evidence that LUC contributes to CC has been known for a long time (Noszczyk, 2019). Charney (1975) investigated the effect of overgrazing on desertification and its relationship with coastal climate, which improved our understanding of how land use activities impact climate. CC is generally expressed in terms of temperature and precipitation. To evaluate land degradation, it is essential to quantify and distinguish between the impact of rising atmospheric CO_2 concentrations, climatic change, and human activity on evapotranspiration and gross primary output. Among the various greenhouse gases (GHGs) released by human activities, CO_2 has emerged as the primary driver of CC, and its significance is expected to increase in the coming years (Malek & Verburg, 2021; Talukder et al., 2021; Xiong et al., 2022). The accurate determination of the carbon-neutrality capacity of a region is crucial to develop policies related to emissions and CC (Bai et al., 2023). Hence, many studies were published that introduced LUC as a major driver of CC in general and CO_2 emissions in particular (Fei et al., 2018; Rothwell et al., 2016; Xie et al., 2021; Y. Zhang et al., 2020).

Among different types of LUC, intensive deforestation and their conversion into pasture or farmland have received more attention (Yu & Leng, 2022). Lutzenberger (2014), for example, studied a decade of LUC (from 2000 to 2009) and showed an increase in global arable land and a decrease in rainfall as a result of deforestation. Consequently, the decade 2000–2009 was the warmest on record. H. Huang and Khanna (2010) found the nonlinear effect of temperature on arable land outputs, like the yields of corn and soybeans. Deforestation also impacts the supply of wood as an industrial raw material, as well as other benefits such as wildlife habitat and ecosystem services (Xiao et al., 2023).

There are a few models (simultaneously contributing to socio-economic and biophysical effects of land on climate) that have been used to calculate the contribution of LUC to global warming during the 20th century. For example, Spawn et al. (2019) estimated that one-third of total anthropogenic carbon emissions have resulted from LUC since 1850. Economic growth has significantly worsened CO_2 emissions (Cao & Yuan, 2019). For example, total energy consumption, gross domestic product (GDP), and the rate of urbanization are among the main drivers of land use-related CO_2 emissions. However, despite the considerable number of scientific works that have focused on LUC and CC, no study has yet been conducted on investigating the impacts of forest LUC, arable LUC, agricultural LUC, irrigated LUC, and GDP on the simultaneous increase of CO_2 emissions simultaneously over some time.

Based on the Paris Agreement, various indicators and methods have been used to reduce CO_2 emissions and limit the increase in the global average temperature to about 2°C (Lim, 2019). Global studies produce nearly identical estimates for LUC involving forests (e.g., deforestation and afforestation) (Xiong et al., 2022), but they differ from protected forests[1] (IPCC, 2013; Jia et al., 2019). Recently, some progress has been made in better quantifying GHGs emissions by combining spatial data with LUC maps derived from satellites (H. Li, Li, et al., 2023; C. Li, Smith, et al., 2023). However, these spatial data are limited to the last decade (i.e., data prior to that are not available) and are limited in scope to represent LUC-derived CO_2 emissions at regional levels only. Overall, LUC is a significant contributor to man-made CO_2 emissions because of deforestation (Manta et al., 2020). However, to investigate the effects of LUC on climate, land surface models have been embedded in regional or global-scale climate models (Jia et al., 2019). Therefore, the aim of this study is to investigate the global association between LUC and CC from 1990 to 2012. For this purpose, the time-series data of the World Bank will be examined for LUC in irrigated lands, agricultural lands, and forest areas.

2 | LITERATURE REVIEW

While LUC is an important driver of CC, a changing climate can lead to changes in land use and land cover. Indeed, land and climate interact in complex ways through changes and multiple biophysical and biochemical feedback across different spatial and temporal scales. In this regard, various studies have explored different global perspectives on the effects of LUC on climate. B. Huang et al. (2023) indicated that due to the increasing attention to CC and increasing CO_2 in the global carbon cycle, land management strategies should be spatially heterogeneous to enhance afforestation and grassland planting contributing to reducing LUC pathways causing CO_2 loss in the global changing environment. Zhu et al. (2021) claimed that the terrestrial ecosystem is a significant carbon pool that is essential to the carbon biogeochemical cycle. The changes in carbon storage in the terrestrial ecosystem are a result of LUC's effects on its structure and function. The type of ecosystem and changes in land use patterns play a major role in the variation in carbon storage. Lawrence (2020) used the National Center for Atmospheric Research (NCAR) climate model to run a typical global simulation of climate with present vegetation versus prospective (no anthropogenic LUCs) vegetation. They discovered that the influence of plant change on the surface hydrologic cycle outweighed the impact of radiation (changes in albedo). In the same model, Sun et al. (2021) discovered large inaccuracies in top-of-atmosphere and surface albedo. The modeling of the atmospheric radiative budget improves when surface albedo is rectified. Huili (2021) discovered that albedo changes are significant in areas where agriculture is the predominant LUC and used a climate model to distinguish between the phenological component of LUC change and albedo changes. However, phenological changes have a significant role in the warming signal in the model. This conclusion is supported by Jaksa et al.'s (2013) examination of the North American Regional Reanalysis (NARR), site temperature records, and time-varying satellite land cover data. Moore et al. (2012) believed that accurate vegetation characteristics across East Africa enhance regional model predictions of temperature, and to a lesser extent, precipitation. Kinnard et al. (2022) stated that, aside from policy, key non-climate drivers of LUC and related CO_2 emissions during the 21st century include elevated CO_2 concentrations and changing rates of atmospheric nitrogen deposition. If other factors, particularly water supply, are not limiting, the former has the potential to significantly increase biomass production from crops, grasslands, and trees. In systems with intense protection, the latter is unlikely to have any significant impact, but it might encourage forests to absorb more CO_2. Jia et al. (2022) have demonstrated how numerous biophysical and biogeochemical feedback result in complex interactions between land and climate. The heterogeneous impact of land use on CC is caused by large gaps in the carbon fixation effect among various land use types and objective conditions among various regions in this interaction mechanism. Furthermore, the effects of various land use types on CC are diverse, and although agricultural land has little effect on CC, the proportion of forest land will rise and help slow down global warming. Regional heterogeneity exists in the impact of land use on CC as well. The mechanism of land use affecting CC between island countries and mainland countries is heterogeneous due to geographical differences.

Barati et al. (2023) stated that LUC has a direct and indirect impact on CO_2 emissions. On the one hand, LUC has a positive direct effect and a negative indirect effect, and on the other hand, deforestation has indirectly increased CO_2 emissions. Thus, it is essential to ascertain the patterns, trends, and impacts of LUC on CC. Because of this, CC mitigation policies ought to take into account both direct and indirect effects. However, this will only be possible once decision-makers and policymakers have a deeper comprehension of the relationship and structure between CC, LUC, and their components. These studies give an example of the difficulty in determining the function of LUC in CC. These studies showed that models are capable of capturing observed changes in land use that may have significant local effects. The impacts of LUC are most obvious at small scales, in contrast to the record of warming from rising greenhouse gas emissions, which is strong at the global scale but is usually poor locally.

As a result, this study explores the worldwide link between CC and LUC, emphasizing the need of reducing CO_2 emissions while also addressing economic growth to generate long-term simultaneous interactions between CO_2 emissions, GDP, and economic growth. The findings of this study will contribute to answering this critical question: Why is it important to increase our understanding of CC and LUC interaction effects at the global level?

Therefore, by employing a time-series analysis, this study provides a clear picture of the CC and LUC interactions that have occurred through the time. Many macroeconomic studies performed the same approach (Alawamy et al., 2020; Guo et al., 2018; Manta et al., 2020) to mitigate the impacts of CC, but this study used the most recent World Bank time-series data from 1990 to 2012. To the best of our knowledge, no time-series study has simultaneously assessed the links between CC, specifically CO_2 emissions, GDP, and world economic growth. Consequently, this study focuses on LUC classified as forest, arable, agricultural, and irrigated agricultural lands, and CC classified as CO_2 emissions. While certain LUC and climate impacts may lead to short-term economic gains, unsustainable practices and failure to address CC can pose significant risks to long-term economic viability. Therefore, the main hypotheses are as follows:

1. There is a significant relationship between economic growth (according to GDP) and CO_2 emissions.
2. There is a significant relationship between different types of LUC, especially forest, arable, agricultural, and irrigated agricultural lands, and CO_2 emissions over time.
3. LUC has a significant effect on economic growth and GDP on regional and global scales.

The findings of this study offer valuable insights into interactions between LUC and global CO_2 emissions, providing critical guidance to shape CC policymaking. In addition, this study emphasizes the importance of adopting sustainable land management practices and implementing coordinated efforts to mitigate and adapt to CC. It also encourages decision-makers to pay more attention to fostering resilient and inclusive economic growth on a global scale.

3 | DATA SOURCES AND RESEARCH METHODOLOGY

This study used the World Bank's time-series yearly data from 1990 to 2012. Time-series data provides a comparative basis for time-series studies, such as "ascending" and "descending" trends according to the selected dataset. For this purpose, first, two lists of countries with time-series data on CO_2 emissions and LUC were extracted. Next, the common countries in both lists were selected. The data were limited to 1990–2012 given the fact that, for the variables of this study, no other reliable global datasets were available beyond this range. Furthermore, given the importance of the economic status of different countries in explaining the variation of LUC and CO_2, this study used the GDP classified (the total revenue of a country is divided by the number of inhabitants in that country to calculate per capita income) by the World Bank (2012). This classification divides countries into three income categories with high-, medium-, and low-income levels. Their nominal income is what they receive after correcting the weight of direct taxes, but their real income is what they receive after adjusting the weight of inflation (World Bank, 2012).

This study was conducted in countries where data were available in the latest World Bank Dataset (2012). Accordingly, out of 78 high-income countries, 49 countries were studied. Furthermore, countries with the highest negative CO_2 emissions change (high CO_2 emissions in 2012 compared with 1990) were considered, but countries with no available data were omitted. Likewise, out of 109 and 31 middle- and low-income countries, 89 and 26 countries were studied (Figure 1). In addition, the reference for grouping variables such as land use and cover change were the indicators included in World Bank Databases.[2]

To analyze the data, this study used two methods: (a) One-way analysis of variance (ANOVA) compares the means between some groups and determines whether each of these tools is statistically

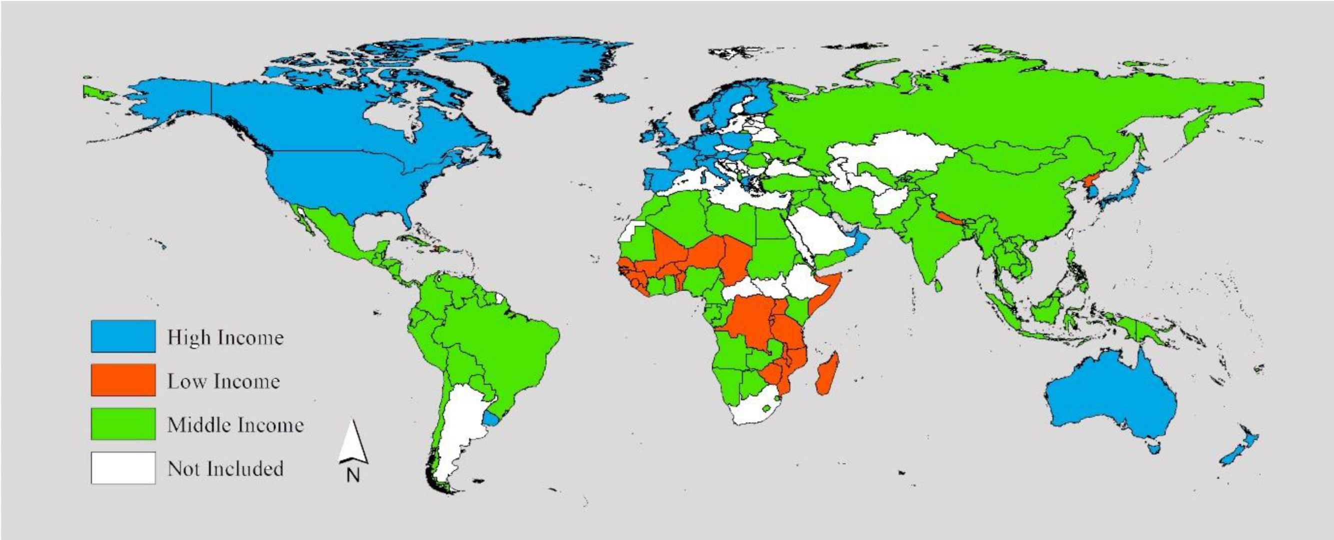

FIGURE 1 Study sample at global view based on income level. *Source*: Gelband et al. (2015). [Colour figure can be viewed at wileyonlinelibrary.com]

different or has significant differences from the others (Field, 2009). It also determines a statistically significant difference between the means of the main indicators between the groups of the country. The null hypothesis in an ANOVA is whether all of the group's means are identical since it examines if three or more means are the same. An *F*-statistic (*F*-ratio), which is provided by ANOVA, contrasts the proportion of systematic variance to unsystematic variance in the data. In other words, *F* is the model's error to its mistake. (b) Multiple regression is an expansion of linear regression model that enables us to predict the behavior of a system with several independent variables. The main objective of using multiple regression analysis was to identify the independent variables whose values could predict the value of the single dependent variable. Formula 1 indicates the general model equation for regression, in which Yi is the outcome that we want to predict (here CO_2 emissions change), b_0 is the intercept of the regression line, b_1 is the gradient of the straight line fitted to the data, and Xi is the participant's score on the predictor variable (here land use, cover, and GDP changes) (Field, 2009). We used this method to predict the CO_2 emissions changes (CC) under the changes of LUC types.

$$Y_i = (b_0 + b_1 X_i) + \varepsilon_i. \quad (1)$$

The steps of performing the research methodology are shown in Figure 2.

4 | RESULTS

4.1 | Comparing countries with different incomes

Table 1 and Figure 3 show the average changes and percentages of different variables in countries with different levels of income. According to Table 1, there is a significant difference (sig. < 0.005) in the means of forest LUC, arable LUC, agricultural LUC, CO_2 emissions change per area, and GDP growth change.

According to Table 1, the average change of different indicators in countries with low- and middle-income has shown a negative trend (−5.54% and −1.22%, respectively). Conversely, among high-income countries, this change has exhibited a positive trajectory, approximately reaching 1.43%. This result is related to different stages of economic development and land use patterns. High-income countries tend to have more advanced economies and more developed infrastructure, which may allow them to use land more efficiently and effectively for economic growth. By contrast, low- and middle-income countries may face greater challenges in terms of land use planning, management, and regulation, which could limit their ability to benefit from LUC in the same way. Direct effects may include the expansion of industrial land, which can provide new opportunities for investment and job creation. Indirect effects may include the development of infrastructure, such as roads and utilities, which can enhance the overall productivity of the economy. These effects may be more pronounced in high-income countries, where there is often more capital available for investment and a more developed business environment. Overall, the study suggests that land use is an important factor in economic growth and development and that different countries may need to approach land use policies and strategies in different ways depending on their level of economic development and other contextual factors. As a result, the study reveals a substantial relationship between LUC and absolute GDP growth. LUC is not solely a consequence of economic growth but also a significant driver, both directly and indirectly, contributing to it. Expansion of industrial land directly boosts economic growth. Land has been effectively exploited to attract foreign investment and sustain infrastructural projects, which indirectly stimulates economic growth. The findings imply

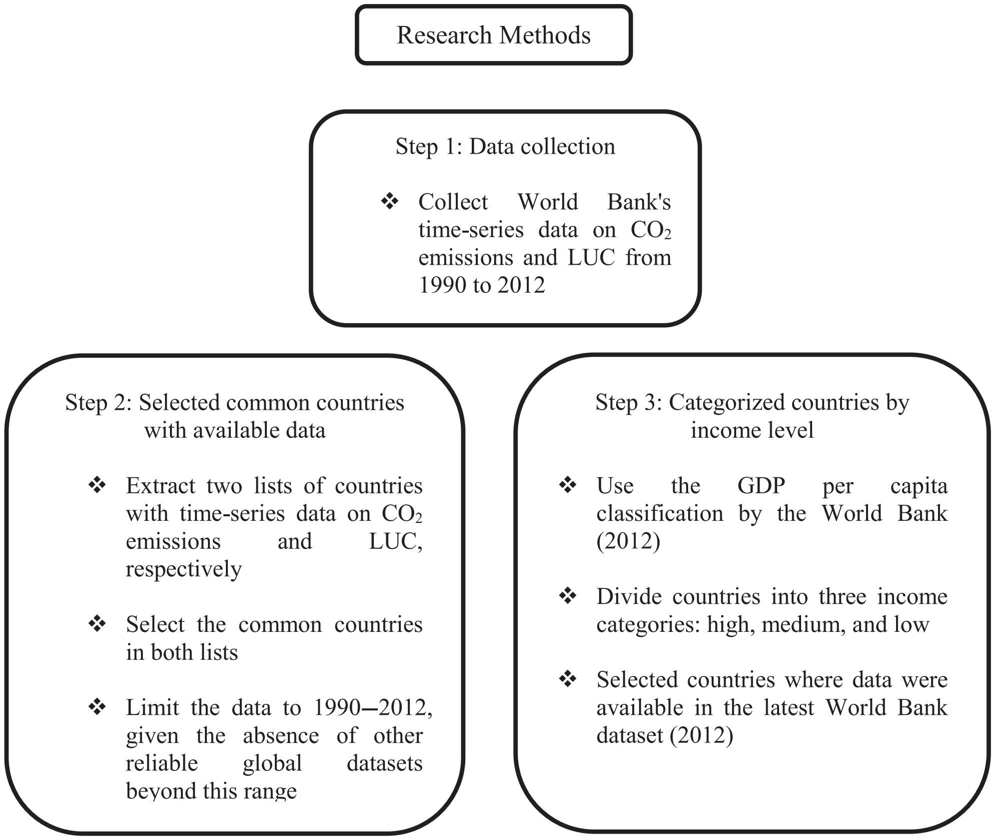

FIGURE 2 Research methods. LUC, land use change.

that land is more than just a factor of production; it is a strategic instrument for economic growth.

In Figure 4, and the first row of Table 2, the studied countries were classified according to the percentage change in forest areas during 1990–2012. The percentage of forest area in 95 countries decreased on average by about 4.62% and increased in 66 countries on average by about 3.82% (Table 2).

Unlike the forest lands, the percentage of arable lands has increased on average by 0.38% in every country. There was a decrease in 74 and an increase in 76 countries (Table 2 and Figure 5).

During the same period, not only the forest area has declined, but also the agricultural (AgL) and irrigated agricultural lands (IAgL) have decreased around the world (respectively, about 0.37% and 0.05% on average per country) (Table 1). Contrary to the forest area, both AgLs and IAgLs have raised in low-income countries (on average, 5.51% and 0.01%). However, among the middle-income countries, the AgLs have increased (0.32%) and the IALs have decreased (−0.03%). In high-income countries, both types of land have decreased (−4.83% and −0.024%). As indicated in Table 2, the agricultural land area decreased in 78 countries and increased in the other 78 countries. According to the last row of Table 2, the area of IAgL decreased in 41 countries while it increased in 75 countries. Figures 6 and 7 show the intensity and direction of AL and IAL changes in all the studied countries. Additionally, the agricultural sector has witnessed a surge in forest expansion, primarily attributed to advancements in policies and market trends that have actively promoted the transition. Notably, the implementation of afforestation initiatives has played a significant role in driving the increase in forested areas. However, the decrease in forest area may be related to human activities and natural processes such as forest fires.

4.2 | Climate change

This study used CO_2 emissions as the main indicator of CC. As shown in Table 1, from 1990 to 2012, every country in the world emitted more than 85 million tons of CO_2 into the atmosphere. Although the share of the middle-income countries in CO_2 emissions has been more than the other two groups, the amount of CO_2 emissions changes per area within the high-income countries has been more than the middle-income countries and the low-income countries. However, as the center for global development has reported, developed countries are responsible for 79% of the historical carbon emissions (1850–2011), whereas developing countries are responsible for 63% of the current carbon emissions. In Figure 8, the studied countries are classified based on the amount of their CO_2 emissions changes per area (1990–2012). Totally, in 39 countries, the amount of CO_2 emissions per area has decreased while in 113 countries, it has increased (Table 3).

4.3 | Land use and climate change relationship

This study used a multiple regression analysis to estimate the relationships between CO_2 emissions (as an outcome variable) and several

TABLE 1 The average change of different indicators by country income group (1990–2012).

Indicators	Country income groups: High income	Middle income	Low income	Total	ANOVA: df	F	Sig.*
Forest LUC (% of land area)	1.43	−1.22	−5.54	−1.16	2	9.26	0.000[abc]
Forest LUC (thousand ha)	2.79	−10.02	−18.13	−7.54	2	1.12	0.329
Arable LUC (% of land area)	−2.53	0.28	5.73	0.38	2	31.85	0.000[abc]
Arable LUC (thousand ha)	−954.18	214.27	1206.36	31.52	2	3.033	0.051
Agricultural LUC (% of land area)	−4.83	0.32	5.51	−0.37	2	23.34	0.000[abc]
Agricultural LUC (thousand ha)	−22.65	−1.01	19.93	−4.04	2	2.64	0.074
IAgL LUC (% of land area)	−0.24	−0.03	0.01	−0.05	2	1.81	0.168
IAgL LUC (thousand ha)	3.7	3.99	5.76	4.3	2	0.18	0.840
CO_2 emissions change (mt)	22.93	147.29	1.45	85.67	2	0.85	0.429
CO_2 emissions change (kt per area)	1.42	0.13	0.01	0.5	2	5.18	0.007[ab]
GDP change (billion US$)	608.57	251.22	7.86	322.54	2	2.61	0.077
GDP growth change (%)	−2.05	0.66	5.81	0.71	2	5.91	0.003[bc]

Abbreviations: ANOVA, analysis of variance; GDP, gross domestic product; IAgL, irrigated agricultural land; LUC, land use change.
*Significance values less than 0.05; a: significant difference among high-income and middle-income countries; b: significant difference among high-income and low-income countries; c: significant difference between low-income countries and middle-income countries.
Source: The study findings.

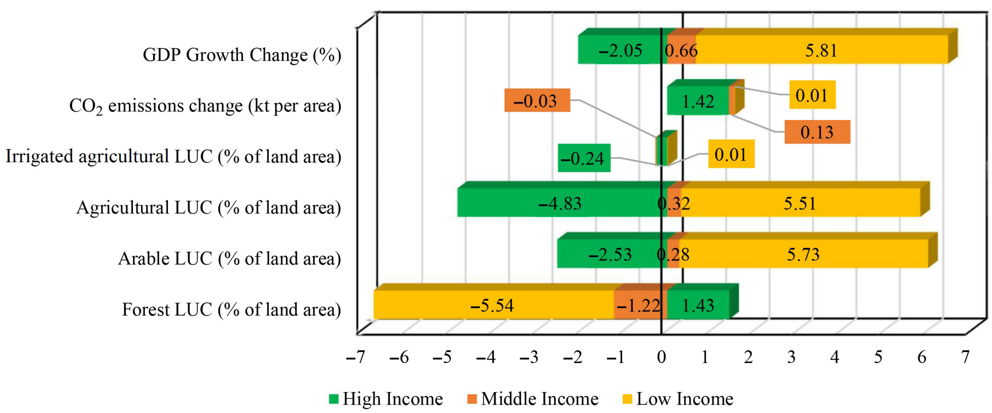

FIGURE 3 The comparison of different indicators by country income group (1990–2012). GDP, gross domestic product; IAgL, irrigated agricultural land; LUC, land use change. [Colour figure can be viewed at wileyonlinelibrary.com]

predictor variables including forest LUC, agricultural LUC, irrigated LUC, and GDP change among three various income group countries. This analysis is extremely useful because it allows us to go one step further than data (Field, 2009). Table 4 shows the outputs of four multiple regression models which were run for every country's income group. The greater value of the R^2 coefficient and the F-ratio in the case of middle-income countries compared with other countries means that the variables of land use and land cover changes in this group of countries have a greater share in explaining the variance of the dependent variable (CO_2 emissions change) than in other countries. In addition, it also statistically means that this relationship can be confirmed statistically with a higher level of confidence.

Model summaries and ANOVA tables may be used to examine the adequacy of the regression model, which employs the values of R, R^2, degrees of freedom, F-ratio, and its relevance for the models. The model coefficients column provides features of the model parameters, that is, beta values, and the importance of these values. In general, regression b coefficient values show the change in CO_2 emissions caused by the predictor's unit change, as well as whether the predictor has a substantial influence on the ability to predict the outcome. As a result, b must deviate from 0 and must have a big ratio to its standard error.

4.4 | All countries together

As shown in the model summary column in Table 4, there is a high multiple correlation coefficient ($R = 0.847$) between the predictors (different LUCs and GDP change) and the outcome (the change in CO_2 emissions). The value of R^2 is 0.717, which indicates the variability of the result predictors. For this model, the predictors (including forest LUC, arable LUC, agricultural LUC, and GDP change) can explain 71.7% of the variation in the changes in CO_2 emissions. The next column of the output report is the analysis of variance. The

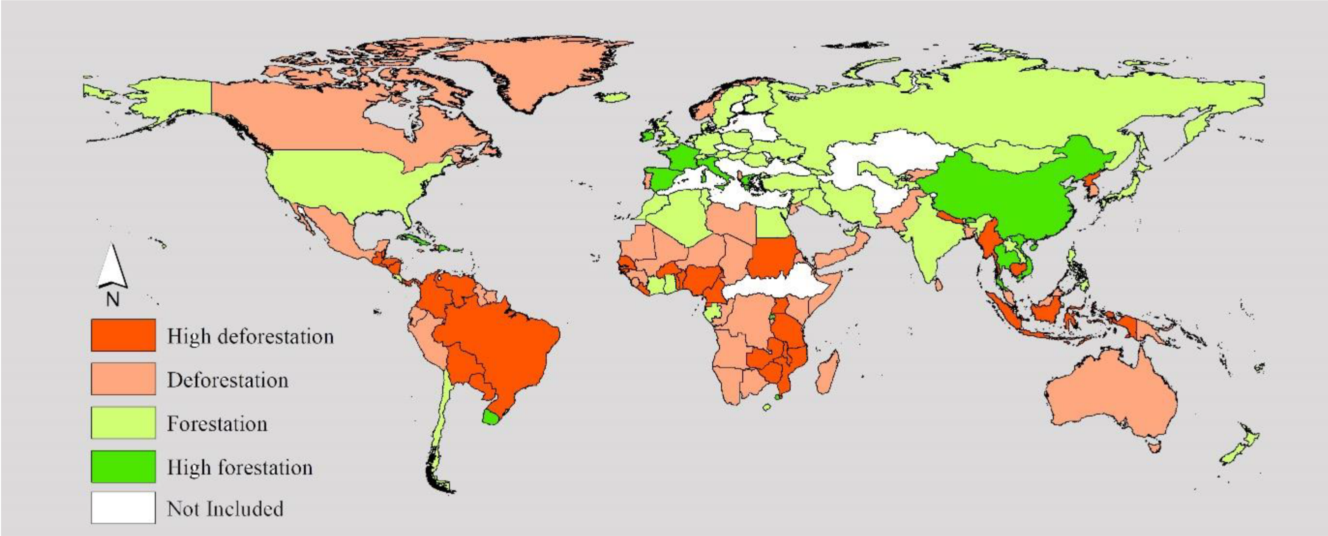

FIGURE 4 The percentage of change in forest area (ha) in different countries (1990–2012). *Source*: Buchhorn et al. (2019); World Bank's internal Global Monitoring Database. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Classification of countries based on land use change (LUC) increase or decrease during 1990–2012.

LUC type	Change	Mean	*N*	SD	Minimum	Maximum
Forest LUC (% of land area)	Decrease	−4.62	95	5.58	−28.46	0.00
	Increase	3.82	66	5.54	0.02	27.32
	Total	−1.16	161	6.93	−28.46	27.32
Arable LUC (% of land area)	Decrease	−2.63	74	3.43	−13.72	0.00
	Increase	3.32	76	4.30	0.01	25.00
	Total	0.38	150	4.90	−13.72	25.00
Agricultural LUC (% of land area)	Decrease	−5.35	78	5.82	−26.85	0.00
	Increase	4.62	78	4.47	0.01	17.39
	Total	−0.37	156	7.19	−26.85	17.39
Irrigated agricultural LUC (% of land area)	Decrease	−0.21	41	0.62	−2.77	0.00
	Increase	0.03	75	0.16	0.00	1.24
	Total	−0.05	116	0.40	−2.77	1.24

Source: The study findings.

significant section of this part is the *F*-ratio, which is the incorporated importance value of that *F*-ratio. For the model of all countries, *F* is 83.7, which is significant (because the sig. value is less than 0.05). This result indicates that our regression model generally predicts the change in CO_2 emissions significantly well. This means that the model has a meaningful fit of the data.

The parameters of the model are concerned with the next part of the output (model coefficients). The first part predicts the values of b, and these values represent the individual contribution of each predictor in the model. In other words, the values of b show the correlation between the CO_2 emissions change and each predictor. If the value is positive, the predictor and the result have a positive relationship, while a negative coefficient shows a negative relation. All b-values have a significant and positive link with the outcome variables for the model of all countries. It means, in the countries where the percentage area of forest, arable, and agricultural lands or GDP growth has increased (during 1990–2012), the CO_2 emissions have also increased. Therefore, LUC is a major source of CO_2 emissions, and these changes are a major contributor to global warming and atmospheric change.

However, the magnitude of the effect of all variables on the dependent variable is not the same. In consonance with the beta coefficient, among the LUC variables, the forest LUC has had the most impact on CO_2 emissions (beta = 0.84), and the agricultural LUC has had the least impact on it (0.10). However, the effect of GDP change has been more than all the LUC variables (0.86). The relationship between temperature change and productivity levels and the effect of the fluctuations of average temperature and GDP growth in a country have been tracked, and there is also a strong relationship between economic change and LUC. Additionally, this study confirms that

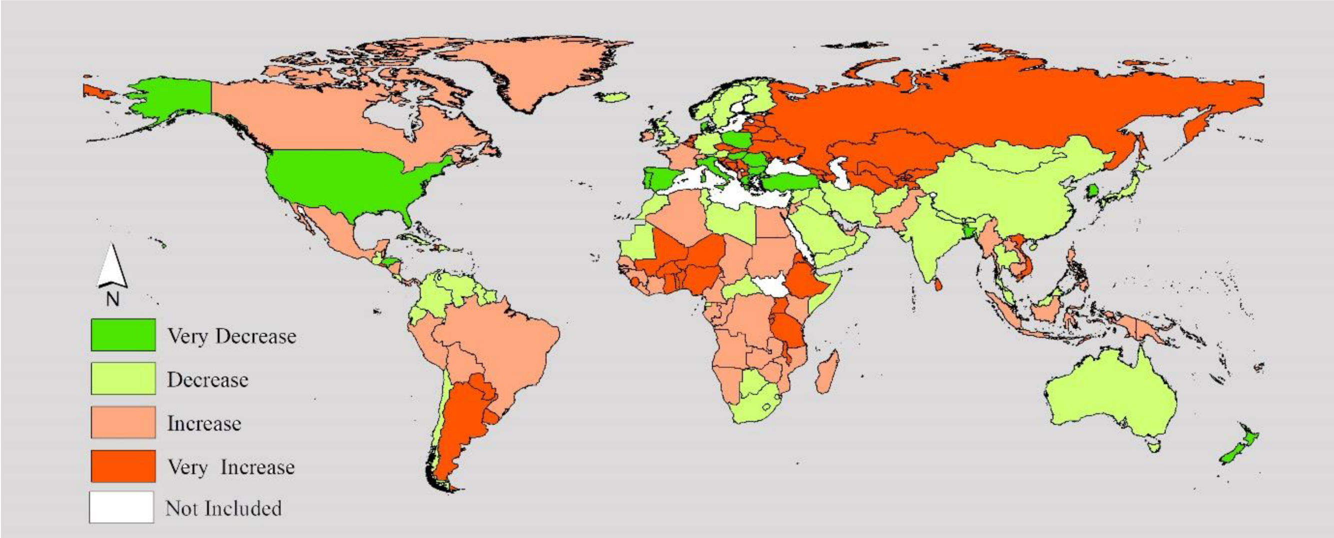

FIGURE 5 The percentage of arable land use change (ha) (1990–2012) for all the studied countries. *Source*: Buchhorn et al. (2019); World Bank's internal Global Monitoring Database. [Colour figure can be viewed at wileyonlinelibrary.com]

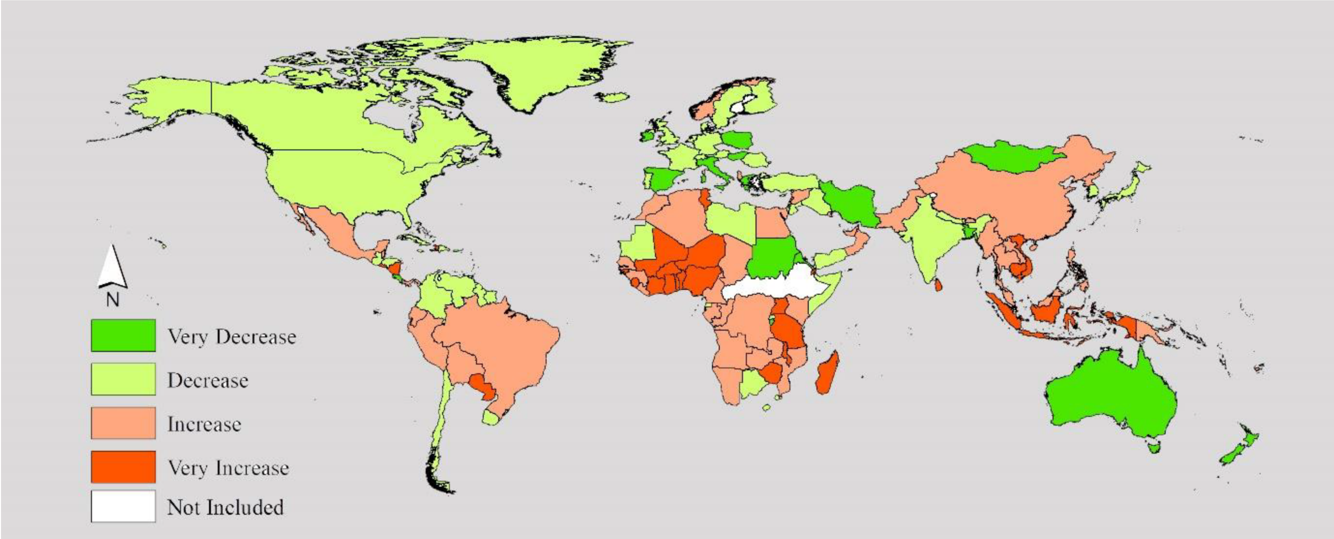

FIGURE 6 The percentage of agricultural land use change(ha) (1990–2012) for all the studied countries. *Source*: Buchhorn et al. (2019); World Bank's internal Global Monitoring Database. [Colour figure can be viewed at wileyonlinelibrary.com]

there is a strong relationship between CC and LUC. This study confirms the studies by Kais and Sami (2016), Lau et al. (2014), Loveland et al. (2012), and Tang et al. (2016) in a way that there is a relationship between economic change and CC. These studies confirmed that economic change and LUC are closely related.

4.5 | High-income countries

Since the value of R^2 is 0.359, it can be concluded that only about one-third (35.9%) of the dependent variable changes can be explained by independent variables (including forest LUC, arable LUC, and agricultural LUC). Furthermore, according to *t*-values, among the independent variables, GDP ($t = 12.63$) is the most contributor to CO_2 emissions. Furthermore, according to *t*-values, among the independent variables, GDP ($t = 12.63$) is the most contributor to CO_2 emissions. In fact, it means, for high-income countries, the changes in CO_2 emissions are more affected by other variables that are not predicted in the current model. The *F*-ratio for the model of high-income countries is 5.55, so it is significant (sig. < 0.05). The subsequent part of the output is related to the model parameters. Based on *t*-values, there is no statistically considerable impact on any of the LUC variables on the dependent variable. For these countries, this is only the GDP change variable that has a statistically important impact on the emissions of CO_2 which is, in fact, the cause of the low level of R^2 in this model. In this context, our findings contrast with those of other studies, such as Schlenker and Roberts (2009) and Tasser et al. (2017), which focused on the relationship between CO_2 emissions and LUC in

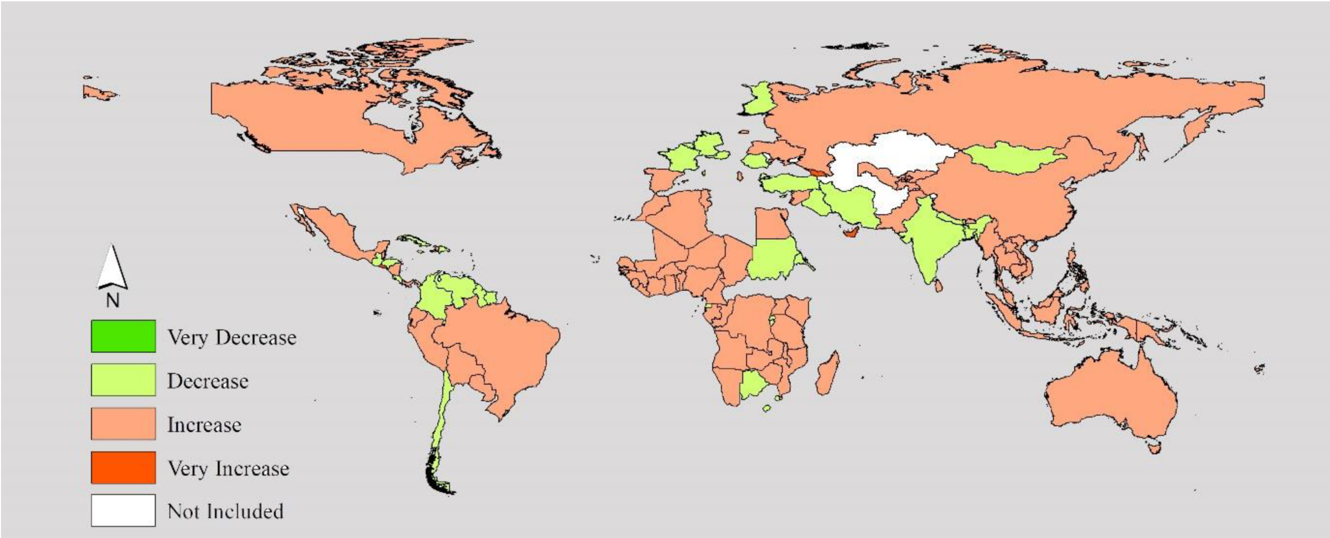

FIGURE 7 The percentage of irrigated agricultural land use change (ha) (1990–2012) for all the studied countries. *Source*: IUCN (2018). [Colour figure can be viewed at wileyonlinelibrary.com]

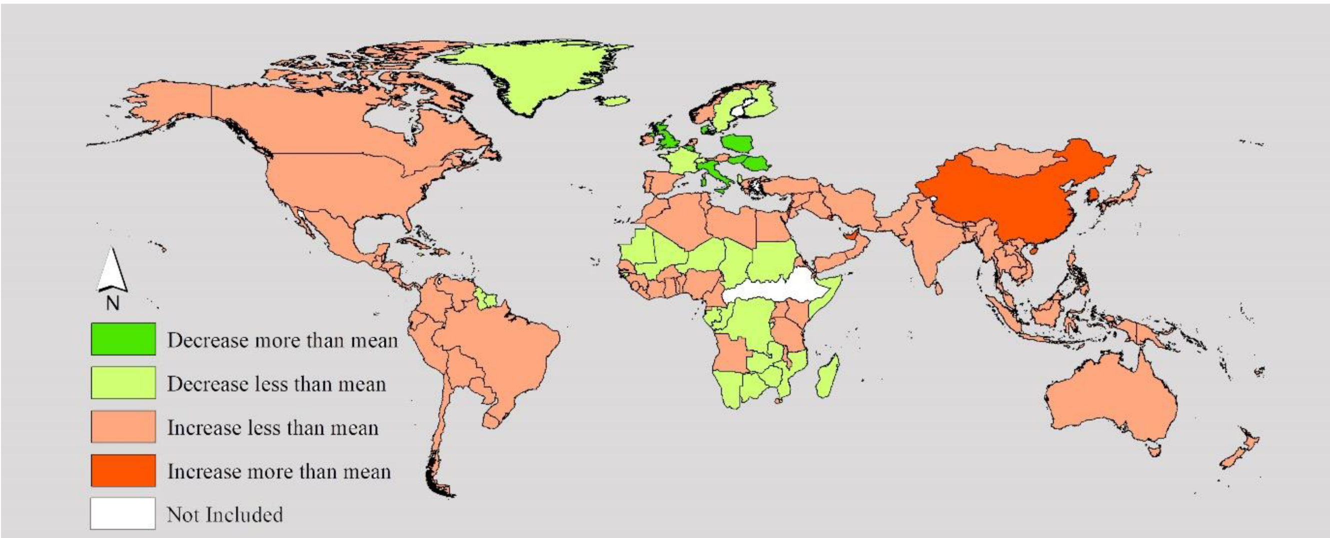

FIGURE 8 The percentage of CO_2 emissions changes per area (1990–2012) for all the studied countries. *Source*: IUCN (2018). [Colour figure can be viewed at wileyonlinelibrary.com]

high-income countries. The result indicated that LUCs have no significant effect on CO_2 emissions in high-income countries. This result is consistent with the results of T. Wei et al. (2012) who have shown the main cause of CO_2 emissions in developed countries has been fossil fuel burning (62%). In other words, the main cause of CO_2 emissions in developed countries is fossil fuel burning and the source other than LUC.

4.6 | Middle-income countries

For middle-income countries (the third model in Table 4), there is a significantly high multiple correlation coefficient ($R = 0.993$) between the predictors (including forest LUC, agricultural LUC, and GDP change) and the change in CO_2 emissions. The value of R^2 is 0.987 meaning that these predictors can explain 98.7% of the variation of the outcome variable. Then, in countries with middle income, the changes in CO_2 emissions are mainly affected by these variables. The *F*-ratio of the model is 1318.5, and it is significant (sig. < 0.05). According to *t*-values, the only variable is the arable LUC which did not have a statistically significant effect on the dependent variable. In addition, based on the beta coefficients, the main cause of CO_2 emissions in countries with middle income (like countries with high income) has been GDP change, and the effect of the forest LUC has been more than the agricultural LUC. In addition, forest LUC has a positive impact on emissions of CO_2, while agricultural LUC has a negative impact on CO_2 emissions. Similar to our results, Xu et al. (2017) showed that in China (the largest country in the world with a middle-

TABLE 3 The CO_2 emissions changes per area (1990–2012) among two different classes of countries.

Country classification[a]	Mean	N	SD	Minimum	Maximum
Decrease in CO_2 emissions (kt per area)	−0.1467	39	0.48793	−3.01	0.00
Increase in CO_2 emissions (kt per area)	0.7291	113	2.72560	0.01	21.64
Total	0.5044	152	2.39110	−3.01	21.64

[a]Based on CO_2 emissions changes between 1990 and 2012.
Source: The study findings.

TABLE 4 The outputs of four multiple regression models for every country's income group.

	Model summary[b]			ANOVA[c]			Model coefficients[b]					
							Unstandardized coef.					
Model[a]	R		R^2	df	F	Sig.[d]	b	SE	Beta[e]	t	Sig.[d]	VIF
All countries	(Constant)	0.847	0.717	4	83.7	0.000	2419.03	32,752.21		0.07	0.94	
	Forest LUC						8.23	0.69	0.84	11.94	0.00	2.29
	Arable LUC						0.13	0.02	0.75	7.93	0.00	4.16
	Agricultural LUC						0.77	0.39	0.10	1.97	0.05	1.12
	GDP change						4.85E-07	3.84E-08	0.86	12.63	0.00	2.18
High	(Constant)	0.628	0.359	4	5.55	0.002	9375.30	12,411.76		0.76	0.46	
	Forest LUC						−1.59	1.31	−0.31	−1.21	0.23	3.78
	Arable LUC						−0.00	0.01	−0.08	−0.19	0.85	9.51
	Agricultural LUC						0.04	0.16	0.05	0.25	0.80	2.17
	GDP change						3.50E-08	1.73E-08	0.73	2.02	0.05	7.41
Middle	(Constant)	0.993	0.987	4	1318.5	0.000	−23,790.64	13,019.39		−1.83	0.07	
	Forest LUC						1.56	0.36	0.16	4.27	0.00	7.08
	Arable LUC						−0.01	0.01	−0.06	−1.61	0.11	6.70
	Agricultural LUC						−0.37	0.16	−0.03	−2.26	0.03	1.22
	GDP change						7.98E-07	1.47E-08	0.89	54.10	0.00	1.44
Low	(Constant)	0.762	0.581	4	6.2	0.002	218.40	500.18		0.44	0.67	
	Forest LUC						0.06	0.02	0.71	3.11	0.01	2.26
	Arable LUC						−1.72E-04	6.25E-04	−0.12	−0.28	0.79	7.92
	Agricultural LUC						0.01	0.03	0.09	0.22	0.83	6.96
	GDP change						3.25E-07	7.05E-08	1.15	4.60	0.00	2.67

Abbreviations: ANOVA, analysis of variance; GDP, gross domestic product; LUC, land use change; VIF, variance inflation factor.
[a]Since the variables of Agricultural LUC and Irrigated Agricultural LUC had collinearity, in order to avoid overestimation, only the variable of Agricultural LUC was included in the regression models.
[b]Predictors: (Constant), forest LUC, arable LUC, agricultural LUC, GDP change.
[c]Dependent variable: CO_2 emissions change.
[d]Significance values less than 0.05.
[e]Standardized coefficients.
Source: The study findings.

income level), the manufacturing industry as the largest source of GDP is one of the main reasons for CO_2 emissions. During the 1990–2015 period, it was responsible for around 58% of the whole CO_2 emissions. Furthermore, the positive effect of LUC on CO_2 emissions is proved by Zhou et al. (2015) in China.

4.7 | Low-income countries

In countries with low income (the fourth model of Table 4), there is a significant multiple correlation coefficient ($R = 0.762$) between the predictors (including forest LUC and GDP change) and the change in CO_2 emissions. The value of R^2 is 0.581 meaning that these predictors can explain only 58.1% of the variation of the outcome variable. Then for low-income countries, the changes in CO_2 emissions are somewhat affected by these variables. According to *F*-ratio, this regression model is significant (sig. < 0.05). The *t*-values show that the arable and agricultural LUCs have no statistically important impact on CO_2 emissions. The forest LUC in low-income countries is the same as in middle-income countries and has a positive impact on CO_2 emissions, but the size of this impact based on the beta coefficients for low-income countries (0.71) is much more than that of middle-income countries (0.16). In addition, like the other two country groups, the main cause of CO_2 emissions in low-income countries has been GDP change, and the size of this effect for this group (1.15) has been more than middle-income countries (0.89) and high-income countries (0.73). Finally, there is no statistically important relationship between CO_2 emissions and arable and agricultural LUCs in countries with low income. The difference between the CO_2 emissions patterns and LUCs among the developed and developing countries was proved by De Campos et al. (2005).

5 | DISCUSSION

5.1 | Interactions of land use change and CO_2 emissions

Historical human-driven LUC has significantly impacted the climate, contributing to approximately one-third of the total carbon dioxide emissions to date (Tripathi et al., 2022). Despite occurring over many centuries, our study indicated that LUC remains one of the major drivers of CO_2 emissions. However, the intensity and nature of the LUC effects vary across different countries. In low-income countries, forest LUC has been particularly impactful, significantly contributing to CO_2 emissions and thereby driving extensive climatic changes. In middle-income countries, changes in agricultural and forest land use have notably increased CO_2 emissions contributing to CC. Conversely, in high-income countries, while agricultural, forest, and arable LUC have a statistically significant effect on CO_2 emissions, the magnitude of these changes is less pronounced compared to those in low-income and middle-income countries. Therefore, it seems that LUC and CC are closely intertwined with each influencing the other in significant ways. For instance, clearing forests for agriculture, urban development, or logging results in significant amounts of CO_2 into the atmosphere, contributing to CC. Increased CO_2 levels from deforestation contribute to global warming, exacerbating conditions like droughts and wildfires, further reducing forest cover.

LUC is among the main drivers of CC with an estimated 3.3 ± 2.6 $GtCO_2$ $year^{-1}$ emissions in 2020 (contributing to around 9% of global CO_2 emissions; Garofalo et al., 2022). CO_2 emission due to deforestation and other changes in land use is calculated to be 180 Gt (1966–2015) (Barati et al., 2023), and based on the findings of this study, forest LUC, arable LUC, agricultural LUC, and GDP change contribute for about 72% of the variation in CO_2 emissions. However, the forest LUC has had the most impact on CO_2 emissions among other types of LUC. Other drivers, especially GDP growth, have played an important role in increasing the carbon dioxide content of the air. However, the severity of the impact of the LUC on CO_2 emissions varies between countries with different levels of income. While developed countries are responsible for 79% of historical carbon emissions, developing countries are responsible for 63% of current carbon emissions. Considering the Paris Agreement, despite the growing awareness of the challenges posed by CC and LUC interactions at the global level, which account for the majority of the total GHG emissions, there was an increase (2.0%) in 2018, reaching a record of 37.5 $GtCO_2$ per year (Eurostat, 2020). Moreover, when it comes to long-term CC policy goals, high-income countries appear to be less ambitious in mitigating CO_2 emissions. As a result, they are failing to adjust their CC mitigation strategies in accordance with the Paris Agreement's goal (Eurostat, 2020).

Dumortier and Elobeid (2021) and Chang et al. (2022) indicated that in some current high- and middle-income countries (e.g., the USA and China), LUC has had a huge impact on historical CO_2 emissions. According to IPCC report (2015), due to the increasing awareness and policies toward CC adoption and mitigation, overall GHG emissions rose from 1970 to 2010, which was significant from 2000 to 2010. Our findings revealed that there was about a 78% increase in total GHG emissions from 1970 to 2010 due to CO_2 emissions released by fossil fuel combustion and industrial processes. Globally, the most significant drivers of increases in CO_2 emissions from fossil fuel combustion have continued to be economic and population growth.

Empirical studies that investigate the amount of CO_2 in the atmosphere derived from LUC can help the understanding of whether and to what extent deforestation can lead to an increase in CO_2 emissions from the land. Agriculture and forestry have contributed to GHG emissions through soil cultivation and fertilization, management of livestock manure, and fuel consumption (USDA, 2016). Many studies (Röös et al., 2017; Tamburini et al., 2020) show that agricultural LUC contributes to GHG emissions and puts constant pressure on land, soil, water, and biodiversity. Thus, there should be more focus on nature-based solutions (e.g., agroecological approaches) toward mitigating CC and economic growth at the same time.

5.2 | Interactions of land use change and GDP

In line with the studies by Canadell et al. (2007) and Henriques and Borowiecki (2017), and as shown in Table 4, in high-income countries, there is a strong correlation between CC and GDP. However, LUC in forest and agricultural lands has not been directly responsible for the CO_2 emissions rise. Similarly, GDP changes in middle-income countries are correlated with CO_2 emissions, but there is a significant relation between forest and agricultural LUC and CO_2 emissions, unlike in high-income countries. This problem appears to be more prevalent in countries with high incomes since their economies rely more heavily on industry and services developed sections, which reduces the demand for new land. This leads to less LUC, including those in the agricultural, forest, and other lands. As a result, in such countries, GDP has a greater influence on the source of greenhouse gas emissions in these nations than changes in land use. This problem is a little bit different in middle-income countries because, while the industrial and service sectors have grown somewhat in these countries, they have not yet reached their full potential and still require expansion. The need for additional land has resulted from this problem, and as a result, there has been a more significant change in the land uses, such as forest and agricultural lands. Because of this, LUC continues to be one of the primary causes of greenhouse gas emissions in these countries, along with GDP. Nevertheless, Henriques and Borowiecki (2017) in another study found that long-term GDP growth is the most crucial driver of CO_2 emissions in countries with high income including the Netherlands, Spain, Denmark, Germany, the UK, France, Portugal, Italy, Sweden, the United States, Canada, and Japan. Likewise, forest area and GDP changes in countries with low income were related to CO_2 emissions rise. In contrast with middle-income countries, agricultural LUC had no significant impact on CO_2 emissions in low-income countries. Therefore, the situation in low-income countries varies slightly. The demand for changing the use of agricultural and forest lands is not very high in this group of countries because many people still rely on them for their livelihood. Therefore, agriculture and natural resources, such as forests, are still considered to be the major sources of GDP in these nations. As a result, changes in land use have little impact on greenhouse gas emissions. The effect of LUC on greenhouse gas emissions in this group of countries will undoubtedly increase in the future due to the declining profitability of agricultural activities, the reducing economic importance of natural resources like forests, and the progressive development of the industrial and service sectors in these countries. Yet, many scholars confirm that there is a direct link between CC derived by LUC and economic goals (Loveland et al., 2012). Likewise, this study confirms that GDP was correlated with CO_2 emissions and changes in forest areas in middle- and low-income countries.

Furthermore, our findings showed that there is a significant difference between the average LUC in forests, LUC in arable land, and LUC in agriculture, in terms of CO_2 emissions in each region and changes in GDP growth in that region. This result can be interpreted as the fact that forests are increasingly being cleared due to overgrazing and because of their conversion to recreational areas and the housing sector. Therefore, increasing human activities in forest areas will lead to an increase in CO_2 emissions. Moreover, improper human use of arable land and the current trend of traditional agriculture instead of agroecological approaches in some developing countries will intensify this emission. These findings are in line with the findings of the studies by Doelman et al. (2018) and Soussana et al. (2019) who stated that human activities, deforestation, and inappropriate agricultural activities will lead to an increase in CO_2 emissions. In another study, Nguyen (2008) showed a loss in Vietnam's forestlands from 2001 to 2005. The major driving force that contributed to this loss was the conversion of forestlands to rice production in order to boost GDP and economic growth. He concluded that rapid urbanization has impacted forestland conversion and has hampered the utilization and management of land resources.

5.3 | Interactions of land use change, CO_2, GDP, and economic growth

As the results show, globally, the forest areas have decreased by about 1.16% in each country from 1990 to 2012. This change has been adverse in low- and middle-income countries (5.54% and 1.22%, respectively), but positive in high-income countries (1.43%). This finding shows that high-income developed countries are more successful in adapting to CC, land use, and mitigating CO_2 emissions. This could be due to stakeholder awareness increase and appropriate land management strategies (Collier et al., 2009; Lake & Barker, 2018). According to the current study's findings, while LUC and GDP growth were the primary causes of global CO_2 emissions (71.7%), the causes of CO_2 emissions increase will differ when countries are classified into different income groups (high, middle, and low). Although LUCs and GDP growth are major drivers of CO_2 emissions in countries with middle income ($R^2 = 0.987$), they are not the only main factor of CO_2 emissions in countries with low income and especially in countries with high income. Therefore, there is a need for further research on investigating different income group countries, especially in high- and low-income countries to identify the main drivers of CC. For example, transportation, industry, and commercial and residential growth are some of the variables that may affect CC. Small cities release more GHG than larger cities in developed countries, while the contrary is true for developing countries (Gudipudi et al., 2019). In such countries, in addition to being an emission source, urbanization contributes to deforestation and the conversion of agricultural and undeveloped lands to urban use (Du et al., 2017).

Agricultural LUC and urbanization, both of which on the rise in metropolitan cities, have resulted in several issues that are complicated from a spatial, economic, social, and environmental perspective. Surya et al. (2020) found that spatial interaction and integration, plus urbanization, affect economic growth and the system of urban activity in the suburbs of Mamminasata, but at the cost of increased CO_2 emissions, ecosystem imbalances, and economic and social inequality.

5.4 | Theoretical contributions and policy implications

There are several policy implications based on the main findings of the study. The first is to underscore the significance of national and international policies prioritizing mitigating LUC's adverse impacts on CC. These policies recognize the economic benefits of addressing climate concerns while emphasizing the need to balance CO_2 emissions.

The second is to update international protocols and enhance monitoring efforts, including ground-based measurements and satellite investigations that can provide objective evidence of the links between LUC and CC. For this purpose, policymakers should thoroughly evaluate the GDP, costs, and income related to the agricultural sector at both local and global levels to address deforestation and LUC caused by agriculture successfully.

The third is to educate the authorities on improving territorial spatial governance and high-quality land use while also changing the land use policy. In order to guarantee that the collective impact of land use surpasses the consumption effect and to successfully encourage carbon emission reductions, they should also actively optimize land use, effectively control the intensity, and work to improve land use efficiency. The state authorities should, in particular, implement differentiated land supply policies to allocate more land indicators to low-carbon and efficient agro-industrial sectors and take control of land use in the agricultural sector, which has high energy consumption and GHGs. These programs will guarantee that local land is used appropriately while simultaneously reducing GHGs emissions.

The fourth is to maximize the structure of energy consumption in the industrial and agricultural sectors, minimize the use of conventional fossil fuels, and increase the use of renewable and environmentally friendly energy sources. When considering the global economy, agriculture plays a vital role. Energy is necessary at every production stage, from producing fertilizers to powering tractors for planting and harvesting. Implementing energy efficiency methods and utilizing renewable energy sources on farms can help agricultural producers save on energy costs. Renewable energy resources (e.g., solar, biomass, wind, and geothermal) are abundantly available in agriculture. Thus, switching to alternative energy sources for agricultural energy management has a lot of potential to lower GHGs emissions, increase energy efficiency, and support sustainable food production. But for implementation to be successful, political, technical, and financial obstacles must be removed, and farmers and other stakeholders' capacities must be developed.

The fifth is for governments to quickly encourage LUC and CO_2 emission reductions by using fiscal funds, tax policies, industrial development support, market-oriented mechanisms, and other policies and measures. This is what that was agreed upon in COP28 as crucial steps to accelerate global action: reducing GHGs emissions, strengthening resilience to CC, and providing financial and technological support to vulnerable countries.

The last is to increase our understanding of the relationship between climate research and LUC studies on a global scale, helping to increase the planning and implementation of more effective land use and CC policies and interventions to reduce CO_2 emissions. This highlights the need for investment in measuring, reporting, and verifying LUC-related activities and developing databases. By implementing the policy recommendations outlined in this study, policymakers can reduce CO_2 emissions from LUC and mitigate its impact on CC, thus helping achieve the global temperature limit of 1.5°C as stated in COP28.

Overall, the findings of this study can be used to develop effective policies and regulations to promote sustainable LUC, reduce CO_2 emissions, and mitigate the effects of CC, particularly in developing and low-income countries. While international agreements concerning CO_2 emissions may ultimately regulate carbon capture, local, state, and federal decisions will primarily shape LUC patterns. Therefore, policymakers can significantly reduce the rate of LUC by effectively managing and upholding national standards that promote a balanced approach to GHGs emissions.

6 | CONCLUSIONS

A significant part of the global CO_2 emission, which has a direct effect on CC, is related to LUC. The interaction between LUC and CC creates a complex web of feedback loops and interdependencies. LUC, such as deforestation, agricultural expansion, and urbanization, directly impacts CO_2 emissions and climate. Conversely, CC influences land use patterns and the viability of different land uses. Addressing these challenges requires integrated strategies that consider both LUC and CC mitigation and adaptation to create sustainable and resilient systems. The estimated cumulative CO_2 emissions over the period 1990–2012 based on IPCC data are approximately 35% of total C emissions. Therefore, in addition to examining the effects of LUC on the global economy and GDP, this study investigated the interactions between different types of LUC, especially forest, arable, agricultural, and irrigated agricultural lands, and CO_2 emissions from 1990 to 2012. The impacts of LUC on the global economy and GDP are multifaceted, with both positive and negative aspects. While LUC can drive economic growth and development, especially in sectors like agriculture, forestry, and urban development, they can also lead to significant environmental and economic costs. Sustainable land use practices are crucial for balancing global economic development with environmental conservation and ensuring long-term economic stability in the face of CC. The findings of this study also highlighted the LUC role in increasing global CO_2 emissions. The findings of this study showed that LUC can alter the state and dynamics of the atmosphere, thereby increasing CC. Based on the obtained results, after studying how CC can be controlled by land use, it is possible to control the CC for the benefit of humans' well-being as well as the environment. The major findings of this study showed that land use in the world is still changing, and its intensity is higher in low-income countries. LUC affects CO_2 exchange because of human activities and, thus, has an impact on CC. The amount of CO_2 emissions per country in the world, especially in middle-income countries, is still on the rise. Therefore, in global planning to mitigate CO_2 emissions, a concerted multidisciplinary effort is needed. Such planning requires a holistic and integrated approach involving local to international cooperation, technological innovation, policy measures, and changes in consumer behavior. It involves reducing emissions from energy production and consumption and mitigating CO_2 emissions from LUC.

Overall, a multifaceted approach is needed, ranging from local to global levels such as engaging local communities in sustainable land management practices and supporting international agreements to prevent harmful LUCs. Financial and technological support for low-income and middle-income countries is crucial, as is the need for regulatory frameworks that incentivize low-carbon solutions. Successful mitigation efforts will depend on the collective action of governments, businesses, and individuals worldwide. Furthermore, it should be noted that the amount of CO_2 emissions per area in high-income countries is more than in middle- and low-income countries. This finding shows that these countries are failing to address the Paris Agreement's goal. In developing countries, the drivers of CO_2 emissions have been more diverse and complex. As a result, there is an urgent need to identify other drivers of CO_2 emissions to mitigate them by the scientific community or decision-makers. However, some countries, particularly developing and low-income countries, may be unable to reduce CO_2 due to barriers such as a lack of awareness, proper infrastructure, good land governance, and sustainable land management. Methodologically, using time-series data, we discovered that there is a significant difference in CO_2 emissions among three income-country groups when we considered the amount of CO_2 emissions per area in each country. One reason for this could be that countries vary in size and land cover. Hence, the amount of CO_2 emissions by different countries is different.

While this study has made valuable contributions to understanding the interaction between LUC and CC, it is important to highlight some limitations. The reliance on World Bank time-series data provides a broad perspective. Still, potential data gaps, inaccuracies, or limitations in representing specific regions or sectors may impact the overall findings. Additionally, the study focuses on CO_2 emissions, and while CO_2 is a significant GHG, the impacts of other GHGs should be investigated in future research. Exploring the socio-economic impacts of these interactions at a regional level and considering additional factors, such as land use policies, technological advancements, and societal behaviors, can provide a more comprehensive understanding. Furthermore, identifying and addressing drivers of CO_2 emissions in developing countries, where the challenges are diverse and complex, requires a multidisciplinary approach. Future research endeavors should prioritize investigating these drivers and proposing strategies to overcome barriers, ensuring a more inclusive and effective approach to mitigating CC.

The study also highlights the need for increased awareness, better infrastructure, good land governance, and sustainable land management, particularly in developing and low-income countries. Therefore, future studies should delve into these challenges and propose targeted solutions, considering the unique contexts of different regions. Moreover, efforts should be made to bridge the gap between scientific findings and actionable policies, ensuring that the knowledge gained from studies like this one translates into practical and impactful interventions. While this study enhances the understanding of the interaction between LUC and CC, it lays the groundwork for future research. Addressing the identified limitations, exploring additional variables, and adopting a multidisciplinary approach will contribute to more robust findings.

It is also necessary to explain that because of the restricted access to conduct analyses utilizing current data for all countries, we were forced to restrict the time frame of the analysis to 1990–2012. To strengthen the validity of the study's conclusions, it is advised to repeat the research in a similar manner but for smaller geographic regions with more recent data and to compare the outcomes.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTES

[1] The purpose of protected forest areas is to preserve forest biodiversity, that is, the diversity of genes and species in forest ecosystems, or to protect landscapes. Compared with unprotected areas, globally protected areas store approximately 1 year's worth of global fossil fuel emissions by avoiding deforestation. Different scholars worked with never-before-used satellite data, gathered by NASA's Global Ecosystem Dynamics Investigation (GEDI). Their findings show that, in comparison with ecologically comparable unprotected areas, protected areas store 9.65 billion metric tons more carbon in their aboveground biomass. Therefore, the primary causes of this increased carbon stock are prevented deforestation and degradation.

[2] https://data.worldbank.org/indicator/.

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