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Financing green futures: renewable energy investment and economic growth in Germany

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Abstract

Global efforts to mitigate greenhouse gas emissions have been driven by increasingly evident adverse impacts of climate change. Countries are adopting renewable energy sources, such as solar, wind, hydropower, geothermal, and bioenergy, which provide cleaner alternatives to fossil fuels. Investments in renewable energy facilitate the decarbonization of the energy sector, while simultaneously stimulating the economy through job creation, technological advancement, and innovation. This study examines the relationship between renewable energy financing and economic growth in Germany. Annual time series data from 1986 to 2022 and a Nonlinear Autoregressive Distributed Lag model were used. The research findings indicate a correlation between renewable energy financing and economic growth. The study indicates that a disturbance in combustible renewable energy and waste will, according to the long-term findings, exert a negative impact of 0.21 on economic growth. In general, financing renewable energy is believed to play a role in Germany's economic growth. The study recommends that policymakers enhance their funding for colleges and research institutions to develop more viable ways to enhance renewable energy production and adoption.

Keywords:
Renewable energy financing; Economic growth; Greenhouse gas emissions; Sustainability; Nonlinear ARDL.

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1. Introduction

An increasing number of individuals have recognized that transitioning from fossil fuels to renewable energy sources is essential for addressing climate change issues and ensuring long-term energy security. Alternatives to traditional energy sources that are sustainable and environmentally benign include renewable energy technologies, such as solar, wind, hydropower, and biomass. Nonetheless,

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substantial investment in their development, execution, and integration into existing energy systems is essential for their widespread acceptance. This has ignited increasing interest in the impact of renewable energy financing on economic growth.

Global efforts to mitigate greenhouse gas emissions have been driven by increasingly evident adverse impacts of climate change. The 2015 Paris Agreement, designed to limit the global temperature rise to below 2°C compared with pre-industrial levels, serves as the foundation of international climate initiatives. To achieve this objective, countries are adopting renewable energy sources such as solar, wind, hydropower, geothermal, and bioenergy, which offer cleaner alternatives to fossil fuels. Despite the recognized potential of renewable energy, significant financial barriers impede its widespread implementation. Acquiring sufficient funding is crucial for success, as renewable energy initiatives are capital-intensive and involve numerous risks and uncertainties. Appropriate financial structures can facilitate the advancement of innovative technologies, the enhancement of energy security, the generation of employment opportunities, and economic growth.

The capacity of renewable energy to transform economies, generate employment, and mitigate the adverse impacts of climate change renders the correlation between financing renewable energy and economic growth significant. Investments in renewable energy facilitate the decarbonization of the energy sector, while simultaneously stimulating the economy through job creation, technological advancement, and innovation (Ashfaq et al, 2023; Shahbaz, et al. 2020). Moreover, reducing dependence on fossil fuel imports through the use of renewable energy sources can bolster energy security by improving the trade balance and overall economic resilience.

The funding of renewable energy projects may differ, and the selected financing technique significantly influences the financial outcomes. Private sector investments in renewable energy are significantly shaped by government rules and incentives. Numerous governments provide financial support through feed-in tariffs, tax incentives, grants, and subsidies to promote the advancement of renewable energy sources. Borhanazad and German-Ramirez (2019) asserted that Germany's feed-in tariff policy, introduced in the early 2000s, markedly augmented the proliferation of renewable energy installations and fostered technological advancements within the sector. International cooperation and climate finance mechanisms have evolved into substantial financial resources for renewable energy initiatives, especially in developing countries. The Green Climate Fund (GCF), a funding mechanism of the United Nations Framework Convention on Climate Change (UNFCCC), seeks to support developing countries in their climate change adaptation and mitigation endeavors. GCF has allocated a significant portion of its resources to funding renewable energy projects, aiming to aid governments in transitioning to low-carbon economies and promoting sustainable development.

Germany is a notable example of a country adopting renewable energy sources. Germany has made incredible strides in the deployment of renewable energy, making significant investments in a variety of renewable technologies such as solar, wind, biomass, and hydropower. However, the funding of renewable energy projects and their effect on Germany's economic growth have generated a great deal of attention and discussion. Germany has built a strong structure of laws, rules, and financial incentives to promote investments in renewable energy. The Renewable Energy Sources Act (EEG), passed in 2000, which requires feed-in tariffs (FITs) and fixed purchase prices for renewable electricity, is one of the framework's main cornerstones. Renewable energy companies were able to obtain long-term financing and lower investment risks because of FITs' reliable and alluring return on investment (Martinot et al., 2012). The implementation of EEG facilitated private sector investment and accelerated the expansion of renewable energy projects nationwide.

To promote the growth of renewable energy, the German government has introduced additional supportive measures, including investment grants, tax incentives, and low-interest loans. For instance, firms and people engaging in renewable energy projects can take advantage of subsidies and low-interest loans from the Kreditanstalt für Wiederaufbau (KfW) bank, a state-owned development institution (Sovacool et al., 2019). In the field of renewable energy, these financial incentives have been crucial in luring both local and foreign investments, supporting innovation, and boosting technological diffusion. In addition to government funding, the private sector has significantly contributed to the financing of renewable energy projects in Germany. Institutional investors, including pension funds, insurance companies, and private equity organizations, have become more aware of the potential for long-term profits from renewable energy investments. These investors are drawn to the low operational risks associated with well-established technology and want consistent cash flows from renewable energy assets (Sovacool et al., 2019). Their involvement has brought a lot of money, which has made it possible for project developers to obtain the funding required for renewable energy projects.

Additionally, the variety of funding sources for renewable energy projects in Germany has increased with the advent of cutting-edge financing techniques, such as green bonds and crowdfunding platforms. Investors seeking to support sustainable efforts have taken an interest in green bonds, which are debt securities specifically intended to finance ecologically beneficial projects (Eicke, et al., 2020). Platforms for crowdsourcing investments in renewable energy projects offer an alternative way for people and groups to finance sustainable energy initiatives (Jacobs et al., 2019). This thorough introduction examines the relationship between renewable energy finance and economic growth in Germany. It offers a critical examination of the strategies used by the German government and private sector to foster renewable energy investments, assesses the economic advantages and obstacles related to renewable energy financing, and evaluates the long-term viability of Germany's renewable energy sector. This introduction provides insights into the role of renewable energy financing in promoting economic growth and its potential implications for Germany's transition to a low-carbon economy, based on a thorough examination of pertinent literature.

2. Literature review

Numerous studies have examined the connection between financing renewable energy and economic expansion from various perspectives. These studies concentrated on a variety of topics, including how investments in renewable energy affect GDP growth, job creation, income distribution, and general economic development. Researchers have also examined the role that various funding methods, such as public and private investments, subsidies, tax incentives, and international cooperation, play in promoting the deployment of renewable energy and the ensuing economic advantages.

The fundamental finding in the literature is that investment in renewable energy is positively correlated with economic growth. According to several empirical studies, nations that invest more in renewable energy typically experience faster GDP growth than those that rely mostly on fossil fuels. For instance, Panwar et al. (2011) examined the connection between GDP growth and renewable energy use over 19 years in 62 nations. The study discovered a significant positive link between these two factors, indicating that investments in renewable energy can serve as a catalyst for economic growth.

Li et al. (2021) used panel data analysis with a fixed-effects model to investigate the link between investments in renewable energy and economic growth in Belt and Road Initiative countries. Investments in renewable energy, trade openness, and human capital are treated as independent factors, and GDP growth is considered the dependent variable. This study discovered a favorable and significant correlation between renewable energy expenditure and economic expansion. The results also revealed that trade openness and human capital are important factors in promoting economic growth.

Bertsch et al. (2021) discovered that high-income customers of electric vehicles have received the majority of subsidies; likewise, the percentage of rebates given to low-income groups and underprivileged communities rose. Ouedraogo (2018) employed the autoregressive distributed lag (ARDL) bounds testing methodology to examine the long-term relationship between renewable energy consumption, economic growth, and foreign direct investment (FDI) in a panel of 23 sub-Saharan African countries. The results suggest a long-term advantageous association between renewable energy use and economic expansion. The study also showed that FDI had a favorable impact on the relationship between the use of renewable energy and economic growth, highlighting the need to lure foreign investments to support the development of renewable energy.

Baidoo, Yeboah, and Opoku (2020) analyzed the relationship between renewable energy usage, economic growth, and environmental sustainability in Ghana utilizing the autoregressive distributed lag (ARDL) bounds testing approach. In this study, CO2 emissions were utilized as a proxy for environmental sustainability. This study identified a sustained relationship between renewable energy utilization, economic growth, and environmental sustainability in Ghana. The results indicate the potential for a mutually beneficial scenario, demonstrating that the utilization of renewable energy stimulated economic growth while decreasing CO2 emissions. Moreover, it has been proven that investments in renewable energy have substantial potential to generate employment. A multitude of expert and unskilled laborers are required to build and operate renewable energy plants, thus creating employment possibilities across several sectors.

According to a 2019 study by the International Renewable Energy Agency, over 11 million individuals were employed globally in the renewable energy sector, with projections indicating growth in this figure in the forthcoming years. The advancement of employment in the renewable energy sector not only elevates job rates, but also mitigates poverty and facilitates wealth redistribution, thus promoting inclusive economic growth.

Reviewing studies conducted using a variety of approaches and geographical locations, the literature review investigates the connection between finance for renewable energy and economic expansion. Economic growth and investment in renewable energy are positively correlated. Research has demonstrated that investment in renewable energy has a positive effect on technical innovation, job creation, and GDP growth. For instance, Panwar et al. (2011) discovered a strong positive correlation between GDP growth in 62 countries and renewable energy use. Similar findings were noted by Li et al. (2021) for nations participating in the Belt and Road Initiative, highlighting the importance of human capital and trade openness in addition to investments in renewable energy. Despite the extensive literature, the following gaps have emerged: Long-term vs. short-term trade-offs, the Nonlinear Autoregressive Distributed Lag (NARDL) model captures short- and long-run asymmetries but does not quantify trade-offs.

3. Methods

Using a quantitative time-series approach, this study analyzes the dynamic and asymmetric relationships between nuclear energy, hydropower, renewable electricity, energy intensity, and economic growth from 1986 to 2023. The analysis is based on the Nonlinear Autoregressive Distributed Lag (NARDL) model, which accounts for potential asymmetric responses to positive and negative shocks and captures both the short- and long-term effects of independent variables on the dependent variable.

3.1 Econometrics models

Following the study's objective, we specified a model with nuclear energy, electricity production from hydro, electricity production from hydro, electricity from renewable energy, and energy intensity as regressors, with GDPPC as the dependent variable.

$$GDPPC_t = f(lnCREW_t, LnRPH_t, lnERE_t, LnEINT_t) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

This study employs three phases of the econometric technique. First, the stationarity of the variables is evaluated utilizing the traditional Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests, alongside the nonlinear Fourier-based unit root test proposed by Guris (2018). The latter assesses the nonlinear stationarity of the variables, whereas the former examines the integration sequence to ensure that none of the variables are i(2). Second, we employed the NARDL methodology to examine the asymmetric long- and short-term impacts of the regressors on GDP per capita. Finally, we evaluate the model using various essential diagnostics.

3.2 Nonlinear autoregressive distributed lag (NARDL) model

Asymmetric cointegration is a deconstructed explanatory variable that can be modeled within the context of cointegration, because recent research has demonstrated that macroeconomic variables display nonlinear properties. This is used to determine whether the dependent variables are affected by the independent variables' positive and negative shocks in the same way. The two-stage Engle-Granger technique of asymmetric cointegration was primarily used, according to Shin et al. (2014). The two-step Engle-Granger method of asymmetric cointegration has a number of flaws, including the fact that it only models the short run and is less effective than Shin et al.'s (2014) one-step ECM estimation, which models both short- and long-run asymmetries under the name NARDL.

The need to employ ARDL in time series analysis is applicable to NARDL, as it is an extension of the framework established by Shin et al. (2001). The primary concern is that the two variables should not be stationary. Consequently, we employed the standard unit root tests established by Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS), following the methodology of Shin et al. (2014). Expressing (eq. 1), in the following manner:

$$\begin{aligned}
\Delta lGDPPC_t = {} & \beta_0 + \sum_{i=0}^{m} \beta_1 \Delta lGDPPC_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta lCREW_{t-i}^{+} \\
& + \sum_{i=0}^{m} \beta_3 \Delta lCREW_{t-i}^{-} + \sum_{i=0}^{m} \beta_4 \Delta lRPH_{t-i}^{+} + \sum_{i=0}^{m} \beta_5 \Delta lRPH_{t-i}^{-} \\
& + \sum_{i=0}^{m} \beta_6 \Delta lERE_{t-i}^{+} + \sum_{i=0}^{m} \beta_7 \Delta lERE_{t-i}^{-} + \sum_{i=0}^{m} \beta_8 \Delta lEINT_{t-i}^{+} \\
& + \sum_{i=0}^{m} \beta_9 \Delta lEINT_{t-i}^{-} + \gamma_1 gdppc_{t-1} + \gamma_2 lcrew_{t-1}^{+} \\
& + \gamma_3 \Delta lcrew_{t-1}^{-} + \gamma_4 lrph_{t-1}^{+} + \gamma_5 lrph_{t-1}^{-} + \gamma_6 lere_{t-1}^{+} + \gamma_7 lere_{t-1}^{-} \\
& + \gamma_8 leint_{t-1}^{+} + \gamma_9 leint_{t-1}^{-} + \psi_t DU_t \\
& + \epsilon_t \qquad (2)
\end{aligned}$$

where Δ is the difference operator indicating the first difference of variable, i is the lagged value, β_1 *to* β_9 and γ_1 *to* γ_9 are the short-run and long-run coefficients, respectively, ψ_t is the coefficient of the break date dummy $\in_t$ is the disturbance term.

The above-stated error correction equation for NARDL can be written as;

$$\begin{aligned} \Delta lGDPPC_t = \beta_0 &+ \sum_{i=0}^{m} \beta_1 \Delta lGDPPC_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta lCREW_{t-i}^{+} \\ &+ \sum_{i=0}^{m} \beta_3 \Delta lCREW_{t-i}^{-} + \sum_{i=0}^{m} \beta_4 \Delta lRPH_{t-i}^{+} + \sum_{i=0}^{m} \beta_5 \Delta lRPH_{t-i}^{-} \\ &+ \sum_{i=0}^{m} \beta_6 \Delta lERE_{t-i}^{+} + \sum_{i=0}^{m} \beta_7 \Delta lERE_{t-i}^{-} + \sum_{i=0}^{m} \beta_8 \Delta lEINT_{t-i}^{+} \\ &+ \sum_{i=0}^{m} \beta_9 \Delta lEINT_{t-i}^{-} + \vartheta_t ect_{t-1} + \in_t \qquad (3) \end{aligned}$$

3.3 Dataset and sources

The statistics are an annual series covering the years 1986 to 2022. Data accessibility explains a substantial portion of timeframe decisions. All variables were converted into natural logarithms before estimation. Table 1 explains the variables used in the study, definitions, and sources of data.

4. Results and discussion

The robust statistical, econometric, and forecasting program EViews 12 (Econometric Views) was utilized for the time series data analysis. The nonlinear ARDL model's findings show that different energy sources and energy intensities have asymmetric short- and long-term effects on economic growth during the 1986–2023 study period. The results emphasize the significance of accounting for nonlinear dynamics in energy-economic connections by showing that changes in energy variables, both positive and negative, do not have a symmetrical effect on economic growth.

4.1 Descriptive statistics and correlation matrix

The 36 observations from the annual time-series data used for the study are summarized in Table 2, along with pairwise correlations between the variables. The findings demonstrate a substantial and favorable connection between the four independent variables of LCREW, LRPH, LERE, and LEINT and the dependent variable LGDPPC. All pairwise correlation results fall between 0.65 and 0.95.

Table 1: Variables and measurements

	Abbreviation	Definition	Measurement	Expected Impact
Dependent variable:				
Economic Growth	LGDPPC (Log of GDP per capita)	The total economic output (GDP) divided by the population, adjusted for inflation.	Natural logarithm of real GDP per capita (constant USD)	N/A
Independent variables:				
Combustible renewable energy & waste	LCREW	Energy derived from renewable organic sources (biomass, biofuels, waste incineration).	Natural logarithm of combustible renewables and waste energy consumption (in ktoe)	Mixed (Positive in short-run, Negative in long-run) – Short-term job creation vs. long-term inefficiency concerns.
Hydropower production	LRPH	Electricity generated from hydroelectric sources.	Natural logarithm of hydropower production (in GWh)	Negative shock effect – declines in hydropower may harm energy supply and economic output.
Renewable electricity production	LERE	Total electricity generated from renewable sources (Solar, wind, geothermal, etc.)	Natural logarithm of renewable electricity output (in GWh)	Asymmetric – positive shocks may not significantly boost growth, but negative shocks reduce it.
Energy intensity	LEINT	Energy consumption per unit of GDP (Efficiency measure).	Natural logarithm of energy use (kg of oil equivalent) per USD 1,000 GDP	Positive – Higher energy intensity may indicate industrial expansion, but could also signal inefficiency.

Notes: All data are sourced from the World Development Indicators 2022, except energy intensity data sourced from the International Energy Agency (2022).

Table 2: Descriptive statistics and pair-wise correlations

	LGDPC	LCREW	LRPH	LERE	LEINT
Mean	11.3508	2.1554	6.2136	2.6680	10.3882
Std. Dev.	0.2371	0.3523	3.1508	0.3321	0.52524
Min.	10.6558	1.5989	1.6094	2.1358	9.6934
Max.	11.8101	2.9757	10.5607	3.2146	11.1857
JB	0.9393	1.7447	3.9087	3.8964	4.1977
Probability	0.6252	0.4179	0.1416	0.1425	0.1225
Observations	36	36	36	36	36
LGDPPC	1.0000				
LCREW	0.6509	1.0000			
LRPH	0.8427	0.8403	1.0000		
LERE	0.7186	0.7186	0.7872	1.0000	
LEINT	0.8496	0.8289	0.9581	0.8884	1.0000

4.2 Unit root test

The unit root was calculated using the conventional ADF, PP, and KPSS methods. The findings show that all variables are i(1), except for a few unusual cases identified by the KPSS, which demonstrate the level stationarity of LGDPPC and LRPH. However, there was no one (2) (see Table 3). The variables support the use of NARDL, and the mixed degrees of integration support the use of the NARDL estimation technique.

Table 3: Stationarity test results

	ADF		PP		KPSS	
Variables	level	1st diff.	level	1st diff.	level	1st diff.
LGDPPC	-1.6157	-9.7153**	-1.1779	-15.276**	0.7301*	
LCREW	-0.4666	-5.8386**	0.2281	-6.9630**	0.7365	0.3368**
LRPH	-1.7343	-5.8011**	-1.5853	-9.9767**	0.6649	0.5000*
LERE	-0.4914	-4.7595**	-0.5002	-4.7797**	0.7555	0.1422**
LEINT	-0.9609	-5.7717**	-0.8372	-6.1641**	0.6424*	

Notes: *critical values of 10%; ** critical values of 5%

Table 4 presents results from the Flexible Fourier Form Nonlinear Unit Root Test developed by Güriş (2018), which is used to assess the stationarity of variables under possible nonlinear trends and smooth structural breaks. According to Güriş (2018), traditional unit root tests are likely to be nonstationary when applied to nonlinear variables, rendering the assessment of integration order in nonlinear models inadequate. To address this issue, Güriş (2018) proposed an innovative flexible Fourier form nonlinear unit root test that ascertains the nonlinear stationarity of the variables. This test employs an exponential smooth threshold autoregressive (ESTAR) model to represent the nonlinear adjustment.

Table 4. Nonlinear Unit Root Test

Variables		Test statistics	Decision	Critical values K=1	
LGDPPC	3	16.22887**	Stationary	1%	20.32
LCREW	3	18.97637**	Stationary	5%	14.72
LRPH	3	7.293370	Nonlinear unit root	10%	12.32
LERE	3	12.88887*	Stationary		
LEINT	3	18.65670**	Stationary		

The test determines whether shocks to the variables are temporary or permanent in a nonlinear context. LGDPPC, LCREW, LERE, and LEINT were found to be stationary in a nonlinear framework, indicating that they reverted to a mean or trend over time. Hydropower production (LRPH) is nonstationary, suggesting that its shocks may have permanent effects without reverting. The test supports the use of the NLARDL model, given the absence of i(2) variables and the presence of mixed integration orders i(1) and i(0). This test is an advanced unit root test designed to determine the stationarity of variables under the assumption that the data may have nonlinear characteristics such as smooth breaks, cyclical trends, or structural changes that traditional unit root tests (such as ADF, PP, and KPSS) may fail to detect.

4.3 Short and long-run NARDL results

The results of the estimation of equation (2) are shown in Table 5. A 1% increase in LCRW from the previous year will result in an economic growth of 0.40% in the current period of the short run, although the positive shock of LCREW in the current time is positive but statistically insignificant. In other words, trash and combustible renewable energy may now have a beneficial impact on the rate of economic growth, but this effect has not become noticeable until now.

According to the long-term outcomes, a shock in LCREW+ will have a negative 0.21 effect on economic growth. Although not expected a priori, the outcome may suggest that more combustible renewable energy and garbage are used to fund the purchase of environmentally beneficial or renewable energy-powered goods. This result is in line with studies undertaken in the BRICS, transitional economies, and France, in that order (Tamazian et al., 2009; Tamazian & Bhaskara Rao, 2010; Shahbaz et al., 2018).

A negative shock lowers economic growth by 2.09, whereas a positive shock in the amount of hydroelectricity produced is not thought to have a favorable impact on economic growth. This is because a negative shock in hydroelectricity results in a decrease in energy volume, which directly affects productivity. Economic growth will undoubtedly be reduced by a decrease in production; this is a given. Economic growth is reduced by 0.81 and increased by 0.38 as a result of electricity generation from renewable energy sources (LERE).

Overall, the nonlinear asymmetries in our model were confirmed by the long-run Wald test of the regressors. In general, renewable energy financing is seen to be a contributing factor to the development of economic growth in Germany. This discovery is not unique because it was also published for 52 nations and the French economy by Hafeez et al. (2018) and Shahbaz et al. (2018). The reason for this may not be far from the difference in the methodologies employed. When conducting our estimation, we presumed that the positive and negative effects of the regressors on GDPPC were more asymmetric than the symmetrical connections used in the studies cited above. This claim is supported by the dynamic multiplier graphs generated as a result, which show how GDPPC reacts more to negative shocks than to positive shocks.

Finally, the post-estimation findings show that the bound test validates the cointegration of variables, indicating that there is evidence of a long-term relationship between the variables; ECM is negative, less than unity, statistically significant, and could reverse any shock that causes disequilibrium at a speed of 86%. The adjusted R^2 of 0.73 also supports model fitness. The probability values of 0.1280 and 0.1128 for the heteroscedasticity test and Breusch-Godfrey serial correlation (LM Test) demonstrate that the errors in the model's residuals are homoscedastic and that the model is also devoid of serial correlation. The results of the CUSUM and CUSUM square tests show that the model parameters are stable.

Table 6 presents the long-run nonlinear ARDL (NARDL) estimation results, analyzing the impact of renewable energy and other variables on economic growth (LGDPPC) in Germany, focusing specifically on the aggregated effects of positive and negative changes in renewable energy indicators. The results for ERE^+ (positive shock in electricity from renewable energy, coefficient = -0.0339, p = 0.3939) reveal that a positive increase in electricity from renewable energy does not significantly affect economic growth in the long run. This suggests that improvements or expansion in renewable energy capacity may take time to impact productivity or may be offset by transition costs.

Table 5. Short and long-run NARDL results

Dependent variable: $LC0_2$

Variable	Coefficient	S.E.	*t*-statistics	*p*-values
Short-run results				
Δ LCREW+ -1	0.435727	0.33611	1.296378	0.0966***
Δ LRPH+-1	-1.247151	-2.99502	0.416408	0.0018*
Δ LERE--1	-0.629001	0.38034	-1.653791	0.0418*`*
Δ LEINT+-1	-2.245438	3.46559	-0.647924	0.0048*
Δ LCREW+	0.206396	0.17531	1.177353	0.3398)
Δ LRPH+	0.777132	4.13384	0.187993	0.0260**
Δ LERE-	-0.501581	-4.29686	0.116732	0.2439
Δ LEINT+	0.341742	0.40335	0.847255	0.7203
ECMt-1				
Adj. R2	0.762956			
Hetero. Test	0.8095			
LM Test	0.1278			
Long-run results:				
LCREW+	-0.1486	-0.03355	4.429586	0.0010*
LRPH+	-0.3177	0.07149	-4.443716	0.3055
LRPH-	2.0970	5.03593	0.416408	0.0757***
LERE+	-0.8193	0.49541	-1.653791	0.0004*
LERE-	-0.3856	0.59513	-0.647924	0.0673***
LEINT+	7.4869	6.35909	1.177353	0.1124
LENT-	9.6556	51.3615	0.187993	0.0967***
LCREWLR	25.18963	215.7903	0.116732	0.0000
LRPHLR	14.77864	17.44297	0.847255	0.0006
LERELR	17.56625	92.66317	0.189571	0.0002
LEINTLR	5.79223	13.73693	0.421654	0.0161
ECMt-1	-0.863618			0.0000*
Adj. R2	0.739170			
Hetero. Test	0.8095			
LM Test	0.6445			

NARDL Short-Run Result; Dependent Variable: $LC0_2$

Regressors	Lags	
	0	1
Δ $LCREW^+$	0.206396	0.435727
	(0.3398)	(0.0966)***
Δ $LRPH^+$	0.777132	-1.247151
	(0.0260) **	(0.0018)*
Δ $LERE^-$	-0.501581	-0.629001
	(0.2439)	(0.0418)**
Δ $LEINT^+$	0.341742	-2.245438
	(0.7203)	(0.0048)*

NARDL Long-Run Result

	$LCREW^-$
	-0.2138
	(0.7696)

Diagnostics

Bound test	ECM_{t-1}	Adj. R^2	Hetero. Test	LM Test
4.155510	-0.863618	0.739170	(0.1280)	(0.1277)
	(0.0000)*			

Critical values: **10%*, ***5%*; *** 1%

ERE⁻ (negative shock in electricity from renewable energy; coefficient = -0.1611, p = 0.0007) shows a decline in renewable energy output has a significant and negative effect on GDP per capita. This confirms the asymmetric relationship, where losses in renewable energy capacity hurt the economy more than gains. A 1% increase in energy intensity (LEINT), that is, more energy use per unit of GDP, was associated with an approximately 2.8% increase in GDP per capita (coefficient = 2.7996, p = 0.0469). Although this implies economic growth, high energy intensity may signal inefficiency; therefore, this result may reflect increased industrial activity rather than sustainable growth.

The statistical results for Combustible Renewables and Waste (LCREW) revealed a long-term change in combustible renewable energy, and waste did not have a statistically significant effect on economic growth (coefficient = -0.3267; p = 0.3785). This may be due to inefficiencies in using such sources, or their relatively minor role in Germany's energy mix.

A negative shock in renewable electricity production significantly harms economic growth, while positive shocks do not. Energy intensity positively affects growth, but this may be due to energy-dependent industrial activity rather than efficient energy use. Combustible renewables and waste do not appear to have a significant influence on economic performance. The model demonstrated good fit and stability, with cointegration and no major diagnostic issues. A negative ERE shock increases GDPPC emissions by 0.16, whereas a positive shock is not statistically significant. These findings demonstrate that LEINT and LCREW have no long-term asymmetric impact on GDPPC.

Table 6. NARDL results

	Coefficient	p-values
Dependent Variable: LGDPP		
ERE^+	-0.0339	0.3939
ERE^-	-0.1611	0.0007*
LEINT	2.7996	0.0469**
LCREW	-0.3267	0.3785
Diagnostics		
Bound test	5.9422	
ECM_{t-1}	-0.9179	0.0000*
Adj. R^2	0.5757	
Heteroscedasticity test	0.8095	
LM Test	0.5445	

Critical values: **10%*, ***5%*.

5. Conclusion and policy recommendation

Numerous research has been done on the relationship between renewable energy and economic growth in various nations throughout the world. However, all studies assumed symmetry and linearity in the relationships between variables, except for a very small number. In this study, we investigate the potential for nonlinear relationships inside the NARDL for Germany from 1986 to 2020 under the assumption of asymmetric cointegration. The findings reveal that there is a nexus between renewable energy financing and economic growth. The study also finds that a shock in LCREW+ will, based on the long-term result, has a negative 0.21 impact on economic growth. In general, financing renewable energy is believed to play a role in Germany's economic growth. The bound test confirms the cointegration of variables, demonstrating evidence of a long-term relationship between the variables according to the post-estimation results.

The findings demonstrate that one of the most potent drivers encouraging the consumption of renewable energy in Germany is rising non-renewable energy prices. The nation can typically meet its energy needs at a lower cost than renewable energy sources by using non-renewable energy sources. To boost the production of renewable energy from renewable energy sources, the study recommends that policymakers should enhance their funding for colleges and research institutions to develop more viable ways to enhance renewable energy production and adoption. Contrary to underdeveloped nations, where renewable energy can help increase access to and availability of energy, improving economic production, Germany is already developed, and Europe competes for energy competitiveness as the "Green Wars" around the world. Because renewable energy may have easily replaced fossil fuel-based energy, an increase in renewable energy may not result in an overall increase in the amount of productive resources.

This study suggests that further studies should investigate sector-specific renewable energy financing impacts in Germany, incorporating energy storage advancements and distributional effects of policies, while comparing financing models across similar economies (e.g., Germany vs. Denmark). This addresses gaps in granularity, equity, and scalability.

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Data access statement: Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest declaration: The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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