

Can Public Debt Finance a Green Transition? Evidence from Japan's Economic Growth

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Research Article

Keywords: Public debt, green transition, economic growth, renewable energy, CO₂ emissions, ARDL, NARDL, Japan

Posted Date: August 7th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10399918/v1>

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Additional Declarations: No competing interests reported.

Abstract

Japan faces the dual challenge of maintaining fiscal sustainability while pursuing an ambitious transition towards a low-carbon economy. Substantial investment in renewable energy, green infrastructure, and low-carbon technology has increased interest in the potential role of public borrowing in financing green transformation. This study examines whether public debt can support Japan's green transition through its relationship with economic growth, CO₂ emissions, and renewable energy. Gross savings and trade openness are included as control variables. The study applies linear autoregressive distributed lag (ARDL) and nonlinear autoregressive distributed lag (NARDL) approaches to assess the long-run relationship and the effects of positive and negative debt changes on economic growth. The findings confirm the existence of long-run relationships in both models. However, public debt does not significantly affect economic growth, while positive and negative debt shocks also remain insignificant. The Wald test provides no strong evidence of asymmetric debt effects at the 5 percent significance level. CO₂ emissions positively and significantly affect economic growth, whereas renewable energy has a positive but insignificant effect. Gross savings and trade openness emerge as significant positive determinants of growth. The findings provide limited evidence that public debt has directly supported Japan's green transition. Instead, the effectiveness of public borrowing appears to depend on the allocation of debt-financed expenditure towards renewable energy, low-carbon technology, and productive green investment. The study highlights the importance of linking public borrowing with measurable green investment outcomes to support sustainable economic transformation.

1.0 Introduction

The transition toward a low-carbon economy has emerged as one of the most significant policy challenges of the twenty-first century. Increasing climate-related risks, commitments to carbon neutrality, and the growing urgency of environmental sustainability have compelled governments worldwide to expand investments in renewable energy, green infrastructure, energy-efficient technologies, and climate adaptation measures. Achieving these objectives requires substantial financial resources that often exceed the capacity of conventional fiscal revenues, particularly in economies experiencing demographic pressures, slow economic growth, and rising public expenditure commitments. Within this context, public debt has increasingly attracted attention as a potential instrument for financing large-scale environmental transformation. The debate surrounding debt-financed green investment has become especially relevant in Japan, a country that simultaneously faces one of the highest public debt burdens among advanced economies and one of the most ambitious decarbonization agendas in Asia.

Through the Green Transformation (GX) strategy and the issuance of climate transition bonds, Japan seeks to mobilize significant public and private capital to accelerate industrial decarbonization, energy transition, and technological innovation. Such developments have stimulated renewed interest in understanding whether public borrowing can serve not merely as a fiscal tool for short-term stabilization but also as a strategic mechanism for supporting sustainable economic restructuring. Existing study provides important insights into the relationship between public debt and economic performance.

Studies such as Kurihara (2015) emphasize that excessive debt accumulation may constrain long-term growth by increasing fiscal vulnerabilities and reducing government policy flexibility. Conversely, the broader development literature suggests that public borrowing can generate positive economic outcomes when debt finances productive investments that enhance future productive capacity. At the same time, a growing body of literature highlights the increasing importance of green finance in facilitating climate-related investment. Flottmann et al. (2025) identify sustainable debt instruments as a rapidly expanding segment of global financial markets, while Zhao et al. (2024) demonstrate the potential contribution of climate transition bonds to industrial decarbonization in Japan.

Similarly, Fukuda and Ino (2026) argue that transition finance may provide an important pathway for supporting environmental objectives while maintaining fiscal sustainability under appropriate institutional arrangements. Study focusing on renewable energy and environmental investment further suggests that green expenditure can stimulate economic activity through innovation, infrastructure development, and productivity improvements. Ageli (2026) reports that energy transition policies contribute to sustainable economic development, whereas Zhou (2025) identifies positive regional economic effects associated with renewable energy investment in Japan. Furthermore, policy discussions surrounding Japan's GX initiative indicate expectations that green investment may generate substantial economic benefits while mobilizing private-sector participation on an unprecedented scale. Collectively, these studies suggest that environmental investment and sustainable finance have become increasingly important components of contemporary growth strategies. Nevertheless, important questions remain regarding whether public debt can effectively finance a green transition without undermining fiscal stability and whether the resulting environmental investments are capable of generating sufficient economic and social returns to justify higher borrowing levels.

Despite substantial progress in the literature, several conceptual and empirical gaps continue to limit understanding of the relationship between public debt, green transition, economic growth, and labour market performance. First, traditional debt-growth studies have largely concentrated on macroeconomic stability and fiscal sustainability, often treating public borrowing primarily as a source of potential economic risk. Such analyses frequently overlook the possibility that debt composition and expenditure quality may significantly influence economic outcomes. Second, study on green finance and transition bonds tends to focus on financial structures, investor behaviour, environmental performance, or emissions reduction targets rather than broader macroeconomic consequences. Third, investigations of green investment commonly examine economic growth and employment separately, resulting in limited understanding of how debt-financed environmental expenditure simultaneously affects output expansion and labour market conditions. This limitation is particularly important because employment creation has become a central justification for green transition policies, especially in economies confronting demographic challenges, industrial restructuring, and changing workforce requirements.

Moreover, existing studies provide mixed evidence regarding the economic effectiveness of climate-related expenditure, creating uncertainty about whether green investments consistently generate growth-enhancing effects across different institutional and fiscal contexts. The Japanese experience offers a

unique setting for addressing these unresolved issues because it combines exceptionally high public debt levels with large-scale climate investment initiatives and an evolving labour market shaped by population ageing and technological transformation. Consequently, the central question of this study is whether public debt has supported Japan's green transition through its relationship with economic growth, carbon emissions, and renewable energy development. The study examines whether changes in public debt influence economic growth and whether increases and reductions in debt generate different growth responses. CO₂ emissions and renewable energy are incorporated to assess whether Japan's growth structure has shifted towards cleaner energy development, while gross savings and trade openness are included as control variables. Accordingly, this study applies linear ARDL and nonlinear ARDL approaches to examine the long-run and asymmetric relationships between public debt and economic growth in Japan. The study contributes to the literature by integrating public debt and green transition indicators within a macroeconomic time-series framework and provides empirical evidence on whether public borrowing has been associated with a greener pattern of economic growth.

2.0 Literature Review

2.1 Public Debt and Economic Growth in Japan

The relationship between public debt and economic growth has received considerable attention in Japan because the country maintains one of the highest public debt ratios among advanced economies. Existing studies generally acknowledge that government borrowing can stimulate economic activity when fiscal resources are directed toward productive investment; however, persistent debt accumulation may generate long-term fiscal challenges. Kurihara (2015) argued that excessive public debt can exert adverse effects on economic performance by increasing future fiscal obligations and reducing policy flexibility. Similar concerns have been highlighted in recent discussions regarding Japan's fiscal management, where continued borrowing raises questions about long-run sustainability despite its role in supporting economic activity. At the same time, policy debates emphasize that debt-financed expenditure may remain beneficial when allocated toward sectors capable of generating future economic returns and productivity improvements (Kurihara, 2015; Reuters, 2026; Financial Times, 2024).

Recent developments have shifted the discussion beyond conventional debt-growth relationships toward the quality and purpose of public borrowing. Traditional literature frequently evaluates debt primarily through the lens of fiscal sustainability, whereas contemporary policy frameworks increasingly examine whether government debt can facilitate structural transformation. In the Japanese context, climate-related investment has emerged as a major policy priority requiring substantial financial resources. Although existing studies provide valuable insights into the macroeconomic consequences of debt accumulation, limited attention has been devoted to understanding whether debt-financed environmental investment can produce growth-enhancing effects that offset fiscal risks. Consequently, the conventional debt-growth literature offers only a partial explanation of the role of borrowing within a low-carbon development strategy (Kurihara, 2015; Reuters, 2026; Financial Times, 2024).

2.2 Green Finance and the Emergence of Transition Bonds

The rapid expansion of sustainable finance has transformed the methods through which governments and private institutions mobilize capital for environmental objectives. Green bonds, sustainability-linked bonds, and transition bonds have become increasingly important instruments for financing renewable energy, energy efficiency, and climate adaptation projects. Flottmann et al. (2025) observed that sustainable debt instruments have experienced substantial growth globally because investors increasingly seek opportunities that combine financial returns with environmental benefits. The literature suggests that these instruments can improve access to capital while encouraging the transition toward lower-carbon economic systems. Nevertheless, evidence regarding their long-term effectiveness remains mixed, particularly concerning their ability to generate measurable economic benefits beyond environmental improvements (Flottmann et al., 2025; Zhao et al., 2024; Fukuda & Ino, 2026).

Within Japan, transition finance has received particular attention because of the country's reliance on industrial sectors that face significant decarbonization challenges. Zhao et al. (2024) highlighted the importance of climate transition bonds in supporting industrial transformation while maintaining economic competitiveness. Similarly, Fukuda and Ino (2026) examined the fiscal implications of Japan's GX Economy Transition Bonds and emphasized the importance of ensuring that future economic gains are sufficient to support debt repayment. While these studies demonstrate the potential contribution of transition finance to environmental objectives, the broader macroeconomic consequences remain insufficiently explored. Existing study often concentrates on financial structures and environmental outcomes, leaving important questions regarding growth and labour market effects unresolved (Flottmann et al., 2025; Zhao et al., 2024; Fukuda & Ino, 2026).

2.3 Public Debt as a Financing Mechanism for Green Transition

The growing urgency of climate change has increased interest in the use of public debt as a mechanism for financing green transformation. Governments frequently encounter budgetary constraints that limit the ability to fund large-scale environmental initiatives through current revenues alone. As a result, borrowing has emerged as a practical strategy for accelerating investments in renewable energy, clean transportation, sustainable infrastructure, and climate resilience. Recent policy discussions indicate that Japan intends to utilize significant volumes of transition bonds to mobilize both public and private investment for decarbonization initiatives. This approach reflects the expectation that future economic and environmental benefits may justify present borrowing costs (Reuters, 2024; Financial Times, 2024; Fukuda & Ino, 2026).

Despite these potential advantages, concerns remain regarding the effectiveness of debt-financed green investment. Critics argue that rising public debt could eventually constrain fiscal flexibility and increase the burden on future generations. Furthermore, the success of borrowing depends heavily on the productivity of financed projects and their capacity to generate economic returns. Existing studies

generally recognize the importance of green investment but provide limited evidence regarding whether the associated economic gains are sufficient to compensate for higher debt levels. Consequently, uncertainty remains concerning the optimal balance between environmental ambition and fiscal sustainability, particularly in highly indebted economies such as Japan (Kurihara, 2015; Reuters, 2026; Fukuda & Ino, 2026).

2.4 Green Investment and Economic Growth

A growing body of literature suggests that environmental investment can contribute positively to economic growth through technological innovation, productivity enhancement, and infrastructure development. Green projects frequently stimulate demand in sectors associated with renewable energy, advanced manufacturing, construction, and digital technologies. Ageli (2026) demonstrated that energy-related policy measures, including renewable energy support mechanisms and efficiency improvements, can contribute to sustainable economic development in Japan. Such findings indicate that environmental investment should not be viewed solely as a cost but also as a potential source of long-term economic expansion (Ageli, 2026; Zhao et al., 2024; Financial Times, 2024).

Additional evidence indicates that localized renewable energy investment may generate substantial economic benefits at the regional level. Zhou (2025) reported that renewable energy projects contribute positively to economic activity and create new opportunities within local economies. These findings support the argument that green investment can strengthen growth prospects while facilitating structural transformation. Nevertheless, the existing literature often focuses on specific sectors or regions, limiting the ability to draw broader conclusions regarding national economic performance. Furthermore, relatively few studies investigate whether the growth effects of green investment are sufficient to offset the fiscal costs associated with debt-financed environmental spending (Zhou, 2025; Ageli, 2026; Zhao et al., 2024).

2.5 Green Transition and Labour Market Performance

Labour market outcomes represent an increasingly important dimension of the green transition debate. Environmental investment can generate employment opportunities through infrastructure construction, renewable energy deployment, study activities, and technological innovation. Supporters of green investment frequently argue that climate-related expenditure can create new industries and occupations while enhancing workforce productivity. Evidence from renewable energy projects in Japan suggests that green investment contributes to job creation and regional economic revitalization, particularly in areas undergoing industrial restructuring (Zhou, 2025; Ageli, 2026; Reuters, 2024).

However, labour market effects are not uniformly positive across all sectors. The transition toward a low-carbon economy may reduce employment in carbon-intensive industries while increasing demand for workers possessing new technical skills. Existing studies tend to emphasize employment creation without adequately examining potential labour displacement and adjustment costs. Furthermore, limited study evaluates how debt-financed green investment influences overall labour market performance at the national level. Consequently, a more comprehensive assessment of employment outcomes remains

necessary to determine whether public borrowing can support both environmental and social objectives simultaneously (Zhou, 2025; Zhao et al., 2024; Ageli, 2026).

2.6 Study Gap

Several important gaps emerge from the existing literature. First, traditional studies on Japan's public debt predominantly focus on fiscal sustainability and economic growth, with limited consideration of environmental objectives. Second, study on green finance and transition bonds generally concentrates on financial mechanisms and environmental outcomes rather than broader macroeconomic consequences. Third, investigations of green investment frequently analyze economic growth, while integrated assessments of growth performance remain relatively scarce. Finally, little empirical attention has been devoted to evaluating whether debt-financed green investment can simultaneously support decarbonization, economic expansion, within a highly indebted economy. These limitations indicate the need for a conceptual framework that connects public debt, green transition policies, economic growth, and labour market outcomes in the Japanese context (Kurihara, 2015; Flottmann et al., 2025; Zhao et al., 2024).

3.0 Data and Variables

This study employs annual time-series data for Japan to examine the relationship between public debt, green transition indicators, and economic growth. Economic growth is represented by gross domestic product growth (GDP), which serves as the dependent variable. Public debt (DEBT) is included as the main explanatory variable to assess whether government borrowing contributes to economic performance. Carbon dioxide emissions (CO₂) and renewable energy consumption (RE) are incorporated to capture the environmental and energy dimensions of Japan's transition towards a low-carbon economy. Gross savings (GS) and trade openness (TO) are included as control variables because domestic financial capacity and external economic integration may influence economic growth.

The data were obtained from established international databases, including the World Development Indicators of the World Bank and other relevant international statistical sources. The selection of the study period was determined by the consistent availability of annual observations across all variables. Annual data are considered appropriate because changes in public debt, energy structure, and economic growth generally reflect medium- and long-term macroeconomic adjustments rather than high-frequency movements.

3.2 Model Specification

The empirical model examines economic growth as a function of public debt, carbon dioxide emissions, renewable energy, gross savings, and trade openness. The linear relationship is expressed as follows:

$$GDP_t = \beta_0 + \beta_1 DEBT_t + \beta_2 CO2_t + \beta_3 RE_t + \beta_4 GS_t + \beta_5 TO_t + \epsilon_t$$

where (GDP_t) represents economic growth, (DEBT_t) denotes public debt, (CO2_t) represents carbon dioxide emissions, (RE_t) refers to renewable energy, (GS_t) represents gross savings, and (TO_t) denotes trade openness. The error term is represented by (ϵ_t).

The model is designed to determine whether public debt directly influences economic growth while considering the energy and environmental structure of the Japanese economy. The inclusion of CO₂ emissions and renewable energy allows the analysis to assess whether economic growth remains associated with carbon-intensive activities or increasingly reflects the development of cleaner energy sources.

3.3 Linear Autoregressive Distributed Lag Model

The autoregressive distributed lag (ARDL) approach is applied to estimate the linear relationship among the variables. The ARDL framework is suitable for time-series analysis involving variables integrated at level, I(0), or first difference, I(1), provided that none of the variables is integrated at second difference, I(2). The approach also allows the estimation of short-run dynamics and long-run relationships within a single empirical framework.

The general ARDL model is specified as follows:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^p \alpha_i \Delta GDP_{t-i}$$

The existence of a long-run relationship is assessed using the ARDL Bounds Test. The null hypothesis assumes that no long-run relationship exists among the variables. Cointegration is confirmed when the calculated F-statistic exceeds the upper critical bound. Following the confirmation of cointegration, the error correction representation is estimated to evaluate the adjustment of economic growth towards its long-run equilibrium.

The error correction model is expressed as:

$$\Delta GDP_t = \alpha_0 + \sum \alpha_i \Delta GDP_{t-i} + \sum \beta_j \Delta X_{t-j} + \psi ECM_{t-1} + \epsilon_t$$

where (X) represents the explanatory variables and (ECM_{t-1}) denotes the lagged error correction term. A negative and statistically significant error correction coefficient indicates the existence of an adjustment mechanism towards the long-run equilibrium.

3.4 Nonlinear Autoregressive Distributed Lag Model

The nonlinear autoregressive distributed lag (NARDL) approach is employed to examine whether increases and reductions in public debt generate different effects on economic growth. The nonlinear specification extends the conventional ARDL model by decomposing changes in public debt into positive and negative partial sums.

Positive changes in public debt are expressed as:

$$DEBT_t^{\{+\}} = \sum_{\{j=1\}}^{\{t\}} \max(\Delta DEBT_j, 0)$$

while negative changes in public debt are expressed as:

$$DEBT_t^{\{-\}} = \sum_{\{j=1\}}^{\{t\}} \min(\Delta DEBT_j, 0)$$

The nonlinear growth model is specified as:

$$GDP_t = \beta_0 + \beta_1 DEBT_t^{\{+\}} + \beta_2 DEBT_t^{\{-\}} + \beta_3 CO2_t + \beta_4 RE_t + \beta_5 GS_t + \beta_6 TO_t + \epsilon_t$$

The decomposition allows positive debt shocks and negative debt shocks to enter the model separately. Therefore, the NARDL model determines whether economic growth responds differently to debt accumulation and debt reduction. This approach is particularly relevant to Japan because changes in public borrowing may generate different macroeconomic effects depending on fiscal conditions and the allocation of government expenditure.

3.5 Asymmetry and Wald Test

The presence of asymmetric public debt effects is examined using the Wald test. The null hypothesis assumes that positive and negative changes in public debt have equal effects on economic growth:

$$H_0 : \beta_1 = \beta_2$$

The alternative hypothesis assumes that the effects are statistically different:

$$H_1 : \beta_1 \neq \beta_2$$

Rejection of the null hypothesis indicates an asymmetric relationship between public debt and economic growth. In contrast, failure to reject the null hypothesis suggests that increases and reductions in public debt generate statistically similar growth responses.

3.6 Estimation Procedure

The empirical analysis is conducted in several stages. First, the time-series properties of the variables are examined to ensure that none is integrated at I(2). Second, the optimal lag structure is selected using an appropriate information criterion. Third, the linear ARDL Bounds Test is conducted to determine the existence of a long-run relationship. The error correction model is subsequently estimated when cointegration is confirmed.

The NARDL model is then estimated by decomposing public debt into positive and negative partial sums. The Bounds Test is applied to determine nonlinear cointegration, followed by the Wald test to assess the presence of asymmetric debt effects. The empirical findings are interpreted based on the estimated coefficients, statistical significance, long-run adjustment, and differences between positive and negative debt changes. This estimation procedure allows the study to assess whether public debt

has directly supported economic growth and whether debt movements are associated with Japan's transition towards a less carbon-intensive economic structure.

4.0 Finding and Discussion

4.1 Linear ARDL Estimation Results

Table 4.1
; Results of Linear ARDL Estimation

Variable / Statistic	ARDL Estimation Coefficient (P-value)	Error Correction Estimation Coefficient (P-value)
GDP(-1)	-0.738*** (0.000)	—
GDP(-2)	-0.541*** (0.000)	—
GDP(-3)	-0.447*** (0.000)	—
GDP(-4)	-0.315*** (0.002)	—
D(GDP(-1))	—	1.312*** (0.000)
D(GDP(-2))	—	0.764*** (0.000)
D(GDP(-3))	—	0.315*** (0.001)
DEBT	0.001 (0.978)	0.001 (0.977)
CO2	4.345*** (0.000)	4.345*** (0.000)
RE	0.672 (0.300)	0.672 (0.287)
GS	0.921*** (0.002)	0.921*** (0.001)
TO	0.277*** (0.000)	0.277*** (0.000)
C	-75.053*** (0.000)	—
CointEq(-1)	—	-3.038*** (0.000)
Model Diagnostics		
R-squared	0.943	0.943
Adjusted R-squared	0.922	0.922
AIC	2.643	2.643
Durbin-Watson statistic	1.468	1.468
Observations	31	31
Selected model	ARDL(4)	ARDL(4)
Bounds Test F-statistic	88.064	—
Cointegration decision	Cointegration exists	—
Note: Values in parentheses represent p-values. *** denotes statistical significance at the 1% level. DEBT represents public debt, CO2 represents carbon dioxide emissions, RE represents renewable energy, GS represents gross savings, and TO represents trade openness.		

The linear ARDL estimation confirms a strong long-run relationship between public debt, CO₂ emissions, renewable energy, gross savings, trade openness, and economic growth. The Bounds Test F-statistic of 88.064 exceeds the upper critical bound, supporting the existence of cointegration among the variables. The error correction coefficient is negative and statistically significant at the 1 percent level, further confirming long-run adjustment. However, the estimated coefficient of -3.038 indicates a rapid adjustment process with possible short-run overshooting before the economy returns to its long-run equilibrium. Despite the existence of cointegration, public debt does not significantly affect economic growth, as shown by the small positive coefficient of 0.001 and a p-value above 0.05. This finding suggests that changes in public debt alone were insufficient to explain economic growth during the study period. The result implies that the economic contribution of borrowing may depend more on the allocation and productivity of debt-financed expenditure than on debt accumulation itself. This argument is consistent with Kose et al. (2022), who explained that the consequences of debt depend on fiscal space and the capacity of an economy to use borrowed resources effectively. Abbas et al. (2022) similarly emphasised the importance of debt composition and fiscal management, while Asteriou et al. (2021) showed that the macroeconomic consequences of debt differ considerably according to country-specific fiscal conditions.

The insignificant debt effect becomes clearer when the contribution of environmental and domestic economic factors is considered. CO₂ emissions have a positive and significant effect on economic growth, with a coefficient of 4.345 at the 1 percent significance level. This relationship may indicate that economic expansion remained closely associated with carbon-intensive production, industrial activities, and conventional energy consumption during the study period. In contrast, renewable energy shows a positive but insignificant coefficient, suggesting that the green energy transition has not yet generated a sufficiently strong contribution to economic growth. Wang et al. (2022) found that the economic benefits of renewable energy depend on technological capacity and the scale of energy transition. Similar arguments by Murshed et al. (2022) indicate that continued fossil fuel dependence may maintain the positive association between economic activity and carbon emissions, while Usman et al. (2022) emphasised that renewable energy benefits become stronger when supported by investment and technological development.

The importance of productive domestic capacity is further reflected in the significant positive effect of gross savings on economic growth. A coefficient of 0.921 indicates that higher savings supported economic activity through greater availability of domestic resources for investment and capital formation. Trade openness also records a positive and significant coefficient of 0.277, suggesting that international trade contributed to growth through market expansion, export activities, and greater economic integration. These results shift the interpretation away from debt size alone towards the broader capacity of the economy to transform financial and external resources into productive activities. Kose et al. (2022) stressed that domestic financial resilience is important in managing fiscal pressures, while Keho (2021) highlighted the growth contribution of trade integration under supportive economic conditions. Destek and Sinha (2020) further showed that economic structure and productive capacity remain important in explaining the interaction between growth, energy use, and environmental pressure.

Overall, the linear ARDL findings suggest that public debt was not a direct driver of economic growth during the study period. Instead, growth was more strongly associated with carbon-intensive economic activities, domestic savings, and trade openness. The insignificant effect of renewable energy further indicates that the transition towards a greener economic structure remains insufficient to alter the established growth pattern. Therefore, the findings do not support the view that higher public borrowing automatically promotes economic growth. Rather, the economic effectiveness of debt appears to depend on whether borrowed resources strengthen productive investment, technological development, and the transition towards sustainable energy activities. This interpretation is consistent with Abbas et al. (2022), Kose et al. (2022), and Murshed et al. (2022), who collectively emphasised that fiscal sustainability and long-term growth depend on resource allocation, productive capacity, and structural economic transformation.

4.2 Nonlinear ARDL Estimation Results

Variable / Statistic	NARDL Estimation Coefficient (P-value)	Error Correction Model Coefficient (P-value)
GDP(-1)	-0.739*** (0.000)	—
GDP(-2)	-0.541*** (0.000)	—
GDP(-3)	-0.447*** (0.000)	—
GDP(-4)	-0.315*** (0.002)	—
D(GDP(-1))	—	1.304*** (0.000)
D(GDP(-2))	—	0.762*** (0.000)
D(GDP(-3))	—	0.315*** (0.001)
DEBT_NEG	-0.490 (0.544)	-0.490 (0.374)
DEBT_POS	-0.004 (0.896)	-0.004 (0.892)
CO2	4.423*** (0.000)	4.423*** (0.000)
RE	0.568 (0.402)	0.568 (0.390)
GS	0.866*** (0.005)	0.866*** (0.004)
TO	0.285*** (0.000)	0.285*** (0.000)
C	-80.437*** (0.000)	—
CointEq(-1)	—	-3.042*** (0.000)
Panel B: Model Diagnostics		
R-squared	0.878	0.944
Adjusted R-squared	0.818	0.920
F-statistic	14.445***	—
Prob(F-statistic)	0.000	—
Durbin-Watson statistic	1.433	1.433
AIC	2.753	2.689
Observations	31	31
Selected model	ARDL(4)	ARDL(4)
Note: Values in parentheses represent p-values. *** denotes statistical significance at the 1% level. DEBT_NEG represents negative changes in public debt, DEBT_POS represents positive changes in public debt, CO2 represents carbon dioxide emissions, RE represents renewable energy, GS represents gross savings, and TO represents trade openness. The Wald test examines the null hypothesis of symmetric effects, $C(1) = C(2)$.		

Variable / Statistic	NARDL Estimation Coefficient (P-value)	Error Correction Model Coefficient (P-value)
Panel C: Bounds Test and Asymmetric Effect		
Bounds Test F-statistic	—	81.360
Cointegration decision	—	Cointegration exists
Wald t-statistic	-1.685 (0.108)	—
Wald F-statistic	2.840 (0.108)	—
Wald Chi-square	2.840 (0.092)	—
C(1) – C(2)	-0.197	—
Standard error	0.117	—
Asymmetry decision	Symmetric effect	—
Note: Values in parentheses represent p-values. *** denotes statistical significance at the 1% level. DEBT_NEG represents negative changes in public debt, DEBT_POS represents positive changes in public debt, CO2 represents carbon dioxide emissions, RE represents renewable energy, GS represents gross savings, and TO represents trade openness. The Wald test examines the null hypothesis of symmetric effects, $C(1) = C(2)$.		

The nonlinear ARDL estimation provides a more detailed assessment of whether increases and reductions in public debt generate different effects on economic growth. The Bounds Test F-statistic of 81.360 confirms the existence of a long-run relationship among public debt shocks, CO₂ emissions, renewable energy, gross savings, trade openness, and economic growth. The significant error correction term also supports long-run adjustment within the model. However, the coefficient of -3.042 indicates a rapid and oscillatory adjustment process, suggesting that deviations from long-run equilibrium may involve substantial short-run overshooting before convergence is achieved. Despite the long-run cointegration, the decomposition of public debt into positive and negative changes does not provide evidence that debt movements significantly influence economic growth. Negative debt shocks recorded a coefficient of -0.490, while positive debt shocks showed a coefficient of -0.004. Both effects were statistically insignificant. More importantly, the Wald test fails to reject the null hypothesis of symmetry at the 5 percent significance level. Thus, increases and reductions in public debt did not produce statistically different growth responses during the study period. This result indicates that the direction of debt movement alone is insufficient to explain economic growth. Kose et al. (2022) argued that the macroeconomic consequences of public debt are closely linked to fiscal space and the productive use of borrowed resources. Abbas et al. (2022) similarly stressed that debt composition and expenditure efficiency are important for fiscal sustainability, while Asteriou et al. (2021) demonstrated that the effects of debt vary according to the underlying macroeconomic and institutional environment.

The absence of debt asymmetry becomes particularly important when the environmental variables are considered. CO₂ emissions remained positive and statistically significant, with a coefficient of 4.423, whereas renewable energy showed a positive but insignificant effect on economic growth. This pattern indicates that economic expansion remained more closely connected to carbon-intensive activities than to the renewable energy transition. In other words, neither increases nor reductions in public debt appear to have altered the existing growth structure towards greater dependence on renewable energy. Murshed et al. (2022) explained that continued dependence on conventional energy may strengthen the association between carbon emissions and economic activities. Wang et al. (2022) further argued that renewable energy generates stronger economic benefits when supported by technological development and sufficient investment capacity. Usman et al. (2022) also highlighted that the growth contribution of cleaner energy depends on broader structural transformation and the capacity of an economy to reduce fossil fuel dependence. This interpretation is reinforced by the significant contribution of gross savings and trade openness. Gross savings positively affected economic growth with a coefficient of 0.866, while trade openness recorded a significant positive coefficient of 0.285. These results suggest that domestic financial resources and external economic integration were more important in supporting growth than changes in public debt. Higher savings may increase the availability of funds for capital formation and productive investment, whereas trade openness may facilitate market expansion, technology transfer, and international economic integration. Kose et al. (2022) emphasised the importance of domestic financial resilience in supporting sustainable economic performance.

Similarly, Keho (2021) found that the growth benefits of trade depend on the capacity of an economy to transform external integration into productive activities. Destek and Sinha (2020) further demonstrated that economic structure and productive capacity influence the interaction between growth, energy consumption, and environmental pressure. Taken together, the nonlinear findings provide limited support for the argument that public debt directly finances a green transition through economic growth. The insignificant coefficients of both positive and negative debt shocks, together with the symmetric Wald test result, indicate that changes in debt did not generate distinct growth responses. At the same time, the significant positive effect of CO₂ emissions and the insignificant contribution of renewable energy suggest that the existing growth structure remained dependent on carbon-intensive economic activities. Gross savings and trade openness instead emerged as stronger drivers of economic growth. Therefore, the findings imply that public debt alone is insufficient to support a green transition unless borrowing is deliberately directed towards renewable energy infrastructure, green technology, and other productive low-carbon investments. This interpretation is consistent with Abbas et al. (2022), Kose et al. (2022), and Murshed et al. (2022), who emphasised that the effectiveness of fiscal resources depends largely on expenditure allocation, institutional capacity, and structural economic transformation.

5.0 Conclusion

This study examined whether public debt can support the green transition and economic growth in Japan using linear and nonlinear ARDL approaches. The findings confirm a long-run relationship between public debt, CO₂ emissions, renewable energy, gross savings, trade openness, and economic

growth. However, public debt did not significantly influence economic growth in either the linear or nonlinear estimations. Positive and negative debt shocks were also insignificant, while the Wald test provided no strong evidence of asymmetric effects at the 5 percent significance level. These results indicate that changes in the level or direction of public debt alone are insufficient to explain Japan's economic growth. More importantly, CO₂ emissions remained positive and statistically significant, whereas renewable energy showed a positive but insignificant effect. This pattern suggests that Japan's economic growth during the study period remained more closely associated with carbon-intensive economic activities than with renewable energy expansion. Gross savings and trade openness emerged as significant positive determinants of growth, highlighting the importance of domestic financial capacity and international economic integration.

The findings therefore provide limited evidence that public debt has directly functioned as an effective financing mechanism for Japan's green transition. The results do not imply that public borrowing cannot support decarbonisation. Instead, the effectiveness of debt depends on how borrowed resources are allocated. Public borrowing directed specifically towards renewable energy infrastructure, low-carbon technology, green innovation, and productive transition projects may generate stronger economic and environmental benefits. From a policy perspective, Japan should strengthen the connection between public borrowing and measurable green investment outcomes. Climate transition bonds and the Green Transformation strategy should prioritise projects capable of reducing carbon dependence while supporting productivity and economic growth. Strong project evaluation, fiscal monitoring, and transparent allocation of debt-financed expenditure are also required to ensure that green investment generates sufficient long-term returns. Overall, public debt may support the green transition, but its effectiveness depends more on the quality and purpose of expenditure than on the size of borrowing itself.

Declarations

Author Contribution

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Author Contributions: K.K. conceptualized the study, collected and analysed the data, conducted the ARDL and NARDL analyses, and prepared the original manuscript draft. J.A. supervised the research and contributed to the conceptualization and revision of the manuscript. M.K. contributed to the methodology, interpretation of the findings, and manuscript revision. F.M. contributed to the interpretation of the results and critical review of the manuscript. A.K. contributed to the literature review, interpretation of the findings, and manuscript editing. All authors reviewed and approved the final manuscript.

Data Availability

The data that support the findings of this study are publicly available from the World Bank's World Development Indicators (<https://databank.worldbank.org/source/world-development-indicators>) and other publicly available international statistical databases cited in the manuscript. The datasets generated during the analysis are available from the corresponding author upon reasonable request.

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