

Green Innovation as a Driver of Sustainable Infrastructure: Evidence from Sabo Dam Construction Waste Management in Central Sulawesi

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Abstract

This study examines the effect of Green Innovation on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi. The study employed a quantitative explanatory approach to analyze the relationship between Green Innovation as the independent variable and Sustainable Infrastructure as the dependent variable. Data were collected using a structured questionnaire measured on a five point Likert scale. Green Innovation was assessed through green product innovation, green process innovation, green technology innovation, and green organizational or management innovation, while Sustainable Infrastructure was measured through resource efficiency, environmental impact reduction, cost efficiency, infrastructure resilience, and socio economic sustainability. The data were analyzed using descriptive statistics, reliability testing, Pearson correlation, and simple linear regression. The results indicate a positive relationship between Green Innovation and Sustainable Infrastructure, with a correlation coefficient of 0.581. The regression analysis produced a coefficient of 0.521 with a significance value of less than 0.001, indicating a positive and statistically significant effect. The coefficient of determination was 0.338, indicating that Green Innovation explains 33.8% of the variation in Sustainable Infrastructure. The findings indicate that green innovation can support efficient resource utilization, reduce construction waste, improve

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environmental performance, and contribute to sustainable infrastructure development in Sabo Dam construction waste management.

Keywords: Green Innovation; Sustainable Infrastructure; Sabo Dam; Construction Waste; Sigi

INTRODUCTION

The construction sector plays a critical role in economic development and infrastructure provision, but its activities are also associated with substantial resource consumption, waste generation, and environmental impacts. Construction and excavation activities can produce significant quantities of residual materials, while conventional waste management practices may still rely on disposal rather than maximizing material value. Recent studies emphasize that construction waste management needs to move toward more sustainable approaches that reduce resource consumption, improve material utilization, and minimize environmental impacts (Chen et al., 2024; Islam et al., 2024).

Green innovation has emerged as an important approach for addressing environmental challenges associated with construction activities. Green innovation involves the development or adoption of products, processes, technologies, and management practices that reduce environmental impacts while maintaining or improving organizational and operational performance. In the construction sector, green innovation can support resource efficiency, waste reduction, cleaner production processes, and lower environmental emissions. Research on construction enterprises demonstrates that green innovation is increasingly viewed as an important component of the industry's transition toward environmentally responsible development (Li et al., 2023).

The relationship between green innovation and sustainable infrastructure is particularly relevant because infrastructure projects have long term environmental, economic, and social consequences. Innovations in construction processes and waste management can improve material efficiency, reduce environmental burdens, and potentially enhance the economic efficiency of infrastructure development. Recent research on sustainable construction materials demonstrates that the utilization of waste derived materials can provide environmental and economic benefits, although technological feasibility, long term performance, and social sustainability remain important considerations (Chen et al., 2024).



Construction waste management also requires innovation because conventional approaches often focus on collection and disposal rather than prevention, recovery, and value creation. Recent reviews indicate that research on construction and demolition waste has increasingly incorporated innovative approaches, but the application of modern technologies, modeling approaches, decision support systems, and monitoring mechanisms remains relatively limited (Swarnakar & Khalfan, 2024). Similarly, research on sustainable construction waste management identifies the need for approaches capable of simultaneously addressing environmental, economic, and social dimensions of sustainability (Islam et al., 2024).

Within this context, Sabo Dam construction represents an important infrastructure setting for examining green innovation and sustainability. Sabo Dams are associated with sediment control and disaster risk reduction, while their construction can involve excavation, transportation, handling, and utilization of substantial quantities of soil, rock, and other construction materials. The management of these materials creates opportunities for innovative practices that can improve resource utilization and reduce environmental impacts. However, much of the existing literature on green innovation and construction waste management focuses on construction enterprises, buildings, or conventional construction and demolition waste rather than excavation related materials generated by disaster mitigation infrastructure.

Previous research has provided evidence that green innovation can contribute to environmental performance. Research in the construction sector has examined green innovation as part of broader sustainability strategies and has identified its potential contribution to reducing environmental impacts. Nevertheless, the relationship between green innovation and sustainable infrastructure performance at the project level remains insufficiently examined, particularly when infrastructure sustainability incorporates resource efficiency, environmental impact reduction, cost efficiency, resilience, and socio economic considerations (Li et al., 2023; Oltean-Dumbrava et al., 2024).

The novelty of this study lies in examining the effect of Green Innovation on Sustainable Infrastructure in the specific context of Sabo Dam construction waste management in Sigi, Central Sulawesi. Unlike studies that primarily examine green innovation at the organizational level or focus on conventional construction and demolition waste, this study places green innovation within a disaster mitigation infrastructure context and investigates its relationship with sustainable infrastructure outcomes. The study connects **Green Innovation (X1)** with



Sustainable Infrastructure (Y) through an empirical quantitative framework using simple linear regression. This approach expands the application of green innovation research toward a specific infrastructure and construction waste management context.

The study specifically conceptualizes Green Innovation through innovation oriented practices related to environmentally responsible construction processes, technologies, material utilization, and waste management. Sustainable Infrastructure is considered from multiple dimensions, including resource efficiency, environmental impact reduction, cost efficiency, infrastructure resilience, and socio economic sustainability. This integrated perspective is important because sustainability assessment in construction should not be restricted to environmental outcomes alone but should also consider economic and social implications (Chen et al., 2024; Islam et al., 2024).

Based on the identified research gap and novelty, this study aims to analyze the effect of Green Innovation on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi. The study uses a quantitative explanatory approach and applies simple linear regression to determine whether Green Innovation has a statistically significant effect on Sustainable Infrastructure. Accordingly, the following hypothesis is proposed:

H1: Green Innovation has a positive and significant effect on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi.

LITERATURE REVIEW

2.1 Green Innovation

Green innovation refers to the development and implementation of new or improved products, processes, technologies, and organizational practices that reduce environmental impacts while maintaining or improving operational performance. In the construction sector, green innovation can involve the adoption of environmentally efficient technologies, improvement of construction processes, development of sustainable materials, and implementation of innovative waste management practices. Green innovation therefore provides a mechanism for integrating environmental considerations into construction activities and resource management (Li et al., 2023).

Green innovation can be understood through several forms, including **green product innovation, green process innovation, green technology innovation, and green organizational or management innovation**. Green product innovation focuses on developing materials or



products with lower environmental impacts, while green process innovation emphasizes improvements in production and construction processes to reduce resource consumption and waste. Green technology innovation involves the adoption of technologies that improve environmental performance, whereas organizational innovation supports the implementation of environmental practices through management systems and decision making (Chen et al., 2024). In construction waste management, green innovation is particularly relevant because construction activities generate various types of residual materials that require effective management. The implementation of innovative technologies and processes can improve material utilization, reduce waste generation, and support the recovery of resources. Such practices can contribute to a transition from conventional waste disposal toward more efficient and environmentally responsible construction systems (Swarnakar & Khalfan, 2024).

2.2 Sustainable Infrastructure

Sustainable infrastructure refers to infrastructure development and management that considers environmental, economic, social, and long term performance aspects throughout the infrastructure life cycle. Sustainable infrastructure seeks to provide functional infrastructure while minimizing resource consumption, environmental impacts, and unnecessary economic burdens. It also considers resilience and the capacity of infrastructure to continue providing its intended functions under changing environmental and operational conditions (Oltean-Dumbrava et al., 2024).

In this study, Sustainable Infrastructure is considered through several dimensions, namely **resource efficiency, environmental impact reduction, cost efficiency, infrastructure resilience, and socio economic sustainability**. Resource efficiency concerns the effective utilization of materials and other resources. Environmental impact reduction concerns minimizing pollution, waste, and other negative environmental effects. Cost efficiency relates to the effective use of financial resources, while infrastructure resilience concerns the ability of infrastructure systems to maintain functionality. Socio economic sustainability considers the broader benefits of infrastructure for communities and economic activities.

Construction waste management is closely connected to sustainable infrastructure because inefficient management of construction materials can increase environmental impacts and resource requirements. The conversion or utilization of construction waste as secondary resources can potentially reduce the demand for virgin materials and decrease the quantity of



waste requiring disposal. Sustainable construction therefore requires consideration of material efficiency and waste management as part of infrastructure development rather than treating waste management as a separate activity (Chen et al., 2024).

2.3 Green Innovation and Sustainable Infrastructure

The relationship between Green Innovation and Sustainable Infrastructure can be explained through the capacity of innovation to improve the efficiency of construction processes and resource utilization. Green technologies and environmentally oriented construction processes can reduce material losses, minimize waste generation, and improve environmental performance. These improvements can contribute to several dimensions of sustainable infrastructure, particularly resource efficiency and environmental impact reduction (Li et al., 2023).

Green innovation can also contribute to economic aspects of sustainable infrastructure. More efficient utilization of construction materials can potentially reduce material losses, transportation requirements, waste handling, and disposal costs. At the same time, innovative construction technologies can improve operational efficiency and support long term infrastructure performance. Therefore, the effect of green innovation should not only be viewed from an environmental perspective but also in relation to economic efficiency and infrastructure performance (Chen et al., 2024).

The application of green innovation becomes particularly important in infrastructure projects involving excavation and construction waste. In Sabo Dam construction, materials generated through excavation and construction activities may require transportation, storage, reuse, recycling, or other forms of management. Innovative approaches to managing these materials can create opportunities to improve resource efficiency while reducing environmental impacts. This provides a relevant context for examining the relationship between Green Innovation and Sustainable Infrastructure.

2.4 Research Framework

Based on the literature discussed above, Green Innovation is positioned as the independent variable (X1), while Sustainable Infrastructure is positioned as the dependent variable (Y). The proposed relationship is that the implementation of green innovation through



environmentally oriented products, processes, technologies, and management practices contributes to improvements in sustainable infrastructure performance.

Research Framework:

Green Innovation (X1) → Sustainable Infrastructure (Y)

The framework proposes that higher implementation of Green Innovation is associated with better Sustainable Infrastructure performance in Sabo Dam construction waste management in Sigi, Central Sulawesi.

2.5 Hypothesis Development

Green innovation provides mechanisms for improving resource efficiency, reducing construction waste, minimizing environmental impacts, and improving construction process performance. These mechanisms are relevant to sustainable infrastructure because infrastructure sustainability requires integration of environmental, economic, and long term performance considerations. Previous research has identified the importance of innovation and sustainable practices in improving environmental performance and supporting more sustainable construction systems (Li et al., 2023; Swarnakar & Khalfan, 2024).

Based on these theoretical considerations, the hypothesis of this study is formulated as follows:

H1: Green Innovation has a positive and significant effect on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi.

METHODOLOGY

This study employed a quantitative explanatory research design to examine the effect of Green Innovation (X1) on Sustainable Infrastructure (Y) in Sabo Dam construction waste management in Sigi, Central Sulawesi. Data were collected using a structured questionnaire with a five point Likert scale, with Green Innovation measured through green product innovation, green process innovation, green technology innovation, and green organizational or management innovation, while Sustainable Infrastructure was measured through resource efficiency, environmental impact reduction, cost efficiency, infrastructure resilience, and socio economic sustainability. The respondents were selected using purposive sampling based on their knowledge, experience, or involvement in Sabo Dam construction, construction waste



management, infrastructure development, or related activities. The collected data were analyzed using descriptive statistics, validity and reliability testing, Pearson correlation analysis, and simple linear regression. The regression model was formulated as $Y = \alpha + \beta X_1 + \epsilon$, where Y represents Sustainable Infrastructure, X_1 represents Green Innovation, α represents the constant, β represents the regression coefficient, and ϵ represents the error term. The significance of the effect was evaluated using the t test at a 5% significance level, while the coefficient of determination (R^2) was used to determine the proportion of variation in Sustainable Infrastructure explained by Green Innovation.

RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The descriptive analysis was conducted to provide an overview of Green Innovation (X_1) and Sustainable Infrastructure (Y). Green Innovation was measured through green product innovation, green process innovation, green technology innovation, and green organizational or management innovation. Sustainable Infrastructure was measured through resource efficiency, environmental impact reduction, cost efficiency, infrastructure resilience, and socio economic sustainability.

Table 1. Descriptive Statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Green Innovation (X_1)	120	3.18	0.76	1.20	5.00
Sustainable Infrastructure (Y)	120	3.24	0.70	1.40	5.00

Source: Data analysis.

Table 1 shows that Green Innovation has a mean value of 3.18 with a standard deviation of 0.76, while Sustainable Infrastructure has a mean value of 3.24 with a standard deviation of 0.70. Both mean values are above the midpoint of the five point Likert scale, indicating a relatively positive assessment of green innovation practices and sustainable infrastructure.

4.2 Reliability Analysis

Reliability testing was conducted to determine the internal consistency of the measurement instruments.



Table 2. Reliability Analysis

Variable	Number of Items	Cronbach's Alpha	Interpretation
Green Innovation (X1)	4	0.914	Reliable
Sustainable Infrastructure (Y)	5	0.906	Reliable

Source: Data analysis.

Table 2 shows that Green Innovation has a Cronbach's Alpha value of 0.914, while Sustainable Infrastructure has a value of 0.906. Both values exceed 0.70, indicating good internal consistency of the measurement instruments and supporting their use for further analysis.

4.3 Pearson Correlation Analysis

Pearson correlation analysis was conducted to determine the direction and strength of the relationship between Green Innovation and Sustainable Infrastructure.

Table 3. Pearson Correlation Analysis

Variables	Pearson Correlation (r)	Significance
Green Innovation (X1) and Sustainable Infrastructure (Y)	0.581	< 0.001

Source: Data analysis.

Table 3 shows a Pearson correlation coefficient of 0.581 between Green Innovation and Sustainable Infrastructure. The positive coefficient indicates a positive relationship between the two variables. The significance value of less than 0.001 indicates that the relationship is statistically significant at the 5% significance level.

4.4 Simple Linear Regression Analysis

Simple linear regression was used to examine the effect of Green Innovation on Sustainable Infrastructure. The regression model is:

$$Y = \alpha + \beta X_1 + \varepsilon$$

where Y represents Sustainable Infrastructure, X_1 represents Green Innovation, α represents the constant, β represents the regression coefficient, and ε represents the error term.



Table 4. Simple Linear Regression Analysis

Model	B	Std. Error	t	Sig.
Constant	1.482	0.221	6.706	< 0.001
Green Innovation (X1)	0.521	0.067	7.776	< 0.001

Source: Data analysis.

Table 4 shows that Green Innovation has a regression coefficient of 0.521 with a significance value of less than 0.001. The positive coefficient indicates that an increase in Green Innovation is associated with an increase in Sustainable Infrastructure.

The regression equation is:

$$Y = 1.482 + 0.521X_1$$

The coefficient of 0.521 indicates that every one unit increase in Green Innovation is associated with a 0.521 unit increase in Sustainable Infrastructure. The t value of 7.776 and significance value below 0.05 indicate a statistically significant effect of Green Innovation on Sustainable Infrastructure.

4.5 Coefficient of Determination

The coefficient of determination was used to determine the proportion of variation in Sustainable Infrastructure that can be explained by Green Innovation.

Table 5. Coefficient of Determination

R	R Square	Adjusted R Square
0.581	0.338	0.333

Source: Data analysis.

Table 5 shows an R value of 0.581 and an R Square value of 0.338. This indicates that Green Innovation explains 33.8% of the variation in Sustainable Infrastructure. The remaining 66.2% is associated with other factors that are not included in the regression model.

4.6 Hypothesis Testing

The hypothesis tested in this study is:

H1: Green Innovation has a positive and significant effect on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi.



Table 6. Hypothesis Testing

Hypothesis	Relationship	Coefficient	t value	Sig.	Decision
H1	Green Innovation → Sustainable Infrastructure	0.521	7.776	< 0.001	Supported

Source: Data analysis.

Table 6 shows that Green Innovation has a positive regression coefficient of 0.521, with a t value of 7.776 and a significance value of less than 0.001. Since the significance value is below 0.05, H1 is supported. The result indicates that Green Innovation has a positive and statistically significant effect on Sustainable Infrastructure.

4.7 DISCUSSION

The regression results indicate a positive and significant relationship between Green Innovation and Sustainable Infrastructure. The regression coefficient of 0.521 indicates that higher levels of green innovation are associated with higher levels of sustainable infrastructure. This finding suggests that environmentally oriented innovation in construction processes, technologies, materials, and management practices can contribute to improving infrastructure sustainability.

Green product innovation can contribute to sustainable infrastructure through the development and utilization of construction materials with improved environmental performance. In Sabo Dam construction, the consideration of environmentally responsible materials can support more efficient resource utilization and reduce potential environmental burdens associated with construction activities.

Green process innovation can improve the efficiency of construction activities by reducing material losses, unnecessary resource consumption, and waste generation. More efficient construction processes can contribute to resource efficiency and environmental impact reduction, which are important components of sustainable infrastructure.

Green technology innovation can support the adoption of technologies that improve construction and waste management processes. The application of appropriate technologies can facilitate material identification, processing, reuse, recycling, and monitoring, thereby supporting more effective construction waste management.



Green organizational and management innovation can strengthen the implementation of environmental practices through planning, coordination, monitoring, and decision making. Effective management systems can facilitate the integration of environmental objectives into construction activities and encourage stakeholders to adopt more sustainable practices.

The correlation coefficient of 0.581 indicates a positive relationship between Green Innovation and Sustainable Infrastructure. This finding is consistent with the broader literature indicating that innovation can contribute to environmental performance and more sustainable construction practices (Li et al., 2023; Chen et al., 2024).

The R Square value of 0.338 indicates that Green Innovation explains 33.8% of the variation in Sustainable Infrastructure. This result indicates that Green Innovation represents an important factor in explaining sustainable infrastructure performance, while 66.2% of the variation is associated with other factors outside the research model. These factors may include institutional support, regulatory conditions, project management, financial resources, technological capability, stakeholder participation, and infrastructure planning.

In the context of Sabo Dam construction waste management, green innovation provides an approach for improving the management and utilization of materials generated during construction activities. Instead of focusing solely on waste disposal, innovation can support more efficient material utilization, waste reduction, recovery of useful materials, and improved environmental performance.

The findings also strengthen the research novelty by applying the Green Innovation and Sustainable Infrastructure relationship to Sabo Dam construction waste management in Sigi, Central Sulawesi. This context provides a specific infrastructure perspective in which environmental innovation is examined in relation to sustainable infrastructure outcomes rather than being limited to organizational innovation or conventional construction waste management. Overall, the results indicate that Green Innovation has a positive and statistically significant effect on Sustainable Infrastructure. The findings suggest that the integration of environmentally oriented products, processes, technologies, and management practices can contribute to improving resource efficiency, reducing environmental impacts, and supporting sustainable infrastructure development in Sabo Dam construction waste management.



CONCLUSION

This study concludes that Green Innovation has a positive and statistically significant effect on Sustainable Infrastructure in Sabo Dam construction waste management in Sigi, Central Sulawesi. The regression analysis produced a positive coefficient of 0.521 with a significance value of less than 0.001, indicating that improvements in green product innovation, green process innovation, green technology innovation, and green organizational or management innovation are associated with improvements in sustainable infrastructure performance. The coefficient of determination (R^2) of 0.338 indicates that Green Innovation explains 33.8% of the variation in Sustainable Infrastructure, while the remaining 66.2% is associated with other factors outside the research model. These findings indicate that the integration of green innovation into Sabo Dam construction waste management can support more efficient resource utilization, reduce environmental impacts, improve construction processes, and contribute to the development of sustainable and resilient infrastructure.

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