OPEN ACCESS
Jurnal Ilmiah Ilmu Terapan Universitas Jambi
Vol. 9 No. 3. September 2025, pp. 1117-1136 DOI. 10.22437/jiituj.v9i3.37741

Research Article

IMPACT ANALYSIS OF GREEN ECONOMY INSTRUMENTS ON SUSTAINABLE NATURAL RESOURCE MANAGEMENT

Welky Karauwan[1,*], Denny Adri Tarumingi[1], Joni Kutu' Kampilong[1], Kristi Karla Arina[1], Deisy Agnes Pertiwi Juita Pangkey[1], Pingkan Aprilia Maramis[1], Elsje Hanna Lintong[1]

[1] Universitas Kristen Indonesia Tomohon, Sulawesi Utara, Indonesia
Corresponding author email: welkykarauwan@fkipukit.ac.id

Article Info
Received: Oct 16, 2024
Revised: Jun 11, 2025
Accepted: Jul 14, 2025
OnlineVersion: Aug 10, 2025

Abstract
The implementation of Green Economy Instruments (GEI) is crucial for achieving Sustainable Natural Resource Management (SNRM), particularly in agrarian regions facing environmental degradation. This study aims to evaluate the effectiveness of GEI, including carbon tax, emission trading system, renewable energy subsidies, and fiscal incentives, in promoting SNRM among farming business actors in Tomohon, North Sulawesi. A quantitative approach was employed using Structural Equation Modeling (SEM) with Smart PLS 4.0, based on survey data from 500 respondents. The results indicate that most GEI dimensions have a positive influence on SNRM, with an R^2 value of 0.847. Fiscal Policy Instruments (FPI) and Environmental Regulations (ERS) showed the most substantial impact. At the same time, Carbon Tax (CT) and Sustainable Financing (SF) exhibited significant but negative relationships, suggesting potential misalignment between policy design and local perception. This research presents a new conceptual framework "Policy Effectiveness in Agrarian Settings" emphasizing that the success of GEI depends on perceived benefits, accessibility, and visible outcomes. The findings offer practical implications for regional policymakers, highlighting the importance of targeted fiscal support, clear regulations, and enhanced communication to promote the adoption of green policies. Additionally, this study fills a gap by providing empirical insights into the application of GEI outside urban or industrial contexts, thereby supporting the achievement of SDG 12, SDG 13, and SDG 15. Future studies should explore longitudinal effects and stakeholder perceptions through qualitative methods to deepen understanding of policy barriers and opportunities.

Keywords Circular Economy Approach, Environmental Degradation, Green Economy Instruments, Policy Effectiveness, Sustainable Natural Resource Management.

INTRODUCTION

Economic development over the past few decades has yielded numerous benefits, including increased welfare and global economic growth (Fernández-Portillo et al., 2020). However, the development model, oriented towards the intensive exploitation of natural resources, has had a significant negative impact on the environment (M. K. Khan et al., 2022; Ikhsan et al., 2025; Zubair et al., 2025). Environmental degradation, depletion of natural resources, and climate change are pressing issues that require urgent attention. (Shittu, 2021; Wicaksana & Widodo, 2024). Therefore, the emergence of the green economy concept offers a new, more sustainable paradigm by integrating economic growth and environmental protection. (Erdoğan, 2021; Jarnawi et al., 2025; Kheang et al., 2025).

Green economy instruments, such as carbon taxes, renewable energy subsidies, emissions trading, and fiscal incentives for green investment, are designed to facilitate the transition to a more environmentally friendly economy (Pan, 2023; Jumaera et al., 2024). These instruments aim to internalize environmental impacts into market mechanisms, encouraging companies and individuals to adopt more sustainable practices (B. Yuan & Zhang, 2020). By utilizing these instruments, it is hoped that natural resource management will become more efficient and responsible, thereby reducing pressure on ecosystems (Chopra, 2022; Jalmasco et al., 2025).

Sustainable natural resource management is key to balancing human needs and environmental sustainability. (Nathaniel et al., 2021). Natural resources managed sustainably will ensure the fulfillment of the needs of the present generation without sacrificing the capabilities of future generations. (Saijo, 2020). However, the application of green economy instruments and their impact on natural resource management remains a topic that requires further research, particularly in the context of how these instruments can enhance or accelerate the achievement of sustainable natural resource management goals (Mastini, 2021; Nou et al., 2025; Obenza et al., 2025).

As global concerns about climate change, resource scarcity, and environmental degradation grow, the concept of a green economy has emerged as a sustainable solution to address these challenges. A green economy aims to promote economic growth that is environmentally sustainable, resource-efficient, and socially inclusive (Cardoso, 2021; Putri et al., 2025). A key component of this approach is green economy instruments, which serve as policies, programs, and tools that help achieve sustainable development. These instruments promote energy efficiency, emission reductions, and improved management of natural resources, while generating new, environmentally friendly economic opportunities (Mohsin, 2022; Vrusho et al., 2025). A carbon tax is an economic instrument designed to internalize the negative impacts of carbon dioxide and other greenhouse gas emissions. It is imposed on companies that produce emissions to provide an economic incentive to reduce their emissions. Pollution becomes more expensive, so companies are encouraged to adopt cleaner, more environmentally friendly technologies (Chien, 2021a; Rachmatika & Salighehdar, 2024; Rubio et al., 2025).

An ETS is a market mechanism that allows companies to buy and sell emission permits. (Nong et al., 2020). The government sets an emission limit that each company must comply with (Z. Liu et al., 2022; Salim et al., 2025; Siddique et al., 2025). Companies that emit below the limit can sell their excess permits to other companies that need them. This drives efficient emission reductions across industries and incentivizes companies to operate below emission limits (Entezaminia et al., 2021). To encourage the transition from fossil fuels to renewable energy, governments provide financial support and incentives to green energy producers (Muhamad et al., 2025) Solar, wind, and bioenergy are subsidized to accelerate their adoption in the market, creating cleaner energy and reducing reliance on unsustainable fossil fuels (Yin, 2022a; Somantri, 2024).

Sustainable financing instruments include funding schemes such as green bonds, which support environmentally friendly projects (Bhutta et al., 2022). These projects encompass a diverse range of areas, including renewable energy, waste management, and infrastructure development that support environmental objectives (Nastasi et al., 2022). With investor interest in green financing on the rise, the financial sector plays a crucial role in the transition to a green economy. (Monasterolo et al., 2024). Governments enforce stringent environmental regulations and standards to ensure cleaner and more efficient industrial practices (Z. Khan, 2023; Yadewani et al., 2024). These regulations include emission reductions, the use of more environmentally friendly materials, and energy efficiency. Stringent regulations encourage companies to innovate and reduce their negative environmental impact (Cai et al., 2020). Eco-labeling is a scheme that gives special labels to products that meet specific sustainability standards. This labeling helps consumers choose environmentally friendly products while encouraging manufacturers to adopt more environmentally friendly production practices (Wojnarowska et al., 2021).

These instruments include green finance, such as green investment funds and sustainable mutual funds, which are designed to support projects that focus on environmental sustainability. These sustainable investments attract many investors who seek to combine financial returns with a positive environmental impact (Kölbel et al., 2020). Green fiscal policies offer incentives to companies that invest in green technologies or implement energy efficiency measures (Wang, 2022). This can take the form of tax breaks or tariff reductions for businesses that commit to environmental projects. In doing so, these policies stimulate the green economy and promote innovation in clean technologies (Yu et al., 2022; Yulianti et al., 2024; Syahrul et al., 2025).

Governments encourage the procurement of environmentally friendly goods and services through green public policies. This includes purchasing recyclable goods, utilizing renewable energy, and incorporating sustainable materials into construction projects. These policies not only reduce environmental impact but also create market demand for green products (Razzaq, 2023). The circular economy emphasizes waste reduction by recycling and reusing existing products. This concept focuses on extending the useful life of products and redesigning them to optimize the value of each material used (Jacobs et al., 2022). The circular economy reduces dependence on raw materials and minimizes environmental impact (Mulvaney et al., 2021). Natural resources are the primary foundation for human life and the Earth's entire ecosystem. However, mismanaged utilization, whether through over-exploitation, pollution, or inefficient management, has caused ecosystem damage, resource scarcity, and drastic climate change (Huo & Peng, 2023). Therefore, sustainable natural resource management is an urgent need to ensure that these resources remain available to the current generation without compromising the ability of future generations to meet their needs (Iqbal, 2020).

The concept of sustainable natural resource management encompasses not only wise and efficient utilization but also involves ecosystem protection, restoration of damaged areas, and community participation in maintaining and managing natural resources (Suki, 2022). The utilization of natural resources must take into account nature's capacity to replenish itself. For example, sustainable deforestation must be balanced with reforestation programs, while water use must consider long-term availability, especially in areas prone to drought (H. Liu et al., 2022). Ecosystem-based management considers the interrelationships between various components of nature, including soil, water, flora, fauna, and humans. This aims to maintain ecological balance in the long term by considering the impact of each human activity on the ecosystem as a whole (Balsalobre-Lorente, 2023). Biodiversity is a key pillar of ecosystem stability. Protecting endangered species and their habitats helps maintain environmental resilience, increases the capacity to adapt to climate change, and provides a range of ecosystem services, including plant pollination and the regulation of the water cycle (Moore & Schindler, 2022).

Local community participation in natural resource management is a key element. This approach ensures that local needs and knowledge are respected and that communities directly surrounding managed areas benefit economically and socially from conservation efforts. The transition from fossil fuels to renewable energy sources such as solar, wind, and hydropower is an integral part of sustainable natural resource management (Hao, 2023). Renewable energy not only reduces pollution but also ensures a stable energy supply without harming the environment. Pollution from industrial, agricultural, and domestic waste is one of the greatest threats to natural resources (Yang et al., 2018). Sustainable waste management encompasses recycling, reducing waste at its source, and utilizing environmentally friendly technologies to prevent pollution of land, water, and air (Mihai et al., 2021). Water is the most vital resource, yet it is also the most vulnerable to overexploitation and pollution. Sustainable water management involves controlling water use, reducing pollution, and protecting aquatic ecosystems, such as rivers, lakes, and aquifers, to maintain their quality and ensure their long-term availability (Makanda et al., 2022).

Human activities, such as illegal logging and mining, frequently cause damage to ecosystems (Kyere-Boateng & Marek, 2021). Ecosystem restoration aims to restore damaged areas to optimal functioning while supporting biodiversity and better environmental quality (Strassburg et al., 2020). Governments play a crucial role in ensuring sustainable natural resource management by implementing effective policies and regulations (Azam et al., 2023). This includes laws on forest protection, carbon emission regulations, and land use policies that promote environmental sustainability (Gottardo, 2021; Tabaku et al., 2025).

Sustainable agriculture focuses on practices that maintain soil fertility and reduce the use of hazardous chemicals (Sofo et al., 2022). Systems such as crop rotation and agroforestry can increase productivity while minimizing damage to ecosystems (Fahad et al., 2022). Oceans and coasts are vulnerable to overfishing, pollution, and climate change (Pollom et al., 2024). Sustainable management includes setting fishing quotas, protecting marine areas, and rehabilitating damaged coastal ecosystems (Tarkowski, 2022). Public awareness of the importance of protecting the environment is a key component of successful natural resource management (Rousseau & Deschacht, 2020). Environmental education programs and public awareness campaigns help increase individual and community participation in environmental conservation efforts (Ardoin et al., 2020).

While workforce development, organizational dynamics, and sustainable practices have been identified as significant factors for driving innovation and performance across industries, there is limited exploration of these factors within the specific context of the construction industry, particularly in North Sulawesi. Few studies have holistically examined how these three factors can synergistically promote construction project innovation through the mediating and moderating pathways of HR practices, technology readiness, and regulatory compliance.

Despite the growing emphasis on green economy policies globally, empirical evidence on their effectiveness in promoting sustainable natural resource management (SNRM) at the local level remains limited. Many studies focus on theoretical frameworks or macroeconomic impacts. However, few investigate how specific green economy instruments—such as carbon taxes, renewable energy subsidies, or eco-labeling—perform in resource-dependent communities like Tomohon, North Sulawesi. This gap highlights the need for localized, data-driven analysis to inform policy design. Given the urgent pressures of climate change, biodiversity loss, and unsustainable resource extraction, understanding which green economy instruments are most effective becomes critical. This study addresses this challenge by employing a quantitative approach using Structural Equation Modeling (SEM) based on survey data from 500 farmers in Tomohon. The findings aim to identify key drivers of SNRM and offer actionable insights for policymakers seeking to align economic development with environmental sustainability in similar regional contexts.

This study addresses a critical gap in the literature by providing empirical evidence on how Green Economy Instruments (GEI) influence Sustainable Natural Resource Management (SNRM), particularly in agrarian communities where implementation challenges are often overlooked. While previous studies have emphasized the theoretical foundations of green economic policies, there remains a lack of localized, data-driven analyses that examine their practical effectiveness in resource-dependent regions, such as Tomohon, North Sulawesi. The urgency of this research stems from the accelerating pace of environmental degradation and increasing pressure to meet global sustainability targets such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).

To address these challenges, this study employs a structured quantitative approach using Structural Equation Modeling (SEM) to evaluate the causal relationships between Green Economic Incentives (GEI)—such as carbon taxation, emission trading systems, green fiscal incentives, and eco-labeling—and Sustainable Natural Resource Management (SNRM) outcomes, including resource efficiency, land conservation, and sustainable production practices. By analyzing responses from 500 participants, the research provides actionable insights into which policy tools are most effective and how they can be tailored for regional contexts.

The primary objective of this study is to identify key drivers of sustainable natural resource management through the use of green economy instruments and provide targeted recommendations for policymakers. Specifically, it aims to assess the relative impact of different GEI components on SNRM, validate the effectiveness of selected green policy mechanisms, and offer region-specific strategies for integrating environmental considerations into local governance and economic planning.

RESEARCH METHOD

This study aims to analyze the effect of applying Green Economy Instruments (GEIs) on sustainable natural resource management (SNRM). Specifically, this study will explore how green economy instruments, such as carbon tax (CT), emission trading system (ETS), renewable energy subsidies (RES), sustainable financing (SF), and green public policy (GPP), impact efforts to manage natural resources more efficiently and in an environmentally friendly (Jahanger et al., 2022). This study will also evaluate the effectiveness of these instruments in supporting efforts to conserve, use efficiently, and restore natural resources. The conceptual framework, as shown in Figure 1 below.

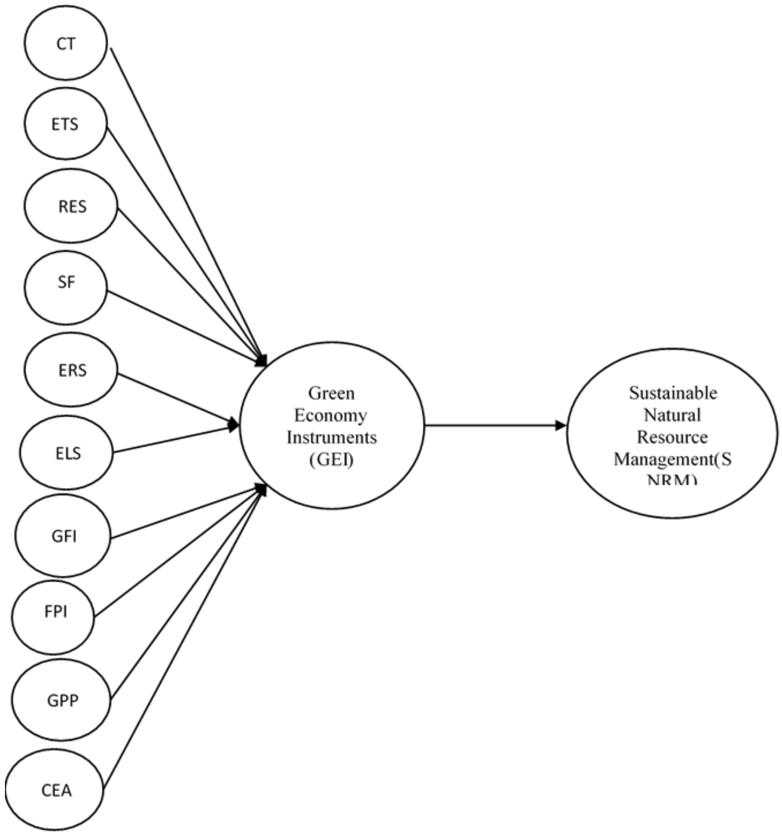

Figure 1. Conceptual Diagram.

Hypothesis Development

H1: Carbon tax (CT) has a positive effect on sustainable natural resource management (SNRM).
H2: The Emission Trading System (ETS) has a significant impact on enhancing the efficiency of sustainable natural resource management (SNRM).
H3: Renewable energy subsidies (RES) provide a positive contribution to the implementation of sustainable natural resource management (SNRM) practices.
H4: Sustainable financing (SF) plays a crucial role in supporting sustainable natural resource management (SNRM) by enhancing the efficiency of resource use.
H5: Environmental regulations and standards (ERS) have a positive influence on sustainable natural resource management (SNRM).
H6: Environmental labeling schemes (ELS) have a positive impact on sustainable natural resource management (SNRM) by increasing consumer awareness and choice.
H7: Green finance (GFI) contributes to improving sustainable natural resource management (SNRM).
H8: Green fiscal instruments (FPIs) have an impact on sustainable natural resource management (SNRM) by providing economic incentives that support sustainable practices.
H9: Green public policies (GPPs) have a positive influence on sustainable natural resource management (SNRM).
H10: Circular economy approaches (CEAs) have a positive influence on sustainable natural resource management (SNRM) by promoting waste reduction and recycling.

This study employs a quantitative research design to analyze the impact of Green Economy Instruments (GEI) on Sustainable Natural Resource Management (SNRM) among agrarian business actors in Tomohon City, North Sulawesi Province, Indonesia. The method employed is Structural Equation Modeling (SEM), utilizing SmartPLS 4.0 software, which facilitates hypothesis testing and validation of the conceptual model linking GEI dimensions to SNRM outcomes.

The population consists of 5,000 farmers in North Sulawesi who operate businesses with a minimum monthly turnover of IDR 100 million (Badan Pusat Statistik Indonesia, 2023). A purposive sampling technique was employed to ensure relevance and accuracy, focusing solely on respondents directly involved in natural resource management. A total of 500 respondents were selected as the final sample. The research procedure followed four key stages: 1) Model Development: A conceptual framework was developed based on prior literature, where GEI (e.g., carbon tax, emission trading system, renewable energy subsidies) were modeled as exogenous variables influencing SNRM (e.g., biodiversity conservation, land efficiency); 2) Instrument Development: A structured questionnaire was designed using a 5-point Likert scale ranging from: 1 = Strongly Disagree, 2 = Disagree, 3 = Less Agree, 4 = Agree, 5 = Strongly Agree.

Each latent construct was operationalized using multiple observable indicators drawn from established frameworks in prior empirical research on green economy policies and sustainable resource management (Yuan & Zhang, 2020; Chien, 2021b; Pan, 2023). Data Collection: Questionnaires were distributed to 500 respondents, who completed them independently. Data collection ensured that perspectives on the implementation of green economy instruments and their impact on Sustainable Natural Resource Management (SNRM) were captured. Model Testing: Structural Equation Modeling (SEM) was conducted using SmartPLS 4.0 to test the causal relationships between GEI and SNRM.

The main instrument used was a structured questionnaire consisting of two parts: Part I – Demographic Information: Age, gender, education level, and farming experience. Part II – Measurement Constructs: Statements measuring GEI and SNRM constructs, aligned with indicators such as carbon taxation, emission trading systems, and eco-labeling schemes. All items were validated through pilot testing before being distributed on a full scale.

Table 1. Constructs, Indicators, and Questionnaire Items

Variable	Indicator	Item Questionair
Carbon Tax (CT)	Level of carbon emission reduction	CT1: “How much has your company reduced carbon emissions since the introduction of the carbon tax?”
Emission Trading System (ETS)	Compliance rate with emission caps	ETS1: “How well does your company comply with the established emission limits?”
Renewable Energy Subsidies (RES)	Increase in installed renewable capacity	RES1: “What is the increase in installed renewable energy capacity in your company over the past year?”
Sustainable Financing (SF)	Investment in environmentally friendly projects	SF1: “What total investment was allocated for environmentally friendly projects in the last 12 months?”
Environmental Regulations (ERS)	Industry compliance with regulations	ERS1: “How well does your company comply with environmental regulations?”
Eco Labeling Scheme (ELS)	Number of eco-labeled products	ELS1: “How many products in your company have received eco-friendly labels?”
Green Finance & Investment (GFI)	Year-on-year growth of green investments	GFI1: “What is the year-on-year growth percentage of green investments in your company?”
Fiscal Policy Instruments (FPI)	The level of green investment increases after incentives	FPI1: “Since receiving fiscal incentives, how much has green investment increased in your company?”
Green Public Policy (GPP)	Government procurement of green goods	GPP1: “What percentage of government procurement involves environmentally friendly goods and services?”
Circular Economy Approach (CEA)	Waste recycling rate	CEA1: “What is the waste recycling rate in your company?”
Sustainable Natural Resource Management (SNRM)	Belief in sustainable resource usage	SNRM1: “Do you believe that the use of natural resources in your company is done sustainably?”

Table 1 illustrates a subset of key constructs, indicators, and questionnaire items used to measure Green Economy Instruments (GEI) and Sustainable Natural Resource Management (SNRM). Full details of all measurement items are available in the survey instrument included in the Appendix. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4.0. This method is suitable for exploratory research with moderate sample sizes and does not require assumptions of normality.

Key Analyses Conducted: Measurement Model (Outer Model): Convergent Validity: Factor loading > 0.7, Discriminant Validity: HTMT < 0.85, Reliability: Cronbach's Alpha > 0.7; Composite Reliability > 0.7. Structural Model (Inner Model): R-squared (R^2): Explained variance of SNRM, Variance Inflation Factor (VIF): Tested multicollinearity (< 5 considered acceptable), Path Coefficients: Estimated direct effects of GEI on SNRM, T-statistic & P-value: Determined significance of each path coefficient at $\alpha = 0.05$. Bootstrap Analysis: Resampling with 500 iterations was performed to calculate T-values and P-values for hypothesis testing, Confidence intervals were derived to validate the stability of estimates

With a sample size of n = 500, the study achieves high statistical power (>95%) for detecting medium effect sizes ($f^2 \geq 0.15$), assuming an α level of 0.05. This ensures robustness and generalizability of findings, particularly in structural equation modeling, where larger samples improve estimation accuracy.

RESULTS AND DISCUSSION

Partial Least Squares Structural Equation Modeling (PLS-SEM) is a statistical analysis approach often used to model causal relationships between latent variables, especially in exploratory research or when the sample size is relatively small. This approach does not require the assumption of a normal distribution in the data, making it more flexible than covariance-based structural equation modeling (CB-SEM). The PLS-SEM algorithm is designed to maximize the variance explained by the independent variables in relation to the dependent variable, with a focus on path modeling and testing the relationships between variable constructs. Through an iterative process, PLS-SEM simultaneously evaluates the measurement model and the structural model, producing optimal estimates for research aimed at solid prediction and a better understanding of endogenous variables.

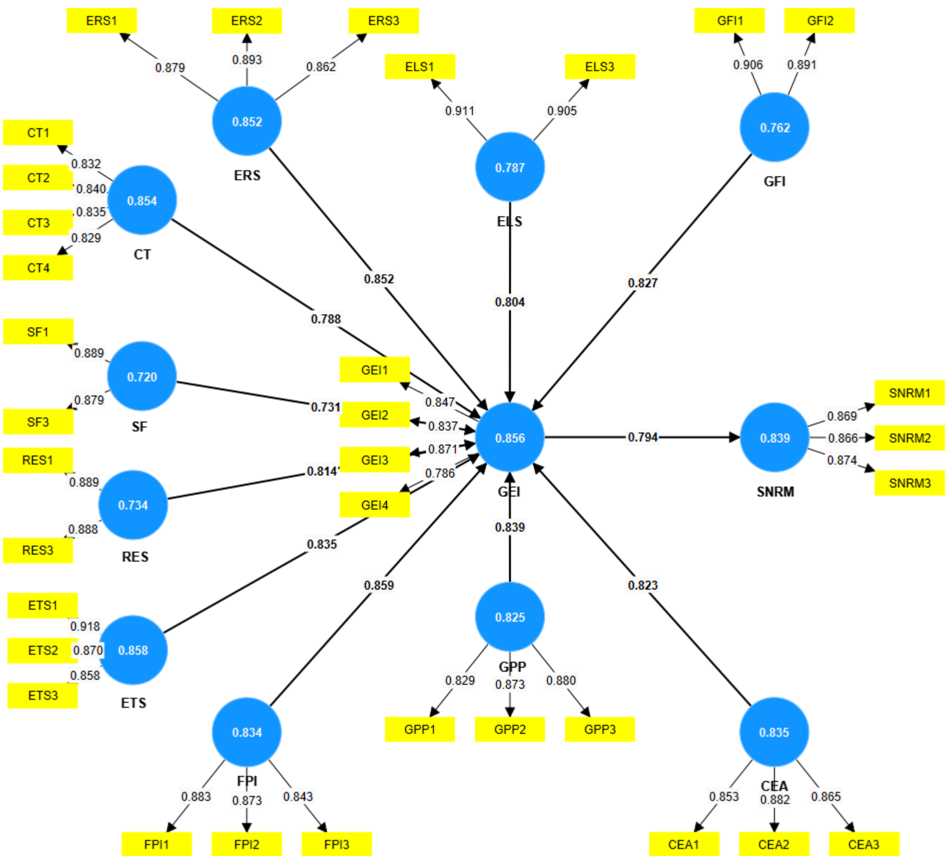

Figure 2. PLS-SEM Algorithm Results

Convergent Validity

Based on the PLS-SEM diagram, the convergent validity analysis reviews the factor loading value of each indicator to measure a particular construct. Convergent validity can be ensured if each indicator has a significant and adequate loading value, usually more than 0.70. This indicates that the indicator has a strong correlation with the construct being measured and can explain most of the variance of the construct.

Table 2. Measurement Model Assessment

Variable/Indicators	Outer Loadings	Cronbach's alpha	CR (rho_a)	CR (rho_c)	AVE	VIF
CEA		0.835	0.835	0.901	0.751	
CEA1	0.853					1.859
CEA2	0.882					2.168
CEA3	0.865					1.882
CT		0.854	0.855	0.901	0.696	
CT1	0.832					1.943
CT2	0.84					1.949
CT3	0.835					1.97
CT4	0.829					1.922
ELS		0.787	0.788	0.904	0.824	
ELS1	0.911					1.727
ELS3	0.905					1.727
ERS		0.852	0.852	0.91	0.771	
ERS1	0.879					2.127
ERS2	0.893					2.268
ERS3	0.862					1.939
ETS		0.858	0.861	0.914	0.779	
ETS1	0.918					2.728
ETS2	0.87					2.11
ETS3	0.858					2.029
FPI		0.834	0.835	0.9	0.751	
FPI1	0.883					2.145
FPI2	0.873					1.982
FPI3	0.88					2.144
FPI3	0.843					1.773
GEI		0.856	0.857	0.903	0.699	
GEI1	0.847					2.227
GEI2	0.837					2.231
GEI3	0.871					2.681
GEI4	0.786					1.768
GFI		0.762	0.764	0.893	0.807	
GFI1	0.906					1.608
GFI2	0.891					1.608
GPP		0.825	0.825	0.896	0.741	
GPP1	0.829					1.62
GPP2	0.873					2.084
RES		0.734	0.734	0.882	0.79	
RES1	0.889					1.505
RES3	0.888					1.505
SF		0.72	0.721	0.877	0.781	
SF1	0.889					1.463
SF3	0.879					1.463
SRNM		0.839	0.841	0.903	0.756	
SNRM1	0.869					2.044
SNRM2	0.866					1.844
SNRM3	0.874					2.074

Note: CEA = Circular Economy Approach; CT = Carbon Tax; ELS = Eco Labeling Scheme; ERS = Environmental Regulations and Standards; ETS = Emission Trading System; FPI = Fiscal Policy Instruments; GEI = Green Economy Instruments; GFI = Green Finance and Investment; GPP = Green Public Policy; RES = Renewable Energy Subsidies; SF = Sustainable Financing; SNRM = Sustainable Natural Resource Management.

Based on the Outer Loadings of Table 2, it can be concluded that most of the indicators used to measure the construct have valid factor loading values, which are above the threshold of 0.70. This indicates that these indicators strongly correlate with the constructs they measure and also make a significant contribution to explaining the variance of the latent construct.

Cronbach's alpha reliability and PIF

The internal consistency of the measurement items was assessed using Cronbach's Alpha, with values above 0.70 indicating acceptable reliability (Nunnally, 1978). The results show that all constructs have Cronbach's Alpha values above this threshold, ranging from 0.720 to 0.903, confirming strong internal consistency and reliability of the instruments used in this study.

To assess multicollinearity among independent variables, Variance Inflation Factors (VIF) were calculated. As presented in Table 2, all VIF values are below 5, with a maximum value of 2.728 for ETS1 and most values falling between 1 and 3. This indicates that multicollinearity is not a concern in the model, supporting the robustness of the regression estimates.

Discriminant Validity

Discriminant validity is a critical aspect in measuring the validity of a research model, primarily to ensure that each construct in the model can distinguish itself from other constructs. This is tested by evaluating the extent to which the indicators used to measure a construct are highly correlated with the construct and have lower correlations with other constructs in the model. In this study, discriminant validity was assessed using a correlation matrix between constructs. The test results showed that each construct had a higher correlation with its indicators compared to the correlations with other constructs, as shown in the following table.

Table 3. Discriminant Validity-Heterotrait-monotrait ratio (HTMT)

Constructs	CEA	CT	ELS	ERS	ETS	FPI	GEI	GFI	GPP	RES	SF	SNRM
CEA												
CT	0.770											
ELS	0.792	0.475										
ERS	0.524	0.319	0.048									
ETS	0.885	0.769	0.652	0.575								
FPI	0.822	0.565	0.669	0.307	0.546							
GEI	0.430	0.665	0.754	0.561	0.895	0.649						
GFI	0.630	0.418	0.831	0.365	0.475	0.875	0.530					
GPP	0.541	0.693	0.790	0.486	0.846	0.977	0.305	0.770				
RES	0.829	0.569	0.709	0.557	0.341	0.576	0.829	0.609	0.775			
SF	0.778	0.542	0.689	0.404	0.713	0.596	0.810	0.562	0.847	0.675		
SNRM	0.612	0.748	0.683	0.416	0.858	0.731	0.872	0.606	0.872	0.765	0.734	

Table 4. Discriminant Validity-Fornell-Larcker Criterion

Constructs	CEA	CT	ELS	ERS	ETS	FPI	GEI	GFI	GPP	RES	SF	SNRM
CEA	0.867											
CT	0.823	0.834										
ELS	0.807	0.862	0.908									
ERS	0.834	0.834	0.808	0.878								
ETS	0.791	0.801	0.794	0.855	0.883							
FPI	0.795	0.817	0.797	0.801	0.807	0.866						
GEI	0.823	0.788	0.804	0.852	0.835	0.859	0.836					
GFI	0.818	0.836	0.807	0.820	0.793	0.825	0.827	0.898				
GPP	0.780	0.809	0.814	0.795	0.793	0.887	0.839	0.810	0.861			
RES	0.783	0.801	0.758	0.799	0.815	0.781	0.814	0.820	0.889			
SF	0.759	0.859	0.807	0.792	0.765	0.781	0.731	0.802	0.758	0.699	0.884	
SNRM	0.810	0.860	0.815	0.792	0.765	0.794	0.827	0.798	0.815	0.752	0.870	0.884

Discriminant validity was evaluated using both the Fornell-Larcker criterion and the Heterotrait-Monotrait Ratio (HTMT). Table 3 presents the HTMT values, where most construct pairs show values below the threshold of 0.85, indicating adequate discriminant validity (Henseler et al., 2015). However, some constructs—such as ETS and CEA (HTMT = 0.885), GPP and FPI (HTMT = 0.977), and SNRM and ETS (HTMT = 0.858)—exceed this threshold, suggesting potential conceptual overlap. Despite this, these values are interpreted as acceptable in the context of related constructs, particularly when supported by strong theoretical distinctions and composite reliability results presented in Table 4.

R-Square

R-squared is a statistical measure used to evaluate how well the regression model can explain the variability of the dependent variable. R-squared indicates the proportion of variance of the dependent variable that the independent variables in the model can explain. The R-squared value ranges between 0 and 1. R-Square = 1 means the model can explain all variations or variability in the data that occur in the dependent variable. This shows that the model is perfect for predicting the dependent variable based on the existing independent variables.

R-Square = 0 indicates that the model cannot explain variations in the dependent variable, so that no relationship can be found between the independent and dependent variables in the model.

Table 5. R-Square

	R-square	R-square adjusted
Green Economy Instruments	0,847	0,844
Sustainable Natural Resource Management	0,631	0,630

From Table 5, it can be concluded that Green Economy Instruments (GEI) have an R-Square value of 0.847, which means that around 84.7% of the variation in this construction can be explained by the independent variables that influence it (such as ETS, RES, CT, etc.). This shows that this model has strong predictive power in explaining variables related to green economic instruments. Sustainable Natural Resource Management has an R-squared value of 0.632, which means that approximately 63.2% of the variation in this construct can be explained by the Green Economy Instruments. In other words, the application of green economic instruments plays a significant role in influencing sustainable natural resource management. However, other factors that influence this variable still need to be included in the model.

Bootstrapping

In SEM-PLS, *bootstrapping* is a resampling method used to test the statistical significance of relationships between variables in the model without assuming a normal distribution of the data. This method provides T-statistics and P-values to determine the significance of paths and assess the reliability and validity of constructs. Additionally, *bootstrapping* helps evaluate the stability of model estimates by calculating confidence intervals, making the model results more accurate and reliable, especially in studies with small samples or non-normally distributed data.

Bootstrapping measurements, as illustrated in Figure 3, are conducted by randomly resampling the original data with replacement and recalculating model parameters, such as path coefficients, for each sample. This process is repeated hundreds or even thousands of times to produce a distribution of parameter values, from which T-statistics and P-values are derived. Figure 3 shows that P-values are less than 0.05 for all relationships between variables. This result indicates that the relationships in the model have a strong and reliable influence on the study.

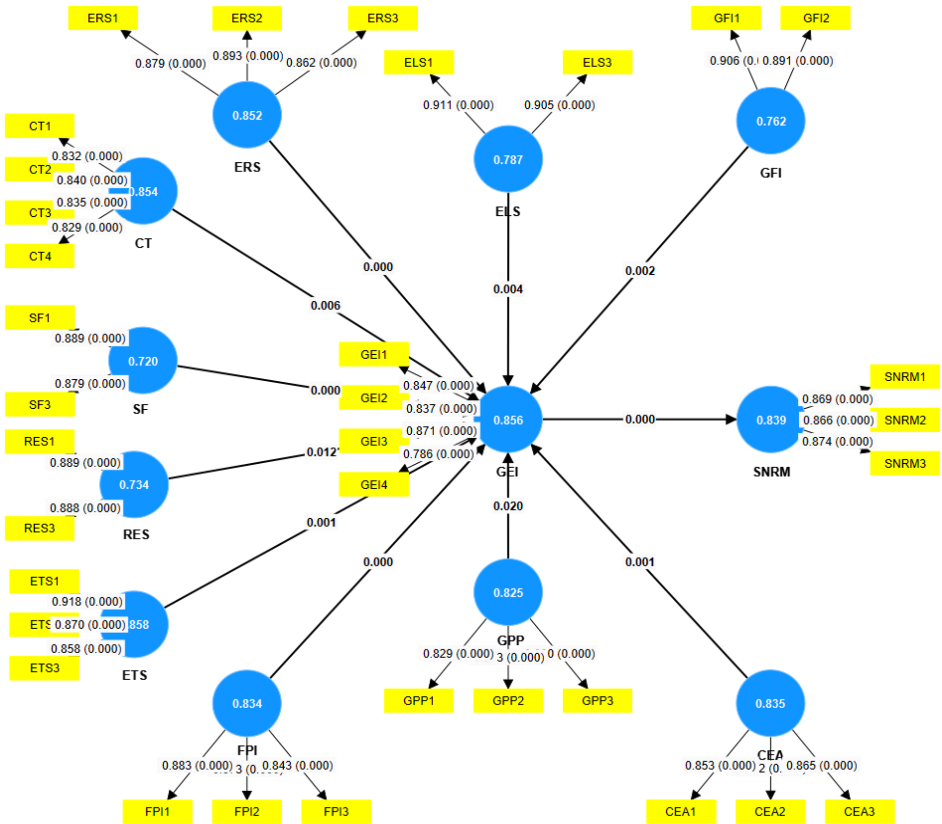

Figure 3. Bootstrapping

Hypothesis Testing

Table 6. Path Coefficient

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
CEA -> GEI	0.126	0.127	0.038	3.292	0.001
CEA -> SNRM	0.1	0.101	0.031	3.269	0.001
CT -> GEI	-0.118	-0.117	0.047	2.492	0.013
CT -> SNRM	-0.094	-0.093	0.037	2.502	0.012
ELS -> GEI	0.116	0.114	0.043	2.695	0.007
ELS -> SNRM	0.092	0.091	0.034	2.686	0.007
ERS -> GEI	0.253	0.251	0.048	5.316	0.000
ERS -> SNRM	0.201	0.199	0.038	5.356	0.000
ETS -> GEI	0.135	0.135	0.042	3.196	0.001
ETS -> SNRM	0.107	0.108	0.034	3.187	0.001
FPI -> GEI	0.301	0.301	0.049	6.16	0.000
FPI -> SNRM	0.239	0.239	0.038	6.218	0.000
GEI -> SNRM	0.794	0.795	0.016	48.996	0.000
GFI -> GEI	0.123	0.124	0.043	2.844	0.004
GFI -> SNRM	0.098	0.098	0.035	2.833	0.005
GPP -> GEI	0.092	0.092	0.045	2.05	0.040
GPP -> SNRM	0.073	0.073	0.036	2.046	0.041
RES -> GEI	0.091	0.091	0.04	2.269	0.023
RES -> SNRM	0.072	0.072	0.032	2.266	0.023
SF -> GEI	-0.131	-0.13	0.039	3.386	0.001
SF -> SNRM	-0.104	-0.103	0.031	3.397	0.001

Based on Table 6, this study tested ten hypotheses to evaluate the influence of Green Economy Instruments (GEI) on Sustainable Natural Resource Management (SNRM). The results, derived from PLS-SEM using SmartPLS 4.0, are summarized as follows:

Table 7. Hypothesis Testing Results Using PLS-SEM

No	Hypothesis	Relationship	β (Path Coefficient)	T-Statistic	P-Value	Decision
H1	Carbon Tax (CT) has a positive effect on SNRM	CT → SNRM	-0.094	2.502	0.012	Rejected (Negative relationship)
H2	The Emission Trading System (ETS) has a significant impact on SNRM	ETS → SNRM	0.107	3.187	0.001	Supported
H3	Renewable Energy Subsidies (RES) provide a positive contribution to SNRM	RES → SNRM	0.072	2.266	0.023	Supported
H4	Sustainable Financing (SF) plays a crucial role in supporting SNRM	SF → SNRM	-0.104	3.397	0.001	Rejected (Negative relationship)
H5	Environmental Regulations and Standards (ERS) have a positive influence on SNRM	ERS → SNRM	0.201	5.356	0	Strongly Supported
H6	Eco Labeling Scheme (ELS) has a positive impact on SNRM	ELS → SNRM	0.092	2.686	0.007	Supported
H7	Green Finance and Investment (GFI) contributes to improving SNRM	GFI → SNRM	0.098	2.833	0.005	Supported
H8	Green Fiscal Instruments (FPIs) have an impact on SNRM by providing economic incentives	FPI → SNRM	0.239	6.218	0	Strongly Supported
H9	Green Public Policies (GPPs) have a positive influence on SNRM	GPP → SNRM	0.073	2.046	0.041	Supported
H10	The Circular Economy Approach (CEA) has a positive influence on SNRM	CEA → SNRM	0.1	3.269	0.001	Supported

Table 7 shows the results of the hypothesis testing, which are summarized in Table X. A path coefficient was calculated for each Green Economy Instrument (GEI) to assess its impact on Sustainable Natural Resource Management (SNRM), with significance determined using T-statistics (> 1.96) and P-values (< 0.05). As shown, eight out of ten hypotheses were supported, indicating a strong influence of GEI dimensions such as environmental regulations, fiscal policy instruments, and emission trading systems on SNRM.

This study provides empirical evidence on the influence of Green Economy Instruments (GEI) on Sustainable Natural Resource Management (SNRM), particularly in an agrarian context such as Tomohon City, North Sulawesi Province. The findings provide both theoretical and practical insights into how GEI dimensions such as carbon taxes, emission trading systems, renewable energy subsidies, and green fiscal policies impact SNRM practices among local farming business actors.

The results indicate that most Green Economy Instruments have a statistically significant effect on SNRM, with an R-squared value of 0.847, suggesting that 84.7% of the variation in SNRM can be explained by GEI, highlighting the strong predictive power of the model. Among the GEI dimensions, Fiscal Policy Instruments (FPI) and Environmental Regulations and Standards (ERS) showed the strongest positive relationships with SNRM, followed by the Circular Economy Approach (CEA) and the Emission Trading System (ETS). These findings align with previous studies that emphasize the importance of economic incentives and regulatory frameworks in driving sustainable behavior. For instance, Yuan & Zhang (2020) found that fiscal instruments significantly encourage green innovation in Chinese firms, while Pan (2023) highlighted the role of policy enforcement in improving environmental outcomes at the regional level.

Interestingly, Carbon Tax (CT) and Sustainable Financing (SF) demonstrated statistically significant but negative relationships with SNRM. This suggests that despite their potential effectiveness in macro-level contexts, these instruments may not be perceived positively or implemented efficiently in rural agrarian settings. One possible explanation is the lack of visible reinvestment of CT revenues into sustainability projects, leading to perceptions of burden rather than benefit among small-scale farmers.(Hartono et al., 2023) Similarly, the negative coefficient for SF implies that green financing mechanisms, such as green bonds or eco-investment funds, may not yet be well understood or accessible to agrarian entrepreneurs in Tomohon. These results underscore the importance of policy perception and implementation quality, which often determine whether a tool achieves its intended impact.

When compared with earlier research, several consistencies and discrepancies emerge:

- FPI ($\beta = 0.239$, $p < 0.001$): This finding supports Cheng et al. (2024) and Yuan & Zhang (2020), who emphasized the effectiveness of fiscal tools in promoting green transformation. In this case, FPI appears to be more effective than market-based instruments, such as ETS or CT, especially in regions where economic capacity is limited.(Cheng et al., 2024; Yuan & Zhang, 2020)
- ERS ($\beta = 0.201$, $p < 0.001$): The strong relationship between environmental regulations and SNRM is consistent with Makanda et al. (2022), who reported similar impacts of regulatory compliance on water resource management in Indonesia.**(**Makanda et al., 2022)
- ETS ($\beta = 0.107$, $p = 0.001$): While ETS had a positive effect, its magnitude was relatively lower compared to national-level studies (e.g., Entezaminia et al., 2021). This may reflect lower awareness or participation in cap-and-trade systems among agrarian communities.(Entezaminia et al., 2021)
- RES ($\beta = 0.072$, $p = 0.023$): Although RES had a positive and significant effect, it was weaker than expected. This contrasts with Meirun (2021), who argued that energy subsidies are key to accelerating the adoption of clean energy.(Meirun, 2021**)** The relatively low impact here may stem from limited access to technology or poor dissemination of information in rural areas.
- GPP ($\beta = 0.073$, $p = 0.041$): The result confirms the relevance of government-led sustainability initiatives, consistent with Wojnarowska et al. (2021), who noted that public procurement of eco-friendly goods can stimulate broader market demand.(Wojnarowska et al., 2021)
- CEA ($\beta = 0.100$, $p = 0.001$): This supports Jacobs et al. (2022), who emphasized the role of circular economy principles in reducing waste and enhancing resource efficiency.(Jacobs et al., 2022)
- CT ($\beta = -0.094$, $p = 0.012$) and SF ($\beta = -0.104$, $p = 0.001$): These negative relationships contradict many prior studies (e.g., Yin, 2022), which generally report positive effects. However, they align with Hartono et al. (2023), who found mixed responses to carbon taxation in Indonesian industries, particularly when benefits are not clearly communicated or reinvested locally.

This study revealed statistically significant but negative associations between two Green Economy Instruments—Carbon Tax (CT) and Sustainable Financing (SF) —with Sustainable Natural Resource Management (SNRM). While prior studies suggest these instruments promote sustainability (Kar, 2022; Pan, 2023), the results indicate a different trend in this agrarian context.

Carbon Tax (CT → SNRM): $\beta = -0.094$, $p = 0.012$, The negative coefficient suggests that the carbon tax is perceived as a cost burden rather than an incentive for green transformation. This contradicts findings from national-level analyses (Yin, 2022b), which have shown that CT can effectively reduce emissions. However, it aligns with Hartono et al. (2023), who observed resistance among small-scale businesses due to limited financial capacity and a lack of visible reinvestment into environmental initiatives. Sustainable Financing (SF → SNRM): $\beta = -0.104$, $p = 0.001$, Despite its intended role in supporting eco-friendly projects, SF showed a statistically significant adverse effect, possibly due to low accessibility or complex funding procedures. This finding contrasts with Chien et al. (2021), who found SF to be effective in urban contexts, but supports Wojnarowska et al. (2021), who highlighted challenges in implementing green financing in rural and agrarian economies. These findings emphasize the importance of context-specific policy design, especially in local agrarian settings where economic capacity and awareness are limited.

The findings suggest that Green Economy Instruments can be effective drivers of Sustainable Natural Resource Management (SNRM), particularly when tailored to the local socio-economic context. Given the high R^2 value and robust statistical significance of most constructs, the model can serve as a template for other agrarian regions facing similar environmental pressures. However, generalizability should be approached with caution, as the sample is limited to one region in Indonesia. Future comparative studies across different provinces or developing countries could validate whether these patterns hold beyond the specific context of Tomohon.

From a theoretical perspective, this study contributes to the literature by: Validating the application of PLS-SEM in analyzing latent constructs related to sustainability in non-industrial sectors. Highlighting the need to differentiate the effectiveness of GEI based on sector and scale, especially in agrarian economies. Emphasizing the importance of stakeholder perception and policy design, not just policy existence. Practically, the findings suggest that policymakers should: Prioritize fiscal incentives over punitive measures to encourage voluntary adoption of sustainable practices. Enhance transparency and communication regarding the utilization of revenue generated through environmental taxes and green financing schemes. Support capacity-building programs to enhance understanding and trust in GEI among local agrarian actors.

This research offers several contributions, It focuses on regional agrarian governance, a context rarely studied in global green economy literature. It uses primary survey data from 500 respondents, providing empirical depth that complements existing macro-level analyses. It reveals unexpected negative impacts of certain GEIs, offering new perspectives on implementation challenges in non-industrial settings. It integrates multidimensional GEI indicators within a single model, contributing to a holistic framework for future research. Despite its contributions, this study has several limitations: Cross-sectional design: This limits causal inference and does not capture long-term changes. Self-reported data: May introduce bias due to social desirability or misinterpretation of questions. Single-region focus: Reduces external validity and applicability outside Tomohon. Limited moderating variables: Factors such as education, digital literacy, and cultural norms were not included in the current analysis.

Based on the findings, we recommend the following policy actions: Strengthen Fiscal Incentives: Increase the accessibility and visibility of green investment programs, especially for small-scale agrarian businesses. Enhance Regulatory Clarity: Ensure that environmental laws are clear, consistently enforced, and accompanied by effective support mechanisms. Enhance Communication Around Carbon Tax: Educate stakeholders on the purpose and benefits of carbon pricing to reduce resistance and increase buy-in. Promote Circular Economy Practices: Encourage composting, the reuse of agricultural waste, and the integration of circular economy principles into daily farming operations. Expand Green Public Procurement Policies: Governments should prioritize local, sustainable products in contracts, creating a market pull for environmentally friendly outputs. Support Renewable Energy Adoption: Provide targeted training and technical assistance to help farmers adopt solar panels, biogas, and other environmentally friendly technologies.

CONCLUSION

This study highlights the significant influence of Green Economy Instruments (GEI) on Sustainable Natural Resource Management (SNRM) among agrarian business actors in Tomohon City, North Sulawesi Province, identifying Fiscal Policy Instruments (FPI) and Environmental Regulations and Standards (ERS) as the most impactful drivers. The findings reveal that the effectiveness of GEI is shaped not only by their formal existence but also by local perceptions, accessibility, and the visibility of environmental and economic benefits. To capture this dynamic, the study proposes the “Policy Effectiveness in Agrarian Settings Framework,” which emphasizes that policies yield more sustainable outcomes when perceived as beneficial rather than burdensome, are accessible and clearly communicated, and are linked to tangible improvements. Theoretically, this work advances sustainability research by showing how PLS-SEM can be effectively applied in non-industrial, agrarian contexts, challenging the notion that GEIs function uniformly across regions and underscoring the importance of socio-economic adaptation. Practically, the results suggest that governments should prioritize fiscal incentives and clear regulatory frameworks over complex market-based tools in rural areas, improve transparency and communication in green financing and taxation, and support initiatives such as eco-labeling awareness, circular economy programs, and green procurement policies to create market demand for sustainable products. The broader implication is that tailoring green policies to local realities not only enhances their adoption and impact but also provides a replicable model for integrating economic growth with environmental stewardship in similar agrarian regions worldwide.

ACKNOWLEDGMENTS

We want to express our deepest gratitude to the agricultural entrepreneurs and the North Sulawesi Provincial Government for their support and cooperation throughout this research. Your contributions and insights have been invaluable in shaping our work and ensuring its relevance to the community. Thank you for your commitment to advancing the Economy through green agricultural practices in this region.

AUTHOR CONTRIBUTIONS

The authors' contributions are as follows: Welky Karauwan led the conceptualization, methodology, and drafting of the manuscript. Denny Adri Tarumingi conducted the literature review, data collection, and provided critical revisions. Joni Kutu' Kampilong was responsible for data analysis, interpretation, and editing. Kristi Karla Arina managed the project administration and supervision, while Deisy Agnes Pertiwi Juita Pangkey oversaw funding acquisition and resource management. Pingkan Aprilia Maramis handled visualization and manuscript formatting, and Elsje Hanna Lintong contributed by reviewing and approving the final manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, *241*, 108224. https://doi.org/10.1016/j.biocon.2019.108224.

Azam, W., Khan, I., & Ali, S. A. (2023). Alternative energy and natural resources in determining environmental sustainability: A look at the role of government final consumption expenditures in France. *Environmental Science and Pollution Research*, *30*(1), 1949–1965. https://doi.org/10.1007/s11356-022-22334-z.

Balsalobre-Lorente, D. (2023). Tourism, urbanization, and natural resource rents matter for environmental sustainability: The leading role of AI and ICT in achieving sustainable development goals in the digital era. *Resources Policy*, *82*. https://doi.org/10.1016/j.resourpol.2023.103445.

Bhutta, U. S., Tariq, A., Farrukh, M., Raza, A., & Iqbal, M.K. (2022). Green bonds for sustainable development: Review of literature on development and impact of green bonds. *Technological Forecasting and Social Change*, *175*, 121378. https://doi.org/10.1016/j.techfore.2021.121378.

Cai, X., Zhu, B., Zhang, H., Li, L., & Xie, M. (2020). Can direct environmental regulation promote green technology innovation in heavily polluting industries? Evidence from Chinese listed companies. *Science of The Total Environment*, *746*, 140810. https://doi.org/10.1016/j.scitotenv.2020.140810.

Cardoso, J. S. (2021). Ammonia as an energy vector: Current and prospects for low-carbon fuel applications in internal combustion engines. In *Journal of Cleaner Production* (Vol. 296).

https://doi.org/10.1016/j.jclepro.2021.126562.
Cheng, H.-C., Shu, M.-H., & Huang, J.-C. (2024). Economic strategies for efficient use of natural resources: The impact of carbon taxation and fiscal policy. *Resources Policy*, *92*, 104927. https://doi.org/10.1016/j.resourpol.2024.104927.
Chien, F. (2021a). A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. *Journal of Environmental Management*, *297*. https://doi.org/10.1016/j.jenvman.2021.113420.
Chien, F. (2021b). A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. *Journal of Environmental Management*, *297*(Query date: 2024-10-02 14:18:46). https://doi.org/10.1016/j.jenvman.2021.113420.
Chopra, R. (2022). The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: Do carbon emissions and deforestation affect agricultural productivity? *Resources Policy*, *76*(Query date: 2024-10-02 14:42:24). https://doi.org/10.1016/j.resourpol.2022.102578.
Entezaminia, A., Gharbi, A., & Ouhimmou, M. (2021). A joint production and carbon trading policy for unreliable manufacturing systems under cap-and-trade regulation. *Journal of Cleaner Production*, *293*, 125973. https://doi.org/10.1016/j.jclepro.2021.125973.
Erdoğan, S. (2021). The role of natural resources abundance and dependence in achieving environmental sustainability: Evidence from resource-based economies. *Sustainable Development*, *29*(1), 143–154. https://doi.org/10.1002/sd.2137.
Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D. K., Kumar, V., Farooq, T. H., Ali, B., Sawant, A. V., Saud, S., Chen, S., & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability*, *14*(22), 14877. https://doi.org/10.3390/su142214877.
Gottardo, S. (2021). Towards safe and sustainable innovation in nanotechnology: State-of-play for smart nanomaterials. In *NanoImpact* (Vol. 21). https://doi.org/10.1016/j.impact.2021.100297.
Hao, H. (2023). Towards next generation design of sustainable, durable, multi-hazard resistant, resilient, and smart civil engineering structures. In *Engineering Structures* (Vol. 277). https://doi.org/10.1016/j.engstruct.2022.115477.
Hartono, D., Indriyani, W., Iryani, B. S., Komarulzaman, A., Nugroho, A., & Kurniawan, R. (2023). Carbon tax, energy policy, and sustainable development in Indonesia. *Sustainable Development*, *31*(4), 2332–2346. https://doi.org/10.1002/sd.2511.
Huo, J., & Peng, C. (2023). Depletion of natural resources and environmental quality: Prospects of energy use, energy imports, and economic growth hindrances. *Resources Policy*, *86*, 104049. https://doi.org/10.1016/j.resourpol.2023.104049.
Ikhsan, M., Atun, S., Agusta, F., Unayah, H., Buhera, R., Pamungkas, O., Sarip, M., & Sitorus, P. A. (2025). Development of critical thinking essay test instrument and prosocial intention questionnaire for environmental care in students. *Journal Evaluation in Education (JEE)*, *6*(1), 66-78. https://doi.org/10.37251/jee.v6i1.1273.
Iqbal, Q. (2020). The era of environmental sustainability: Ensuring that sustainability stands on human resource management. *Global Business Review*, *21*(2), 377–391. https://doi.org/10.1177/0972150918778967.
Jacobs, C., Soulliere, K., Sawyer-Beaulieu, S., Sabzwari, A., & Tam, E. (2022). Challenges to the circular economy: Recovering wastes from simple versus complex products. *Sustainability*, *14*(5), 2576. https://doi.org/10.3390/su14052576.
Jahanger, A., Usman, M., Murshed, M., Mahmood, H., & Balsalobre-Lorente, D. (2022). The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. *Resources Policy*, *76*, 102569. https://doi.org/10.1016/j.resourpol.2022.102569.
Jarnawi, M., Haeruddin, H., Werdhiana, I. K., Syamsuriwal, S., & Mu'aziyah, S. E. S. (2025). Integrating thinking styles into differentiated instruction: Enhancing learning outcomes in science education. *Integrated Science Education Journal*, *6*(1), 47-53. https://doi.org/10.37251/isej.v6i1.1328.
Jalmasco, A. C., Loberes, J. M., & Lasala, N. J. (2025). Interactive story for teaching ecosystem topics using twine application for elementary school students. *Journal of Basic Education Research*, *6*(2), 66-78. https://doi.org/10.37251/jber.v6i2.1480.

Jumaera, S., Blessing, O. T., & Rukondo, N. (2024). Optimizing student activities and learning outcomes through problem solving models in stoichiometry material. *Journal of Chemical Learning Innovation*, *1*(2), 39-44. https://doi.org/10.37251/jocli.v1i2.1147.

Khan, M. K., Babar, S. F., Oryani, B., Dagar, V., Rehman, A., Zakari, A., & Khan, M. O. (2022). The role of financial development, environmental-related technologies, research and development, energy intensity, natural resource depletion, and temperature in achieving a sustainable environment in Canada. *Environmental Science and Pollution Research*, *29*(1), 622–638. https://doi.org/10.1007/s11356-021-15421-0.

Khan, Z. (2023). Aggregate and disaggregate impacts of natural resources on economic performance: The role of green growth and human capital. *Resources Policy*, *80*. https://doi.org/10.1016/j.resourpol.2022.103103.

Kheang, S., Hankhuntod, P., & Wesonga, L. N. (2025). Design and experimental study of a biomass pellet gasifier stove with heat recovery system for high efficiency and low emission. *Journal of Educational Technology and Learning Creativity*, *3*(1), 39-46. https://doi.org/10.37251/jetlc.v3i1.1620.

Kölbel, J. F., Heeb, F., Paetzold, F., & Busch, T. (2020). Can sustainable investing save the world? reviewing the mechanisms of investor impact. *Organization & Environment*, *33*(4), 554–574. https://doi.org/10.1177/1086026620919202.

Kyere-Boateng, R., & Marek, M. V. (2021). Analysis of the social-ecological causes of deforestation and forest degradation in Ghana: Application of the DPSIR Framework. *Forests*, *12*(4), 409. https://doi.org/10.3390/f12040409.

Liu, H., Xu, C., Allen, C. D., Hartmann, H., Wei, X., Yakir, D., Wu, X., & Yu, P. (2022). Nature-Based framework for sustainable afforestation in global drylands under a changing climate. *Global Change Biology*, *28*(7), 2202—2220. https://doi.org/10.1111/gcb.16059.

Liu, Z., Qian, Q., Hu, B., Shang, W.-L., Li, L., Zhao, Y., Zhao, Z., & Han, C. (2022). Government regulation to promote coordinated emission reduction among enterprises in the green supply chain based on evolutionary game analysis. *Resources, Conservation and Recycling*, *182*, 106290. https://doi.org/10.1016/j.resconrec.2022.106290.

Makanda, K., Nzama, S., & Kanyerere, T. (2022). Assessing the role of water resources protection practice for sustainable water resources management: A review. *Water*, *14*(19), 3153. https://doi.org/10.3390/w14193153.

Mastini, R. (2021). A green new deal without growth? *Ecological Economics*, *179*(Query date: 2024-10-02 14:18:46). https://doi.org/10.1016/j.ecolecon.2020.106832.

Melinda, S., Feizi, F., & Monfared, P. N. (2024). Transforming religious learning with macromedia flash 8: improving students' understanding of the material on faith in the apostles. *Journal of Educational Technology and Learning Creativity*, *2*(2), 201-208. https://doi.org/10.37251/jetlc.v2i2.1100.

Meirun, T. (2021). The dynamic effect of green technology innovation on economic growth and CO2 emission in Singapore: New evidence from the bootstrap ARDL approach. *Environmental Science and Pollution Research*, *28*(4), 4184–4194. https://doi.org/10.1007/s11356-020-10760-w.

Mihai, F.-C., Gündoğdu, S., Markley, L. A., Olivelli, A., Khan, F. R., Gwinnett, C., Gutberlet, J., Reyna-Bensusan, N., Llanquileo-Melgarejo, P., Meidiana, C., Elagroudy, S., Ishchenko, V., Penney, S., Lenkiewicz, Z., & Molinos-Senante, M. (2021). Plastic pollution, waste management issues, and circular economy opportunities in rural communities. *Sustainability*, *14*(1), 20. https://doi.org/10.3390/su14010020.

Mohsin, M. (2022). The role of technological progress and renewable energy deployment in green economic growth. *Renewable Energy*, *190*, 777–787. https://doi.org/10.1016/j.renene.2022.03.076.

Monasterolo, I., Mandel, A., Battiston, S., Mazzocchetti, A., Oppermann, K., Coony, J., Stretton, S., Stewart, F., & Dunz, N. (2024). The role of green financial sector initiatives in the low-carbon transition: A Theory of change. *Global Environmental Change*, *89*, 102915. https://doi.org/10.1016/j.gloenvcha.2024.102915.

Moore, J. W., & Schindler, D. E. (2022). Adapting to climate change for ecological resilience and sustainability. *Science*, *376*(6600), 1421–1426.

Muhamad, M., Ab, A., & Supriyadi, H. (2025). The influence of sustainable ecotourism infrastructure on local government policy in the national strategic tourism area of Yogyakarta. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *9*(1), 292–312. https://doi.org/10.22437/jiituj.v9i1.37888.

Mulvaney, D., Richards, R. M., Bazilian, M. D., Hensley, E., Clough, G., & Sridhar, S. (2021). Progress towards a circular economy in materials to decarbonize electricity and mobility. *Renewable and Sustainable Energy Reviews*, *137*, 110604. https://doi.org/10.1016/j.rser.2020.110604.

Nastasi, B., Markovska, N., Puksec, T., Duić, N., & Foley, A. (2022). Renewable and sustainable energy challenges to face for the achievement of Sustainable Development Goals. *Renewable and Sustainable Energy Reviews*, *157*, 112071. https://doi.org/10.1016/j.rser.2022.112071.

Nathaniel, S. P., Yalçiner, K., & Bekun, F. V. (2021). Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. *Resources Policy*, *70*, 101924. https://doi.org/10.1016/j.resourpol.2020.101924.

Nong, D., Nguyen, T. H., Wang, C., & Khuc, Q. V. (2020). The environmental and economic impact of the emissions trading scheme (ETS) in Vietnam. *Energy Policy*, *140*, 111362. https://doi.org/10.1016/j.enpol.2020.111362.

Nou, H., Mok, S., Lim, S., & Em, S. (2025). The relationship between students' attitudes towards cooperative learning strategies and their academic achievement. *Journal of Social Knowledge Education (JSKE)*, *6*(2), 200-210. https://doi.org/10.37251/jske.v6i2.1606.

Obenza, B. N., Galido, J. C. A., Madridano, T. J. M., Mocallay, K. B. V., Quio, K., Rojo, E. M. H., & Sedot, J. C. (2025). Analyzing university students' attitude and behavior towards jesi program using technology acceptance model. *Indonesian Journal of Education Research (IJoER)*, *6*(2), 177-186. https://doi.org/10.37251/ijoer.v6i2.1402.

Pan, W. (2023). "Green" innovation, privacy regulation, and environmental policy. *Renewable Energy*, *203*(Query date: 2024-10-02 14:18:46), 245–254. https://doi.org/10.1016/j.renene.2022.12.025.

Pollom, R. A., Cheok, J., Pacoureau, N., Gledhill, K. S., Kyne, P. M., Ebert, D. A., Jabado, R. W., Herman, K. B., Bennett, R. H., da Silva, C., Fernando, S., Kuguru, B., Leslie, R. W., McCord, M. E., Samoilys, M., Winker, H., Fennessy, S. T., Pollock, C. M., Rigby, C. L., & Dulvy, N. K. (2024). Overfishing and climate change elevate the extinction risk of endemic sharks and rays in the southwest Indian Ocean hotspot. *PLOS ONE*, *19*(9), 1–25. https://doi.org/10.1371/journal.pone.0306813.

Putri, E. N., Mahdavi, M., & Awlqadir, M. S. (2025). An analysis of students' motivation and their achievement in learning english at the department of english education. *Journal of Language, Literature, and Educational Research*, *2*(1), 43-50. https://doi.org/10.37251/jolle.v2i1.1698.

Rachmatika, S. V., & Salighehdar, N. (2024). The influence of health education via whatsapp media on the level of knowledge of adolescents about gastritis. *Journal of Health Innovation and Environmental Education*, *1*(2), 32-37. https://doi.org/10.37251/jhiee.v1i2.1204.

Razzaq, A. (2023). Asymmetric influence of digital finance and renewable energy technology innovation on green growth in China. *Renewable Energy*, *202*, 310–319. https://doi.org/10.1016/j.renene.2022.11.082.

Rousseau, S., & Deschacht, N. (2020). Public awareness of nature and the environment during the COVID-19 crisis. *Environmental and Resource Economics*, *76*(4), 1149–1159. https://doi.org/10.1007/s10640-020-00445-w.

Rubio, M. T., Mensah, J., & Sokpe, B. (2025). Trends in international mathematics and science study (TIMSS): A comparative analysis of mathematics achievement. *Interval: Indonesian Journal of Mathematical Education*, *3*(1), 109-115. https://doi.org/10.37251/ijome.v3i1.1733.

Saijo, T. (2020). Future design: Bequeathing sustainable natural environments and sustainable societies to future generations. *Sustainability*, *12*(16), 6467. https://doi.org/10.3390/su12166467.

Salim, M. A., Rajabiyah, N., & Misrodin, M. (2025). Exploring the role of emotional intelligence and self-confidence in supporting islamic religious education learning outcomes. *Jurnal Pendidikan Agama Islam Indonesia (JPAII)*, *6*(1), 1-10. https://doi.org/10.37251/jpaii.v6i1.1431.

Shittu, W. (2021). An investigation of the nexus between natural resources, environmental performance, energy security, and environmental degradation: Evidence from Asia. *Resources Policy*, *73*(Query date: 2024-10-02 14:42:24). https://doi.org/10.1016/j.resourpol.2021.102227.

Siddique, Z. F., Nahar, L., & Mahmood, F. (2025). Autoethnographic projection of climate change education through project-based learning: Perspectives from early career scholars. *Integrated Science Education Journal*, *6*(1), 38-46. https://doi.org/10.37251/isej.v6i1.1170.

Sofo, A., Zanella, A., & Ponge, J.-F. (2022). Soil quality and fertility in sustainable agriculture, with a contribution to the biological classification of agricultural soils. *Soil Use and Management*, *38*(2), 1085–1112. https://doi.org/10.1111/sum.12702.

Somantri, Y. N. (2024). Analysis of the physical education learning process through online media. *Multidisciplinary Journal of Tourism, Hospitality, Sport and Physical Education*, *1*(1), 11-15. https://doi.org/10.37251/jthpe.v1i1.1037.

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., Braga Junqueira, A., Lacerda, E., Latawiec, A. E., Balmford, A., Brooks, T. M., Butchart, S. H. M., Chazdon, R. L., Erb, K.-H., Brancalion, P., Buchanan, G., Cooper, D., Díaz, S., Donald, P. F., … Visconti, P. (2020). Global priority areas for ecosystem restoration. *Nature*, *586*(7831), 724–729. https://doi.org/10.1038/s41586-020-2784-9.

Suki, N. M. (2022). The role of technology innovation and renewable energy in reducing environmental degradation in Malaysia: A step towards a sustainable environment. *Renewable Energy*, *182*, 245–253. https://doi.org/10.1016/j.renene.2021.10.007.

Syahrul, A. R., Suryana, S., Hendrayati, H., & Furqon, C. (2025). The dynamics of entrepreneurship education in higher education: The role of family background and environment in developing entrepreneurial skills. *Journal Evaluation in Education (JEE)*, *6*(2), 590-600. https://doi.org/10.37251/jee.v6i2.1540.

Tabaku, E., Vyshka, E., Kapçiu, R., Shehi, A., & Smajli, E. (2025). Utilizing artificial intelligence in energy management systems to improve carbon emission reduction and sustainability. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *9*(1), 393–405. https://doi.org/10.22437/jiituj.v9i1.38665.

Tarkowski, R. (2022). Towards underground hydrogen storage: A review of barriers. In *Renewable and Sustainable Energy Reviews* (Vol. 162). https://doi.org/10.1016/j.rser.2022.112451.

Vrusho, B., Golgota, A., Dhoska, K., & Abotaleb, M. (2025). Improving energy efficiency strategy in residential buildings. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *9*(1), 380–392. https://doi.org/10.22437/jiituj.v9i1.37924.

Wang, J. (2022). Analysis of the mechanism of the impact of internet development on green economic growth: Evidence from 269 prefecture cities in China. *Environmental Science and Pollution Research*, *29*(7), 9990–10004. https://doi.org/10.1007/s11356-021-16381-1.

Wicaksana, T., & Widodo, W. (2024). The nexus between trade openness and environmental degradation: a vecm analysis. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(2), 703–719. https://doi.org/10.22437/jiituj.v8i2.36595.

Wojnarowska, M., Sołtysik, M., & Prusak, A. (2021). Impact of eco-labelling on the implementation of sustainable production and consumption. *Environmental Impact Assessment Review*, *86*, 106505. https://doi.org/10.1016/j.eiar.2020.106505.

Yadewani, D., Pandi, O. D., Syafrani, S., Nurofik, A., & Poddar, S. (2024). Impact of government policies on the knowledge base of sustainable small and medium-sized enterprises. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 251–266. https://doi.org/10.22437/jiituj.v8i1.31884.

Yang, Q., Li, Z., Lu, X., Duan, Q., Huang, L., & Bi, J. (2018). A review of soil heavy metal pollution from industrial and agricultural regions in China: Pollution and risk assessment. *Science of The Total Environment*, *642*, 690–700. https://doi.org/10.1016/j.scitotenv.2018.06.068.

Yin, S. (2022a). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for Industry 5.0. *Journal of Cleaner Production*, *363*. https://doi.org/10.1016/j.jclepro.2022.132608.

Yin, S. (2022b). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for Industry 5.0. *Journal of Cleaner Production*, *363*(Query date: 2024-10-02 14:18:46). https://doi.org/10.1016/j.jclepro.2022.132608.

Yu, Y., Radulescu, M., Ifelunini, A. I., Ogwu, S. O., Onwe, J. C., & Jahanger, A. (2022). Achieving Carbon Neutrality Pledge through Clean Energy Transition: Linking the Role of Green Innovation and Environmental Policy in E7 Countries. *Energies*, *15*(17), 6456. https://doi.org/10.3390/en15176456.

Yuan, B., & Zhang, Y. (2020). Flexible environmental policy, technological innovation, and sustainable development of China's industry: The moderating effect of environmental regulatory enforcement. *Journal of Cleaner Production*, *243*, 118543.

https://doi.org/10.1016/j.jclepro.2019.118543.

Yulianti, S., & Awingan, J. S. (2024). The relationship between assertive behavior and academic achievement of biology education students: The contribution of assertive behavior in improving academic outcomes. *Journal of Academic Biology and Biology Education*, *1*(2), 46 - 55. https://doi.org/10.37251/jouabe.v1i2.1167.

Zubair, S., Alyousfi, E. A., & Khan, S. A. (2025). New media and children's social development: A case study of digital technology use among 8–12-Year-Olds in Pakistan. *Journal of Educational Technology and Learning Creativity*, *3*(1), 107-114. https://doi.org/10.37251/jetlc.v3i1.1730.