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Capital formation and production of carbon emissions in low-carbon development

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ABSTRACT

BACKGROUND AND OBJECTIVES: This study aims to examine the endogenous variable, low-carbon development, and valuate its influencing factors, given its pivotal role in environmental protection amid climate change concerns and economic growth. Low carbon development is a new platform to maintain economic growth through reducing carbon emissions and reducing the use of natural resources, because it was predicted that reducing emissions will increase economic growth while preventing forest loss, improving air quality and living standards, and reducing mortality rates.
METHODS: Utilizing a quantitative method, this study integrates a novel viewpoint by combining low-carbon development with related emission factors. The study utilizes secondary data, specifically time series data spanning 31 years from 1991 to 2021, which were analyzed using regression study methods. The factors being examined include capital formation, deforestation, land transportation, agricultural land, and industrialization.
FINDINGS: Findings reveal that low-carbon development in North Sumatra is influenced significantly by capital formation, deforestation, agricultural land, and industrialization, with land transportation showing no substantial impact. Capital formation has a favorable impact on low-carbon development. But, deforestation, land transportation, agricultural land and industrialization have a negative impact on low-carbon development. Together, these determinants account for 77.55 percent of the variance. Capital formation contributes 19.8 percent, deforestation 15.6 percent, agricultural land 19.0 percent, and industrialization 18.9 percent to low-carbon development.
CONCLUSION: The hypothesis established in this study is accepted. To foster low-carbon development in North Sumatra, specific attention is required from local governments. Capital formation is vital. Measures include controlling interest rates, supporting businesses, fostering an investment-friendly climate, ensuring security, and integrating environmental sustainability considerations into project implementation to curb carbon emissions. Prevention of deforestation involves tightening land clearance licenses and enhancing institutional quality through environmental protection and property rights legislation. The government must strive for promoting eco-friendly agricultural practices with mitigated through outreach programs involving experts who educate farmers on minimizing emissions, reducing carbon emissions from pesticide with using biochar sourced from empty palm fruit bunches and also rice straw which is very easy to obtain at a low cost and is environmentally friendly, and emphasizing environmental preservation policies in the industrial sector like industrial transformation efforts with an effective approach to reducing carbon emissions such as restructuring various aspects of industrial activities, including investment, final demand, intensity and production methods. The implementation of tax emissions and strategic interventions increases the likelihood of realizing low-carbon development in North Sumatra, aligning with sustainable development goals.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
40	2	7

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INTRODUCTION

Low carbon development is a crucial initiative supporting sustainable development goals, as outlined by the Ministry of National Development Planning/Bappenas in 2020 (Kementerian PPN/ Bappenas, 2020). This innovative approach serves as a foundation for sustaining economic and social growth by curbing carbon emissions and minimizing natural resource utilization. The essence of a low-carbon economy lies in achieving higher economic output while reducing resource consumption, resulting in a decline in greenhouse gas (GHG) emissions (Yan *et al*., 2019). Indonesia has embarked on a development policy emphasizing the equilibrium between economic advancement, social stability, and emission reduction. The government has assiduously honored its international obligation to reduce GHG emissions under the United Nations Framework Convention on Climate Change (UNFCCC) since 1992, strengthened by Law No. 6 of 1994 and subsequently Law No. 17 of 2004. Indonesia's proactive participation in addressing climate change challenges is paramount due to the nation's significant natural resources and expansive forests, vital for absorbing carbon emissions. Achieving low-carbon development and societal prosperity requires crucial support, particularly in the form of capital formation. Capital plays a pivotal role in these efforts, given the substantial financial resources needed for successful program implementation (Mulugetta and Urban, 2010). The shift toward low-carbon development necessitates significant investments, and financial size and quality are critical variables in this process. Government involvement in financing is essential to enhance the effectiveness of these activities (Dzikuc *et al*., 2021). Paradoxically, the abundance of natural resources, often viewed as an asset for governments, can hinder low-carbon development due to potential environmental harm, such as deforestation. Ignoring these concerns could lead to losses surpassing the benefits obtained. Responsible resource utilization, considering the environmental impact, is essential to ensure sustainable low-carbon development initiatives.

Chen *et al*., (2020) have highlighted that capital formation serves as a key green production factor in measuring the low carbon development index. More capital formation and investment are integral to achieving low carbon development (Dzikuc *et al*., 2021). In the context of capital formation, some sectors and types of projects have greater potential to contribute to carbon emissions in low-carbon development scenarios such as heavy industry, fossil energy, transportation, agriculture and construction. In order to achieve low-carbon development, it is crucial to generate capital formation or investment in industries that support sustainable solutions and lower carbon emissions including capital formation in renewable energy, clean technology, sustainable transportation and environmentally friendly business practices. The sources of carbon emissions are diverse (Kementerian PPN/Bappenas, 2020), encompassing sectors like agriculture, energy, transportation, and various other emission factors. Furthermore, studies by (Tian *et al*., 2019; Raihan, 2023) highlight the role of industrialization, agriculture, energy, transportation, and several other elements in contributing to carbon dioxide emissions, creating barriers to low-carbon development. Initiatives on various sources of emissions, i.e. industrial sector, have an impact not only on low-carbon development, but also on various aspects such as water pollution from industrial waste disposal and also pose a threat to marine life and humans, considerable attention to this issue is necessary. In the context of North Sumatra for the period 2016_2021, the following data outlines variables believed to influence low-carbon development. Table 1 lists the factors considered to affect low-carbon development in North Sumatra.

Factors contributing to carbon emissions significantly impact low-carbon development efforts. Transportation, necessary for economic activities, facilitates the seamless flow of products and services. However, the rising number of vehicles leads to increased carbon emissions, posing threats to both health and the environment. Similarly, agriculture, essential for economic growth and community welfare through food security, also adds to carbon emissions due to the use of various pesticides and fertilizers. Industrialization also plays a role in carbon emissions, with machines in production processes emitting smoke from factories. Essentially, for successful low-carbon development, the government must possess large capital, evidenced by strong capital formation, enabling the

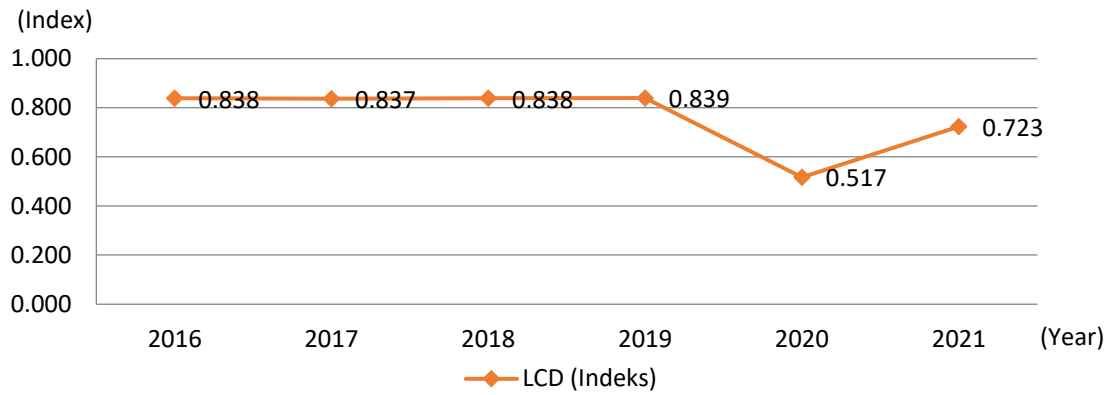

Fig. 1 : The development of low-carbon development in North Sumatera in 2016 to 2021 (Badan Pusat Statistik, 2021)

Table 1: Determinants of low-carbon development in North Sumatra in 2016_2021 (Badan Pusat Statistik, 2021)

Year	Capital formation(%)	Deforestation (%)	Land transportation (%)	Agricultural land (%)	Industrialization (%)
2016	15,57	- 52,99	16,71	13,28	5,05
2017	135,80	132,13	4,35	11,57	2,31
2018	- 28,35	- 67,54	- 77,20	- 58,69	3,66
2019	135,90	69,45	- 67,93	1,22	1,23
2020	- 7,90	- 90,05	6,41	- 5,94	- 0,84
2021	3,62	170,67	- 45,72	1,44	1,43

realization of planned programs and initiatives. Low carbon development represents a developmental approach that harmonizes population growth, economic progress, and environmental preservation. It focuses on generating increased economic productivity utilizing less natural resources and reducing environmental pollution (Yuan *et al.*, 2011). This sustainable economic development model, as outlined by Ravago *et al.*, (2015), strikes a balance in managing capital, human resources, and natural resources, incorporating elements of the social environment, institutions, and economic policies. Sambodo *et al.*, (2022) emphasize that low-carbon development not only aims to reduce emissions but also strives to improve economic growth and lessen poverty. Their study predicts that emission reduction leads to increased economic growth while simultaneously preventing forest loss, enhancing air quality, improving living standards, and reducing mortality rates. This justification emphasizes the idea of low-carbon development as a critical strategy that supports sustainable development goals. It emphasizes the importance of fostering economic growth while simultaneously safeguarding the environment for the well-being of future generations. Carbon emissions, a global problem, are disrupting the delicate ecological balance, leading to negative consequences like heightened greenhouse gas emissions, which fuel global warming and climate change. The swift pace of economic advancement poses a threat to both human and environmental sustainability. An excellent illustration of this is the growing need for fossil fuels, coupled with high carbon emissions, which has created an energy crisis and intensified the problem of global warming. Candrianto *et al,* (2023) explained to make efforts to save the environment, must have an understanding, action related knowledge is knowledge of the impact of behavior on the environment, knowledge of tools for how to reduce environmental impact. Low-carbon development, as highlighted by Airey and Krause, (2017), is a critical tactic meant to propel substantial economic and social advancement while addressing the issues of climate change. However, the expansion of agricultural land (Jebli and Youssef,

2017) leads to increased usage of fuel-powered agricultural equipment, irrigation pump machines, and fertilizers (Samimi *et al.,* 2023), all contributing significantly to carbon emissions. Su *et al*., (2023) argue that agricultural operations exacerbate these emissions, impeding low-carbon development. To mitigate this, adjustments, such as adopting green transportation methods, as suggested Su *et al*., (2012), are crucial. Dzikuc *et al*., (2021) identify main sources of air pollution, including agriculture, fossil fuel combustion, transportation, waste management, and industrial and domestic activities, highlighting the need for efficient control methods. Emphasizing the need for a low-carbon society, (Chen *et al*., 2020) stress the objective of combating climate change, enhancing environmental protection, and ensuring energy security. Progress in low-carbon development is gauged by evaluating the qualitative contributions of economic growth, represented by the inclusion of total green production variables into the assessment process utilizing Eq. 1 (Chen *et al*., 2020).

$$EG = QG + FG \quad (1)$$

where
EG : economic growth
QG : quality growth
FG : factor growth

The equation mentioned above clarifies that the total quality contribution of green production factors serves as a fundamental criterion for evaluating whether an economy has attained low-carbon development. This assessment is made by comparing the quality contribution (QG) to the factor contribution (EG), with a threshold set at QG/EG > 0.5. To quantify low carbon development, index numbers in the equation are utilized as a reliable metric Eq. 2 (Chen *et al*., 2020).

$$\text{LCD Index} = [QG/(QG + FG)] \quad (2)$$

where
LCD : low-carbon development
QG : quality growth
FG : factor growth

The-low carbon development index in the equation not only indicates that a country has moved toward a low carbon economy when the index value exceeds the threshold of 0.5 but also serves as a measure of the extent of low carbon development achieved. However, it is imperative that this development remains firmly grounded in sustainable development principles, aiming to harmonize ecological concerns with the objectives of economic growth and social equity (Mulugetta and Urban, 2010). The realization of low-carbon development is accompanied by several obstacles, including sociocultural, economic, technological, and governmental barriers (Sambodo *et al*., 2022). Moreover, Onyinye *et al*., (2017) posit that the Harrod_Domar growth model underscores the importance of substantial investments to propel economic growth in a positive trajectory, necessitating countries to redirect resources from current consumption toward capital formation. Arrow and Romer, noted in (Wang *et al*., 2021), support the notion that investment plays an essential role in stimulating a nation's economic development, as per the endogenous growth hypothesis. Likewise, with low-carbon development, capital formation is very influential. Reducing emissions by using new technology certainly requires enough funding. New technology can increase energy efficiency in production processes which in turn can reduce carbon emissions. This will promote the use of clean and renewable energy such as solar panels, wind turbines and other energy resources as a replacement for fossil fuels (Samimi and Moghadam, 2024). New technology will also help with sustainable green production processes which include the use of more environmentally friendly raw materials, efficient production processes and better recycling methods (Moghadam and Samimi, 2022). Deforestation poses a serious threat to low-carbon development, contributing to climate change through carbon emissions, particularly during forest fires (Raihan and Tuspekova, 2022). Achieving sustainable development requires striking a balance between economic progress and environmental preservation, with efforts focused on minimizing deforestation to prevent natural disasters (Raihan and Tuspekova, 2022). Furthermore, Begum *et al*., (2020) emphasize the negative effect of carbon emissions resulting from deforestation and forest degradation on the

global climate system. Notably, deforestation exacerbates carbon dioxide emissions, posing a direct hindrance to low-carbon development. The transportation sector also significantly influences low-carbon development, with studies by (Tang *et al*., 2015; Sporkmann *et al*., 2023; Xia *et al*., 2019) highlighting its contribution to carbon emissions. The level of carbon emissions from transportation is contingent upon factors such as transportation frequency and fuel efficiency. Thus, it is imperative to focus on increasing transportation capacity and maximizing its utilization to promote low-carbon development effectively. The transportation sector serves as a major global source of carbon dioxide emissions, contributing significantly to climate change and posing substantial health risks, especially in densely populated areas. The increase in vehicle frequency, driven by economic growth, has led to ecological challenges such as exhaust emissions, energy consumption, and noise pollution, alongside greater social issues (Li *et al*., 2023). To address these issues, policies must be developed and implemented, including fuel-saving standards, the promotion of new energy vehicles, and fiscal incentives (Chun *et al*., 2020). These actions are required for reducing fossil fuel usage and greenhouse gas emissions. Carbon dioxide emissions in the transportation sector are influenced by various factors, including transportation activities, capital structure, energy intensity, and carbon content in fuel. Transportation activity, comprising total transportation demand based on demographics, travel levels, and the number of trips, is further impacted by the ease of transportation, affecting travel rates and trip frequency (Kii *et al*., 2023). The expansion of agricultural land, as highlighted Raihan *et al*., (2023), significantly contributes to environmental degradation, leading to carbon dioxide emissions and global climate change. While there is a critical need for higher agricultural productivity and improved environmental conditions in the long term, balancing these objectives is difficult. Enhanced agricultural output can alleviate poverty, boost income allocation, enhance food production, and support economic expansion. However, the use of fuel in agriculture produces carbon emissions, worsening climate change and global warming (Su *et al*., 2023). Agricultural land plays a pivotal role in the context of low-carbon development, with various carbon emissions originating from agricultural inputs such as fertilizer, pesticides, diesel, irrigation, and land cultivation. Raihan and Tuspekova, (2022) emphasize that the agricultural added value directly impacts low carbon development; an increase in agricultural output value augments carbon emission capacity and vice versa. Economic expansion and growth drive up carbon emissions from land use activities like agriculture (Begum *et al*., 2020). Recognizing this, (Lehtonen *et al*., 2022) stress the importance of curbing carbon emissions from the agricultural sector to control environmental impact while ensuring increased farmers' income. Agriculture remains a sector contributing to carbon emissions, presenting a formidable challenge to low-carbon development efforts. One of the key objectives of sustainable development is industrialization, which involves enhancing infrastructure and implementing sustainable industrial retrofits. This process aims to improve resource efficiency, promote the widespread adoption of technology, and incorporate clean and environmentally acceptable industrial practices (Keeffe *et al*., 2023). While industrialization significantly contributes to economic growth, it comes with substantial environmental challenges, including carbon emissions generated during production and fuel use. The waste produced in the industrial activities also adds to carbon emissions, harming both the environment and community welfare, eventually impeding advancement in low-carbon development initiatives. Zhang *et al*., (2019) elaborate on the influential role of industrial transformation in low-carbon development. A successful strategy for cutting carbon dioxide emissions entails restructuring various aspects of economic operations, including investment, trade, final demand, intensity, and production techniques. Industrial practices rooted in traditional methods lacking technological advancements significantly elevate carbon emissions, ultimately hindering low-carbon development and impeding progress toward sustainable goals. The relationship between industry and carbon emissions, as elucidated (Xiaoqing and Jianlan, 2011), highlights the critical role of industrial structure in emission changes. Alterations in the overall economy serve as a primary driver for emissions. Thus, changing industrial structure and improving technical efficiency become crucial

techniques for emission reduction, benefiting low-carbon development initiatives. Similarly, (Tian *et al.*, 2019) demonstrate that industry influences carbon emissions and low-carbon development by optimizing production across construction, manufacturing, and service sectors. This optimization, achieved through well-managed production activities, product recycling, and the promotion of clean and renewable energy, promotes low-carbon and environmentally friendly industrial development, further aligning industrial practices with sustainable and low-carbon development objectives. This study aimed to prove the effect of determinants on low carbon development in a model. The hypothesis in this study is there is a substantial impact between capital formation, deforestation, land transportation, agricultural land, and industrialization in North Sumatra. The study is expected to compensate for the lack of research. It has been conducted in North Sumatra, Indonesia, between 2022 and 2023.

MATERIALS AND METHODS

Method of the study

This quantitative study was performed using the descriptive and associative methods. Secondary data sourced from the central statistical agency, spanning the period from 1991 to 2021, covering a total of 31 years (n), were regarded in this study. The variables under investigation included capital formation, deforestation, land transportation, agricultural land, and industrialization, all of which are factors assessed for their influence on low-carbon development.

Operational definition of the variables

Measurement of the data of each variable is displayed in Table 2. The data was collected from the documentation, annual reports or records issued by the North Sumatra Central Bureau of Statistics

As can be seen from the conceptual framework in Fig. 2, the mathematical measurements are expressed using Eq. 3 (Tian *et al.*, 2019; Raihan,

Table 2 : Operational definition of the research variables

Variable	Measurement	Unit	Institutions
Low carbon development (Y)	Index	Y	Badan Pusat Statistik, 1991-2021
Capital formation (X1)	Domestic capital formation	Billion/y	Badan Pusat Statistik, 1991-2021
Deforestation (X2)	Area of deforestation	ha/y	Badan Pusat Statistik, 1991-2021
Land transportation (X3)	The number of land transportation	No/y	Badan Pusat Statistik, 1991-2021
Agricultural land (X4)	Area of agriculture	ha/y	Badan Pusat Statistik, 1991-2021
Industrialization (X5)	GRDP in Industry sector	Billion/y	Badan Pusat Statistik, 1991-2021

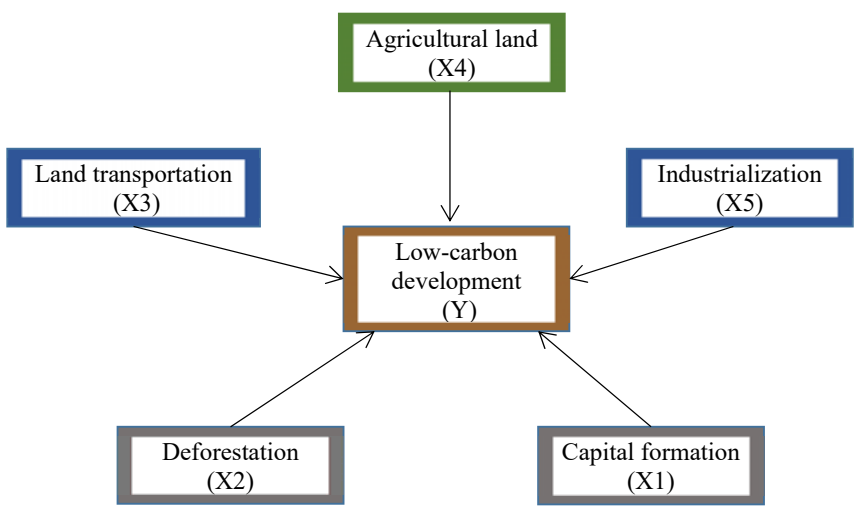

Fig. 2: The study conceptual framework

2023; Chen *et al*., 2020).

$$Y_t = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 X_{2t} + \alpha_3 X_{3t} + \alpha_4 X_{4t} + \alpha_5 X_{5t} + \varepsilon_{1t} \quad (3)$$

Classic assumption test

In this study, classical assumption tests were conducted to ensure the robustness of the analysis. The normality test was performed using the Jarque_ Bera test, where the hypothesis was determined using probability values. If the probability value is > 0.05, the distribution is considered normal; conversely, if the probability value is <0.05, the distribution is considered non-normal. The multicollinearity test utilized the variant inflation factor (VIF) value, with a hypothesis stating that if the data exhibits a VIF value exceeding 10, it indicates no tolerance or multicollinearity issues. Conversely, if the VIF value is smaller than 10, the correlation between each independent variable is deemed acceptable. The heteroscedasticity test was conducted using the Glejser test. In heteroscedasticity testing, if the probability value is > 0.05, it indicates that the regression model is free from heteroscedasticity

Statistical tests

In this study, the t-test was employed to assess the significance of the effect of the exogenous variable (X) on the endogenous variable (Y). If the probability value is smaller than the predefined threshold α = 0.05, Ho (null hypothesis) is rejected, and Ha (alternative hypothesis) is accepted, suggesting a significant effect. Conversely, if the probability value is larger than α = 0.05, the null hypothesis is accepted. Additionally, the F-test was applied to assess the collective influence of the exogenous variables on the endogenous variable. If the probability value is smaller than α = 0.05, Ho is rejected, and Ha is accepted, signifying that the exogenous variables collectively exert a significant influence on the endogenous variable.

RESULTS AND DISCUSSIONS

The results of classical assumption test

Based on Table 3, the normality test results for the low carbon development equation (Y) indicate a Jarque-Bera value of 1.073 and a probability value of 0.584. Since the probability value (0.584) is greater than the significance level of 0.05, it can be concluded that the data follows a normal distribution. Stated differently, the data in the low-carbon development equation for this study is normally distributed.

The multicollinearity test is seen from the VIF value as presented in Table 4.

Based on the findings of the multicollinearity test in the low-carbon development equation, it is clear that the VIF values for each variable are significantly below 10. Specifically, the VIF value for the capital formation variable is 2.924, deforestation variable is 3.814, land transportation variable is 2.058, agricultural land variable is 1.336,

Table 3 : Normality test results

Notes	Score
Mean	3.720016
Median	1.780015
Maximum	1.150014
Minimum	1.420014
Std. dev.	5,460015
Skewness	0l317179
Kurtosis	3.654850
Jarque-Bera	1.073684
Probability	0.584592

Table 4: The results of multicollinearity test

Variable	Coefficient variance	Uncentered VIF	Centered VIF
Capital formation (X1)	8.080031	118.8117	2.924719
Deforestation (X2)	7.940031	74.71421	3.814240
Land transportation (X3)	5.110037	5.353902	2.058448
Agricultural land (X4)	7.670035	36.98119	1.336093
Industrialization (X5)	1.100030	96.84405	2.492157

Table 5: The results of heteroscedasticity test

F-statistic	0.641064
Prob.F(5,25)	0.6706

Table 6 : The results of the equation measurement

Variable	Coefficient	S.E.	T-statistic	Probability	R-squared	F-statistic	Prob (F-statistic)
C	1.400014	2.390014	0.588006	0.5618	0.755544	4.540029	0.000000
Log(Y2)	2.110015	8.990016	2.336947	0.0278			
Log(Y3)	- 2.333315	8.910016	- 2.611337	0.0150			
X1	- 1.150018	7.150019	- 1.611733	0.1196			
X2	2.430017	8.760018	2.777479	0.0102			
Log(X3)	- 1.001120	1.050015	- 9.550014	0.0000			

Table 7 : The partial contribution results

Variable	Standardized coefficients Beta	Correlation	Contribution
X1	0,127	1,181	19,86
X2	0,302	0,391	15,63
X3	0,178	0,09	2,12
X4	0,251	0,573	19,04
X5	0,292	0,489	18,90

and industrialization variable is 2.492. Since all VIF values are less than 10, it suggests that there is no problem of multicollinearity among the independent variables in this equation. Furthermore, the heteroscedasticity test conducted using the Glejser test is presented in Table 5.

Based on the test results above, it can be seen that the F-statistic value is 0.641 and the probability value is 0.670, which indicates it is greater than α (alpha) at 0.05 level, or 0.670 > 0.05. This result indicates that there is no heteroskedasticity in the low-carbon development equation.

The results of hypothesis testing

The findings of the hypothesis test and the estimation of the low-carbon development equation processed using Eviews can be seen in Table 6.

Table 7 shows the partial contribution of variables to the dependent variable.

The model equation for low-carbon development derived from the estimation conducted in this study is as Eq. 4 (Tian *et al*., 2019; Raihan, 2023; Chen *et al*., 2020):

$$Y = 1.400 + 2.110\log(X1) - 2.333\log(X2) - 1.150\,(X3) + 2.430\,(X4) - 1.001\log(X5) \quad (4)$$

In this study, the alternative hypothesis poses a significant influence of capital formation, deforestation, land transportation, agricultural land, and industrialization on the low carbon development of North Sumatra. The estimation findings of the low carbon development equation show an F-statistical probability value of 0.000. When compared to the significance level (α) of 0.05, the probability value of <0.05 (0.000 < 0.05) demonstrates that capital formation, deforestation, land transportation, agricultural land, and industrialization collectively exert a significant impact on North Sumatra's low-carbon development. The constant value for low carbon development is 1.400, meaning that if the variables values capital formation, deforestation, land transportation, agricultural land, and industrialization remain unchanged, low-carbon development will increase by 1.40%. Individually, an increase of 1% in capital formation (X1) corresponds to a 2.110% rise in low-carbon development. Conversely, deforestation (X2) exhibits a negative influence, with an estimated coefficient value of -2.333, indicating that a decrease in deforestation promotes low-carbon development. Similarly, land transportation (X3) and industrialization (X5) exhibit negative effects with coefficient values of -1.150 and

1.001, respectively. Conversely, agricultural land (X4) has a beneficial impact, with a coefficient of 2.430. These findings highlight the variables' contributions to North Sumatra's low-carbon development under the ceteris paribus assumption. In the pursuit of achieving low-carbon development, adequate funding is necessary for implementing ecofriendly initiatives, which inherently incur higher costs compared to conventional or non-environmentally friendly activities. Government bodies and policy-makers require significant funding to create and sustain these initiatives. This relationship between capital formation and low-carbon development is unidirectional, as capital plays an essential role in enabling the shift to eco-friendly practices (Mulugetta and Urban, 2010). Capital formation has synergy with reducing carbon emissions such as sustainable investment. Allocating capital to sustainable and environmentally friendly projects can yield long-term financial rewards while reducing environmental consequences including investments in renewable energy, energy efficiency and other environmentally friendly technologies. Apart from that, strong capital can support technological innovation, sustainable waste management, and various other carbon emission reduction programs. The importance of financial size and quality in facilitating this shift cannot be exaggerated. Ikhsan and Satrianto, (2023) highlights gross fixed capital formation in the form of capital goods is able to encourage investment allocation and have an impact on the growth of productive sectors which can spur economic growth. Enormous investments, especially in areas such as human resources, are necessary for the effective implementation and upkeep of sustainable low-carbon development initiatives (Dzikuc *et al*., 2021). Several economic concepts and theories can help how interventions are designed to drive change toward a low-carbon economy. This can be realized through carbon price or carbon tax, incentives and subsidies, technological innovation, understanding consumer behavior to design promotional models, business desires, and regulations so that effective interventions can be accepted at the economic and societal levels, helping to achieve the goal of sustainable capital formation and low-carbon emissions. Deforestation poses a critical threat to low-carbon development. This damaging activity reduces forest cover, diminishing the number of plants available to absorb carbon dioxide and produce necessary oxygen. As deforestation spreads, the decrease in carbon-absorbing plants leads to a rise in carbon emissions. Begum *et al*., (2020) underscore the noteworthy influence of deforestation on low-carbon development. Addressing this issue is crucial for sustainable development and supporting low-carbon activities. Lowe, (2014) highlights the necessity of reducing carbon emissions resulting from deforestation and forest degradation to bolster sustainable development efforts and support low-carbon practices effectively. Adequate funding and strategic interventions are essential in curbing deforestation and enabling the shift toward a more environmentally friendly, low-carbon future. Land transportation stands as a major source of carbon emissions, impeding advancement in low-carbon development. Emissions from vehicles, primarily exhaust gases, result in harmful air pollution. Futhermore, the use of fuel not only escalates energy consumption but also leads to increased carbon emissions. The rise in the number of vehicles directly correlates with heightened carbon emissions, thereby hindering low-carbon development efforts. The study findings, as indicated (Kii *et al*., 2023), align with this perspective, showing that the reduction in transportation-related carbon emissions stems from a decrease in population and improved fuel efficiency. For instance, in 1998, transportation increased by 3.32%, coinciding with a boost in low-carbon development. However, fuel consumption dropped by 0.92 throughout the same period. Similarly, in 2009, despite a 9.35% rise in transportation, fuel use decreased by 7.17%. Improving fuel efficiency can mitigate vehicle emissions by using higher-quality fuel, leading to reduced consumption. The intensity of travel significantly impacts fuel efficiency and ultimately curtails carbon emissions. Notably, population size serves as one important element affecting carbon dioxide emissions from the transportation sector. Strategies such as maintaining population density and curtailing vehicle use are crucial efforts to mitigate carbon emissions and promote low-carbon development. The major impact of agricultural operations on North Sumatra's low-carbon development is evident, where changes in

agricultural land directly influence the region's low-carbon progress. Research (Su *et al.*, 2023) highlights that agricultural practices contribute to increased carbon emissions, presenting a challenge for low-carbon development. The growth of the agricultural industry intensifies the use of machinery and workforce, increasing emissions. Emissions from fertilizer use, crop residue burning, and flooded rice cultivation further compound the issue as well (Sapkota *et al.*, 2021). The long-term use of pesticides in agriculture will threaten the quality of soil and water resources. Yavari *et al.,* (2022) explained that biochar is a carbon-rich biosorbent which can be used as a medium to stabilize organic substances in the soil. It is sustainable and affordable as it can be made from locally accessible waste from empty palm fruit bunches and rice husks. So, biochar has the potential to reduce emissions from the agricultural sector to the environment with the concept of controlling pesticides which of course can increase the commercial value of biochar. Furthermore, industrialization, particularly in the construction industry, emerges as a significant contributor to carbon dioxide emissions. Satrianto and Juniardi, (2023) explained industrialization growth will have an impact on reducing the quality of the environment and when it reaches a high economic level but is not environmentally friendly, it will result in an increase in carbon emissions which will have an impact of air pollution, decreased air quality and opening up of new land which, if done using traditional methods through burning, will cause environmental damage. The main driver of climate change and global warming is GHG including carbon dioxide, several countries have implemented a tax-based carbon pricing system with lower rates for certain industries and which produces fewer emissions. The emission trading system mechanism is a strategy to improve economic incentives and decrease emissions by establishing pollution restrictions. This mechanism is designed to be environmentally friendly and economical as a driver of the low-carbon economic transition, it has benefit for industry because it offers emissions monitoring, stringent fines for infractions and high compliance. Tian *et al*., (2019) emphasize the industrial sector's significant contribution to emissions, exacerbated by fuel usage and high-intensity machinery, hindering low-carbon development efforts. Raihan *et al.*, (2023) underline that increasing industrialization raises carbon emissions, further exacerbated by industrial waste and insufficient energy-saving measures. Juniardi *et al*, (2002) highlight so that government provides supporting technology environmentally friendly industry to support green industrial programs. Resolving these issues is imperative for reducing emissions and encouraging sustainable, low-carbon development in North Sumatra.

CONCLUSION

Based on the study findings, it is evident that capital formation, deforestation, agricultural land, and industrialization significantly influence low-carbon development in North Sumatra, collectively explaining 75.55% of the variance (R-square 0.7555). Specifically, capital formation contributes 19,8%, deforestation 15,6%, agricultural land 19,0%, and industrialization 18,9% to low-carbon development, while land transportation does not exhibit a significant influence of 2,12%. To promote low-carbon development effectively, the regional government must adopt targeted policies addressing each factor. Capital formation is essential in accelerating economic growth and achievinglow-carbon development. Policies such as interest rate control and support for investor-focused businesses are essential, alongside ensuring an investor-friendly climate and security measures. Additionally, environmental sustainability should be a priority in project realization to curb carbon emissions. Deforestation mitigation measures, including stricter permits for land clearing, improved environmental regulations, and forest area preservation, are vital. Next, is attention to forest preservation, particularly protected forests, so that they are maintained for cleaner air and maximum absorption of carbon dioxide. Apart from absorbing carbon emissions, forests can also maintain the diversity of flora and fauna and also save the Earth from natural disasters caused by reduced forest cover such as landslides and floods. In addition, it must improve the standard of institutions, such as enforcing strict penalties against those who persist in engaging in activities to diminish the area of tree cover resulting in widespread deforestation which harms many people and impedes low-carbon development. To

reduce carbon emissions in land transportation, it is necessary to implement policies and actions that support the use of low-emission vehicles such as electric vehicles, vehicle emissions regulations by using biodiesel and others as an alternative to fossil fuels and restricting vehicles in certain zones, supporting environmentally friendly public transportation, as well as public education and awareness. In the agricultural sector, ecologically sustainable practices should be promoted. Agricultural activities, contribute to carbon emissions, so the government must also pay attention to the agricultural techniques applied. Agriculture as one of the industries that contributes to GRDP certainly cannot be disregarded even though it is a contributor to carbon emissions as a barrier to low-carbon development. However, the government must strive for environmentally friendly agricultural techniques with mitigated through outreach programs involving experts who educate farmers on minimizing emissions. To reduce carbon emissions originating from the use of pesticides in agriculture which contaminates water and soil, this can be done by using biochar made from empty palm fruit bunches and also rice straw which is easily obtained at a low cost and is environmentally friendly. Industrial sector policies aimed at environmental preservation are paramount, increasing the likelihood of achieving sustainable low-carbon development in North Sumatra, aligning with the region's sustainable development goals. Industrial transformation efforts with an effective approach to reducing carbon emissions such as restructuring various aspects of industrial activities, including investment, trade, final demand, intensity and production methods. Then the government also provides environmentally friendly industry supporting technology to support the green industry program. Maximize production in the construction, manufacturing and service industries for effective carbon dioxide reduction, for example, by managing production operations well, using recyclable product, and supporting clean and renewable energy sources. The implementation of tax emissions can also be carried out by considering certain industries and industries that produce fewer emissions and setting emission limits. This is very beneficial to the sector to integrate emissions, penalties for infractions, and increased compliance from associated parties.

AUTHOR CONTRIBUTIONS

E.S. Siregar helped in the design and development of models in the study, collection and analysis of data, and creation of study reports. S.U. Sentosa guided and mentored the literature review. A. Satrianto accompanied and guided the writing of the manuscript.

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CONFLICT OF INTEREST

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ABBREVIATIONS

%	Percent
+	Plus sign
=	Equal sign
>	Strict inequality (greater than)
-	Minus sign
/	Per
A	Alpha
E	Error term
EG	Economic growth
Eq	Equation
et al.	Et alia
F	Simultaneous
Fig.	Figure
FG	Factor growth
GHG	Greenhouse gas
GRDP	Gross regional domestic product
Ha	Hectare
LCD	Low carbon development
Log	Logarithm
No	Number
Prob	Probability
QG	Quality growth
R^2	Correlation coefficient
S.D.	Standard deviation
S.E.	Standard error
T	Time
UNFCCC	United nations framework convention on climate change
Var	Variable
VIF	Variance inflation factor
X1	Capital formation
X2	Deforestation
X3	Land transportation
X4	Agricultural land
X5	Industrialization
y	Year
Y	Endogenous variable

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