

The impact of renewable energy expansion on economic growth and structural transformation in Jordan: An econometric analysis for 2010–2024

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Abstract: This study investigates the relationship between renewable energy growth, real economic growth, and structural change in Jordan over the period 2010–2024, with a special focus on agriculture, industry, and services. The analysis is based on original annual observations with quarterly estimates derived by linear interpolation. Stationarity is tested using Augmented Dickey-Fuller (ADF), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Phillips-Perron (PP) tests. The interpolated quarterly data series is subjected to Johansen cointegration tests and fully modified ordinary least squares (FMOLS) estimations, and annual autoregressive distributed lag (ARDL) models are used for robustness checks based on the original observations. The quarterly evidence indicates cointegration for real gross domestic product and agriculture, rejects cointegration for industry, and is inconclusive for services. The FMOLS results indicate positive coefficients of renewable energy in all four equations. However, the residual diagnostics and the interpolated data suggest a careful interpretation. The annual pattern provides the strongest statistical signal for agriculture, but the estimated autoregressive dynamics do not allow an unconditional long-run interpretation; the evidence for gross domestic product, industry, and services is weaker. In general, the expansion of renewable energy is related to Jordan's economic and structural transformation, but the relationship is heterogeneous and strongest for aggregate output and agriculture. Findings support greater integration of renewable energy into productive sectors, alongside grid modernisation, storage, energy efficiency, targeted finance, and directly observed higher-frequency databases.

Keywords: Economic growth, FMOLS, Jordan, Renewable energy, Sectoral output, Structural transformation.

1. Introduction

For economies that import energy, sustainable development depends not only on capital, labour and technological progress, but also on reliable and competitively priced energy. Electricity influences the cost of production, investment decisions, logistics, refrigeration, water pumping, digital services and the continuance of economic activity. Changes in the cost and security of energy supply can therefore impact aggregate output and the composition of output.

The shift to renewable energy globally has been accelerated by technological advances, falling solar and wind costs, energy-security concerns and the desire to cut exposure to fossil-fuel volatility. Domestic renewable electricity can reduce external vulnerability and provide productive opportunities for countries that are highly dependent on imported energy. But it doesn't automatically contribute to the economy. Grid readiness, storage, access to finance, energy efficiency, capital formation, and the capacity of firms and farms to adopt new technologies condition the gains realized [1-4].

Jordan is especially relevant. The country has few conventional energy resources, but renewable electricity expanded rapidly after 2014. Official annual series used in this study show renewable generation increasing from 18 GWh in 2010 to 2,812.5 GWh in 2024, with its share of electricity generation rising from 0.52% to 26.90%. This shift represents a major change in the electricity mix but does not in itself constitute a corresponding change in real output.

The important question, therefore, is whether the growth of renewable energy has been accompanied by measurable changes in real gross domestic product (GDP) and in agriculture, industry and services. Agriculture could benefit from irrigation, water pumping, cooling and storage. Lower and more predictable electricity costs could benefit industry. Services could benefit commercial buildings, tourism, hospitals, universities and digital infrastructure. These channels deserve a specific sectoral analysis.

The article makes three contributions. First, it generalises Jordan-focused evidence to three major productive sectors in addition to aggregate GDP. Second, it relies on renewable electricity generation rather than a general energy-consumption proxy. Third, it combines a quarterly long-run analysis using transparently interpolated data with annual autoregressive distributed lag (ARDL) models using the original observations. The quarterly layer is treated as indicative, since temporal interpolation increases the apparent frequency without producing commensurate independent economic information.

The study doesn't claim a definitive cause-and-effect relationship. Instead, it assesses whether the variables exhibit long-run relationships that are statistically defensible, compares such relationships across sectors and frequencies, and identifies the results that best survive after accounting for data and diagnostic shortcomings.

1.1. Economic and Policy Context

Energy has a special role in the growth process, as it is not simply another final good. It is an input that enables production at almost every stage. The backbone of machinery, transport systems, irrigation networks, cold chains, hospitals, universities, communications infrastructure and digital platforms is a steady supply of energy. In an economy that imports a large proportion of its energy needs, a supply disruption or an increase in international fuel prices can rapidly transmit to production costs, household expenditure, the current account and the public budget. Thus, the economic significance of domestic renewable resources goes beyond their environmental value.

The development of solar and wind generation can affect output through several channels. The first is an energy-security mechanism, because local production is less exposed to outside supply shocks. The second is a cost mechanism, but the ultimate impact on users will depend on tariffs, contracts, network charges and the capacity of the electricity system to accommodate variable generation. The third is an investment mechanism created by project development, grid reinforcement, storage, maintenance and complementary equipment. A fourth mechanism works through technological learning and technical employment. None of these are guaranteed to be large or immediate, nor are they spread evenly across sectors.

Jordan is therefore a useful case for analysis. The country experienced rapid growth in renewable electricity over a relatively short time, whereas the productive structure changed more slowly. This contrast allows the study to separate electricity sector expansion from structural transformation. A higher renewable share is a significant achievement, but structural transformation requires evidence that cleaner electricity translates into productivity, investment, competitiveness, and sectoral output. This distinction is important for the interpretation adopted in this article.

It discusses the 2020 contraction caused by the pandemic and the subsequent recovery. Those effects may influence output independently of renewable electricity and may also influence time-series properties. The current models do not claim to isolate all transient shocks. Instead, the analysis asks whether the observed trajectories are consistent with stable long-run relationships after capital and labour controls are included, and it reports the limitations that prevent a causal interpretation.

1.2. Significance of the Study

The scientific significance of the study is the combination of aggregate and sectoral dimensions. Much of the energy-growth literature is concerned with GDP only, whereas the present design examines agriculture, industry and services in a common production-function framework. This sectoral

comparison allows us to identify where renewable electricity is most likely to be transformed into productive output and where the evidence is weak.

The practical significance relates to Jordan's energy dependence, water constraints, production costs, and need for competitive investment. Evidence from agriculture can inform policy on irrigation, pumping, cooling, and storage. Evidence from industry can inform energy-efficiency programs and industrial-zone infrastructure. Evidence from services can inform hospitals, universities, hotels, commercial buildings, and digital facilities.

The study is also relevant as it includes the period of rapid evolution through 2024 and makes a clear distinction between directly measured annual information and interpolated quarterly representations. This distinction avoids confusing the higher apparent frequency with an equivalent increase in independent information and lends more credibility to the resulting policy interpretation.

2. Study Problem, Objectives, and Hypotheses

2.1. Study Problem

Although renewable electricity has expanded significantly in Jordan, it is not well established to what extent this expansion has translated into real growth and sectoral transformation. Existing Jordanian studies have mainly focused on aggregate output, energy consumption, emissions or policy conditions [5-12]. The long-run relationships between renewable electricity and agriculture, industry, and services are less well known. The main research question is: To what extent has renewable-energy expansion contributed to real economic growth and structural transformation in Jordan from 2010 to 2024?

2.1.1. Analytical Dimensions of the Research Problem

The research problem has empirical and policy components. Renewable generation has increased dramatically, empirically. But a common upward trend does not establish an economic effect. Output may rise due to capital accumulation, changes in the labour force, technological progress, fiscal policy, external demand, or a recovery from shocks. An assessment that is credible, then, must examine the properties of integration, the long-run relationships and the behaviour of residuals before interpreting coefficients.

The policy dimension concerns the conditions under which progress in the electricity sector translates into gains in the real economy. Grid constraints, storage limits, tariff design, access to credit, firm size, irrigation technology, water scarcity and energy-efficiency practices can reinforce or dampen the transmission mechanism. Hence, the study interprets renewable electricity not as a technical indicator per se but as a component of a broader productive and institutional system.

A sectoral approach is needed, as energy intensity and modes of electricity use vary. Electricity in agriculture is closely linked to pumping, irrigation, refrigeration and storage. The requirements for industrial use are associated with machinery, heating, cooling and continuous production processes. Services include low-energy activities and high-consumption facilities such as hotels, hospitals, universities, data infrastructure and retail buildings. These differences can be hidden by aggregate GDP.

2.2. Objectives

- Estimate the relationship between renewable electricity generation and real GDP.
- Evaluate the respective relationships in agriculture, industry, and services.
- Test the time-series properties of the variables using ADF, KPSS, and PP tests.
- Use Johansen cointegration analysis to test for model-specific long-run relationships.
- Estimate long-run elasticities quarterly when the preconditions for FMOLS are reasonably met.
- Employ original yearly data and ARDL specifications as an extra robustness check.

- Determine the sector with the strongest evidence across methods and frequencies.

2.3. Null Hypotheses

H₀₁: There is no statistically significant association between renewable electricity generation and real GDP.

H₀₂: There is no statistically significant relationship between renewable electricity generation and agricultural production.

H₀₃: No significant relationship between renewable electricity generation and industrial output.

H₀₄: There is no statistically significant association between services output and renewable electricity generation.

H₀₅: No long-run equilibrium relationship exists in the aggregate or sectoral models.

H₀₆: No differences in the sectoral responses to renewable-energy expansion.

3. Theoretical Framework and Literature Review

3.1. Theoretical Framework

The production-function approach posits that output is a function of capital, labour and technology. Energy is a productive input that enables those factors to function. The energy-growth literature has traditionally distinguished between the growth, conservation, feedback, and neutrality hypotheses [13, 14]. Renewable energy can also provide other benefits, such as reducing dependence on imported fuels, increasing the security of supply, encouraging capital formation and fostering technological learning. Conversely, the upfront costs, grid congestion, curtailment, financial constraints and weak sectoral integration could delay or reduce these benefits.

The expected effect is thus conditional, not mechanical. Cross-country analyses tend to find economically relevant links between renewable energy and growth, but they also find that the magnitude depends on institutional quality, economic complexity, investment, and supportive policy [14, 15–17]. This conditional view is particularly relevant for Jordan, where progress in the electricity sector has been fast but the shares of observable sectors have changed at a slower pace.

3.2. Empirical Literature

The general energy-growth relationship was established in early work [13] and subsequent reviews documented significant heterogeneity across countries, periods, and methods [14]. Using panel evidence, long-run relationships, feedback effects, and income-related renewable energy demand were reported in OECD and emerging economies [15, 16]. Later evidence found that the growth contribution of renewable energy is affected by supportive policies and country characteristics [17].

More recent literature has moved beyond a simple average effect. Parab, et al. [1] found evidence of short- and long-run linkages across a wide international sample Parab, et al. [1]. Chhabra, et al. [2] show that renewable energy can be part of a green growth strategy in emerging markets, but only if broader development conditions are present Chhabra, et al. [2]. Sarsar and Echaoui [3] have demonstrated that economic complexity influences the growth effect of the energy transition [3]. These studies indicate the economic importance of renewable energy in the presence of complementary productive capabilities.

Overall, evidence from Jordan has favoured the strategic relevance of energy. AbdAlla Spetan [5] found a long-run relationship and causality from renewable energy to GDP [5]. Similarly, Al-Qudah [6], Alkasasbeh, et al. [7], and Alnabulsi, et al. [8] also found positive aggregate relations using alternative long-run methods and samples. Jaber, et al. [9] found two-way causality between energy consumption and economic growth from 1980 to 2021. Alkhawaldeh, et al. [10] mentioned macroeconomic factors affecting renewable-energy generation, and recent reviews have identified barriers such as regulatory, tariff, grid, and financing [11, 12, 18].

The sectoral motivation is supported by more recent policy evidence. Jordan's Third National Energy Efficiency Action Plan for 2024–2026 includes measures for industry, services, water and agriculture, indicating that the productive value of clean energy relies on end-use efficiency and sector-specific uptake [19]. Similar to the international perspective, the main barriers to continued renewable growth are identified as grid integration and finance [20]. These developments motivate interpreting renewable generation alongside complementary infrastructure and sectoral capabilities, rather than in isolation, as a driver of output.

3.2.1. Critical Comparison of Previous Evidence

The reviewed studies have different measurement choices. Some use renewable energy consumption, others use electricity generation, installed capacity, or the share of renewables. These indicators are related, but not identical. Installed capacity is potential output; generation is actual electricity generated. Consumption may be in the form of imported electricity or non-electric renewable uses, while the share of generation is affected by both renewable output and total system demand. The present study uses renewable electricity generation because it is the most direct available measure of realised expansion in Jordan's electricity system.

The literature also varies in its econometric design. Panel studies have larger sample sizes and cross-country variation, but their average coefficients might not capture a small energy-importing economy with peculiar water and fiscal constraints. The advantage of country studies is institutional relevance, but they suffer from short time series, structural breaks, and sensitivity to lag selection. DOLS, FMOLS, ARDL, VECM, and causality procedures answer related but different questions. Thus, results should be compared according to sign, robustness, and institutional plausibility rather than being viewed as mechanically equivalent estimates.

Evidence in Jordan generally supports a positive relationship between energy and growth, but most studies look at aggregate GDP. This leaves two questions unanswered. First, it is not clear whether a positive aggregate relationship reflects broad gains for sectors or for a limited number of energy-sensitive activities. Second, the literature says little about whether the rapid expansion after 2014 altered the strength of the relationship. The present study offers a systematic sectoral comparison by estimating a common specification for GDP, agriculture, industry, and services.

Recent contributions add an important caveat. Renewable-energy deployment is more likely to support growth where domestic investment, economic complexity, grid capacity, technical skills and finance are sufficiently developed. This conditional reading is of particular interest in the case of Jordan. A project may add renewable generation without lowering the effective energy cost of each producer in the short term, and an abundance of electricity at one point in time does not automatically resolve network congestion or the limitations of peak demand. Thus, the literature offers a prudent interpretation based on complementary conditions.

3.3. Literature Synthesis and Research Gap

Three conclusions are reached. First, there is international evidence in favour of the energy-growth nexus but not of a homogeneous effect. Second, Jordanian research shows aggregate relevance but limited sectoral comparison. Third, the rapid expansion in renewable generation has not been properly evaluated relative to disaggregated real output using a common modelling framework. This work fills that gap while also making explicit the limitations of temporal interpolation.

4. Data, Variables, and Descriptive Evidence

Empirical time span: 2010–2024. The annual series contains 15 original observations. Using linear interpolation, a 60-point mechanical quarterly representation was prepared with annual values as benchmarks for the fourth quarter. This procedure provides for a quarterly long-run analysis on an exploratory basis but does not substitute for directly observed quarterly data. All variables of the model

are defined in natural logarithms and the coefficients are interpreted as elasticities, provided that the appropriate long-run conditions hold.

Table 1.
Definition and Measurement of Variables.

Symbol	Definition	Unit	Source	Role
LNGDP	Natural log of real GDP	Constant-price monetary units	DOS; World Bank	Dependent, aggregate
LNQA	Natural log of real agricultural output	Constant-price monetary units	DOS; World Bank	Dependent, agriculture
LNQI	Natural log of real industrial output	Constant-price monetary units	DOS; World Bank	Dependent, industry
LNQS	Natural log of real services output	Constant-price monetary units	DOS; World Bank	Dependent, services
LNRE	Natural log of renewable electricity generation	GWh	MEMR; NEPCO	Main explanatory variable
LNK/LNKA/LNKI/LNKS	Natural log of capital, aggregate/sectoral	Study database	DOS; World Bank	Control
LNL/LNLA/LNLI/LNLS	Natural log of labour, aggregate/sectoral	Persons or employment index	DOS; World Bank	Control

Note: DOS = Department of Statistics; MEMR = Ministry of Energy and Mineral Resources; NEPCO = National Electric Power Company. Constant-price base-year and detailed construction procedures for capital and labour should be reported exactly as documented in the underlying source workbook before final submission.

Table 2.
Selected Descriptive Indicators, 2010 and 2024.

Indicator	2010	2024	Interpretation
Renewable electricity generation (GWh)	18.00	2,812.50	Rapid expansion
Renewable share (%)	0.52	26.90	Major shift in electricity mix
Agriculture share of real GDP (%)	5.10	5.15	Broadly stable
Industry share of real GDP (%)	26.06	26.93	Moderate increase
Services share of real GDP (%)	55.76	57.15	Largest sector; modest increase

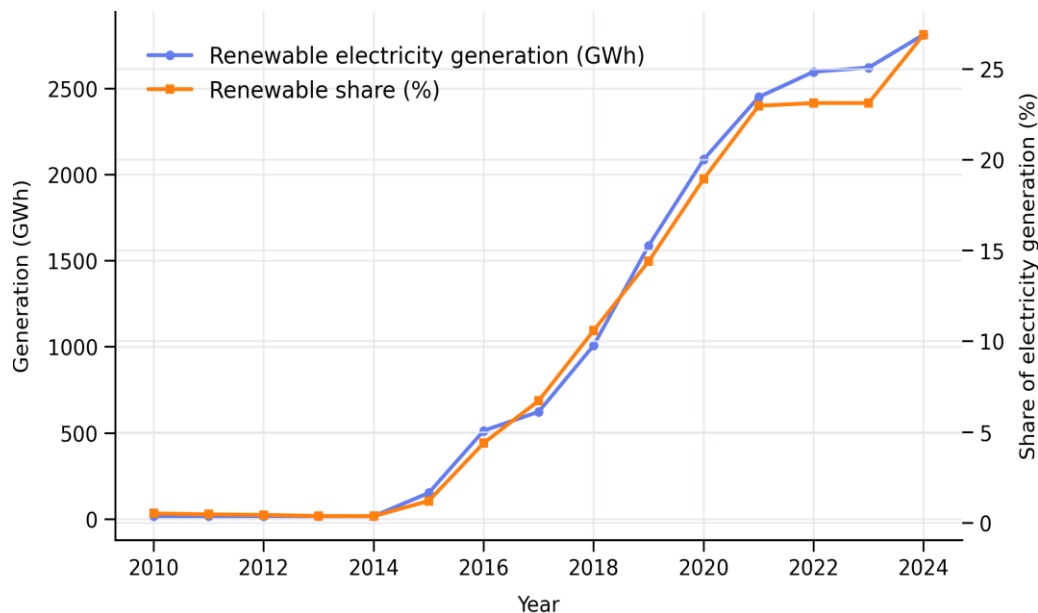


Figure 1.
Renewable electricity generation and its share in Jordan, 2010–2024.
Source: Authors' presentation based on MEMR and NEPCO annual series.

Figure 1 documents a structural change in electricity supply. The expansion is large in both absolute and relative terms. The figure provides the empirical motivation for testing whether the electricity transition is associated with aggregate and sectoral output, but it does not establish causality.

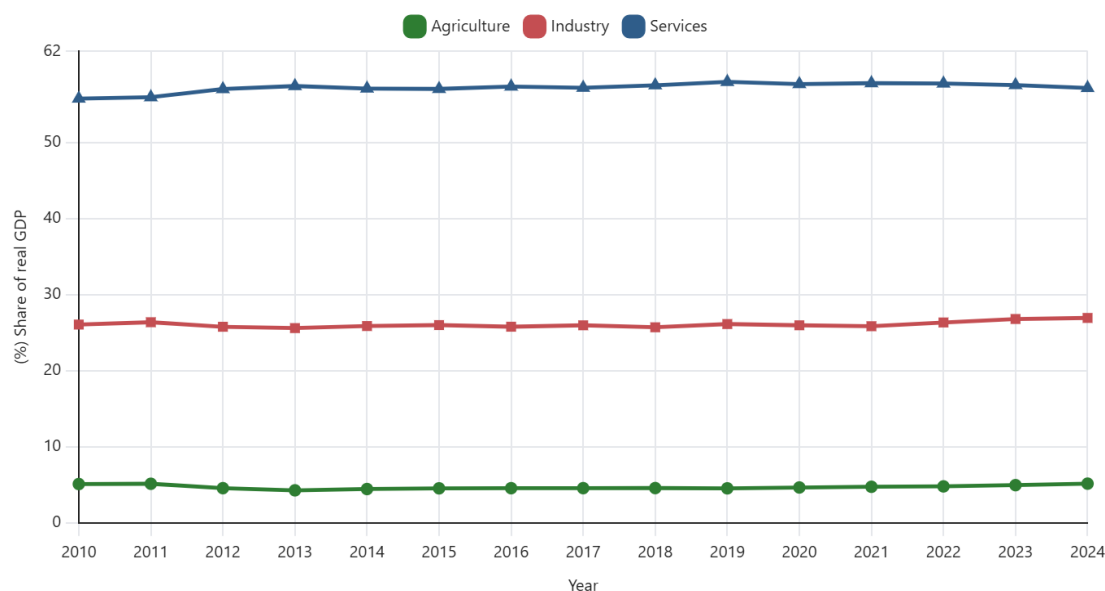


Figure 2.
Shares of agriculture, industry, and services in real GDP, 2010–2024.
Source: Authors' calculations based on DOS and World Bank annual series.

Sector shares are much more stable than renewable generation. So the energy transition was faster than the visible changes in the production structure. Thus, structural change should be assessed by the long-run relationships specific to the model, rather than by inference from the descriptive trend alone.

4.1. Construction and Interpretation of the Dataset

The study is based on annual observations. The quarterly series are a temporal disaggregation of the annual trajectories and should not be treated as a set of independently observed quarterly national accounts and energy data. Annual figures are taken as fourth-quarter benchmarks. Each interval between two benchmarks is divided into four equal steps, which are added one by one. If two adjacent annual values are equal, then the quarterly values between them are equal.

This construction has both practical advantages and material limitations. It produces a regularly spaced sequence that can be treated by quarterly econometric routines and allows a graphic representation of within-year movement. At the same time, it suppresses true seasonality, imposes smooth local paths and mechanically induces serial dependence. The method cannot detect a quarterly shock that is not reflected in the annual endpoints. In this light, the quarterly results are described as interpolated estimates in the rest of the manuscript.

Natural logarithms are used to reduce differences in scale and to enable elasticities to be interpreted. For example, a coefficient on LNRE of 0.05 implies that output varies, conditional on the other regressors, by an estimated 0.05% when renewable generation varies by 1%. This interpretation is valid as a long-run elasticity only if the equation is a stable cointegrating relationship. If there is no cointegration (or if cointegration is uncertain), the coefficient is descriptive and supplementary.

Available data do not distinguish among solar and wind generation, utility-scale projects and distributed systems, or installed capacity and realised generation. Nor do they provide a complete,

directly observed quarterly series for each measure of capital and labour. Interpolation does not cover up these measurement limitations but rather is an explicit part of the interpretation and recommendations.

5. Econometric Methodology

5.1. Model Specification

A log-linear Cobb–Douglas extension is estimated for aggregate and sectoral output:

$$\ln Q_t = \alpha_0 + \alpha_1 \ln K_t + \alpha_2 \ln L_t + \alpha_3 \ln RE_t + \varepsilon_t$$

Where Q denotes real aggregate or sectoral output, K denotes the corresponding capital measure, L denotes labour, RE denotes renewable electricity generation, and ε is the disturbance term. The coefficient α_3 is the elasticity of primary interest.

5.2. Estimation Strategy

The complementary Augmented Dickey-Fuller (ADF), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Phillips-Perron (PP) tests are used to examine the order of the quarterly series. Agreement among tests is more informative than reliance on a single statistic, since the null in ADF and PP is a unit root, and the null in KPSS is stationarity. Then, for the cointegration tests, the Johansen trace and maximum-eigenvalue tests are performed separately for each model. The fully modified ordinary least squares (FMOLS) estimator is interpreted as a long-run estimator only where cointegration is reasonably supported. FMOLS coefficients of models without clear evidence of cointegration are retained as ancillary associations, but not treated as established equilibrium elasticities.

The annual robustness layer is based on the 15 original annual observations. The sample is very small, so we report the ARDL models with caution. In particular, a long-run multiplier is not interpreted substantively if the estimated autoregressive dynamics indicate stability problems. Robustness evidence is based on the joint pattern of bounds tests, coefficient signs, dynamic stability, and diagnostic performance, not on one statistic alone.

5.3. Econometric Decision Rules and Interpretation

The empirical sequence begins with unit-root testing because regression among trending series may produce spurious, apparently significant relationships. The ADF and PP tests assess the null of a unit root, while the KPSS test assesses the null of stationarity. The three procedures are read together. However, a variable is not classified solely based on the most favourable test results, particularly when the data-generating process has been smoothed through interpolation.

We apply the Johansen procedure separately to each of the four model systems. The disagreement contains useful information, so we report both trace and maximum-eigenvalue statistics. Agreement on one cointegrating relationship is more convincing than a result from a single statistic. The industrial system is clearly different from the GDP and agricultural systems, for which no statistic supports cointegration. The services system is considered inconclusive because the two tests do not agree.

FMOLS corrects the long-run covariance structure for serial correlation and endogeneity in a cointegrating relationship. It will not fix a lack of cointegration, recover information lost by interpolation, or automatically correct functional-form mistakes. Thus, the relevance of LNRE is not viewed in isolation from the pre-estimation and diagnostic evidence. This principle accounts for the retention of a large industrial coefficient in the table but not as a confirmed long-run elasticity.

The annual ARDL layer has a different purpose. It uses the original annual observations and so avoids interpolation, but has only 15 observations. The ARDL(1,1,1,1) specification uses a large number of parameters in relation to that sample. Thus, bounds statistics, short-run coefficients, implied multipliers, autoregressive dynamics, and information criteria need to be interpreted together. That is, a

strong bounds statistic and an autoregressive coefficient greater than one do NOT imply a stable long-run effect.

6. Empirical Results

6.1. Quarterly Unit-Root Tests

The ADF results are mixed and do not support a blanket $I(1)$ classification. LNRE and LNLA are stationary after first differencing, LNKI appears stationary in levels, and the remaining series fail to reject a unit root even after first differencing at 5%. This pattern is consistent with the low short-run variation that interpolation produces.

Table 3.
Quarterly ADF Unit-Root Results.

Variable	Level stat.	p	First-diff. stat.	p	Assessment
LNGDP	-0.3858	0.9124	-2.1696	0.2175	Inconclusive
LNQA	0.8333	0.9922	-2.3806	0.1473	Inconclusive
LNQI	0.8775	0.9928	-2.0195	0.2781	Inconclusive
LNQS	-1.6396	0.4624	-2.4861	0.1189	Inconclusive
LNK	0.0351	0.9613	-2.5437	0.1052	Inconclusive
LNL	-1.1933	0.6765	-1.6334	0.4657	Inconclusive
LNRE	-0.8834	0.7934	-4.1690	0.0007	$I(1)$
LNKA	-1.8089	0.3760	-2.4419	0.1303	Inconclusive
LNLA	-1.5352	0.5160	-3.9024	0.0020	$I(1)$
LNKI	-4.1833	0.0007	-2.4193	0.1364	$I(0)$
LNLI	-0.8317	0.8096	-1.9345	0.3160	Inconclusive
LNKS	0.4861	0.9844	-2.1695	0.2175	Inconclusive
LNLS	-1.0350	0.7403	-1.6785	0.4422	Inconclusive

6.1.1. Supplementary Quarterly KPSS Test

The KPSS test was retained in its entirety, as it offers a complementary null hypothesis to ADF and PP. In KPSS, rejection implies non-stationarity. The results indicate that most level series are troublesome and many first-differenced series become acceptable under at least one deterministic specification. The remaining disagreements, especially for variables related to labour, highlight the need to avoid characterising the whole data set as uniformly $I(1)$.

Table 4.
Quarterly KPSS Stationarity Results.

Variable	Deterministic term	Level stat.	Level p	First-diff. stat.	Diff. p
LNGDP	Intercept	1.2845	0.0100	0.0935	0.1000
LNGDP	Intercept and trend	0.1831	0.0223	0.0972	0.1000
LNQA	Intercept	1.1226	0.0100	0.4797	0.0462
LNQA	Intercept and trend	0.2249	0.0100	0.0537	0.1000
LNQI	Intercept	1.2794	0.0100	0.2001	0.1000
LNQI	Intercept and trend	0.1002	0.1000	0.0807	0.1000
LNQS	Intercept	1.2781	0.0100	0.1427	0.1000
LNQS	Intercept and trend	0.2522	0.0100	0.0680	0.1000
LNK	Intercept	1.1243	0.0100	0.2500	0.1000
LNK	Intercept and trend	0.1917	0.0191	0.0685	0.1000
LNL	Intercept	0.8538	0.0100	0.7870	0.0100
LNL	Intercept and trend	0.3028	0.0100	0.1327	0.0747
LNRE	Intercept	1.0227	0.0100	0.1770	0.1000
LNRE	Intercept and trend	0.1761	0.0250	0.1612	0.0373
LNKA	Intercept	1.0829	0.0100	0.1905	0.1000
LNKA	Intercept and trend	0.2527	0.0100	0.0814	0.1000
LNLA	Intercept	0.7023	0.0133	0.1573	0.1000

LNLA	Intercept and trend	0.1535	0.0437	0.1203	0.0975
LNKI	Intercept	0.2777	0.1000	0.0778	0.1000
LNKI	Intercept and trend	0.1402	0.0607	0.0406	0.1000
LNLI	Intercept	0.8074	0.0100	0.6042	0.0223
LNLI	Intercept and trend	0.2943	0.0100	0.1479	0.0484
LNKS	Intercept	1.2180	0.0100	0.1189	0.1000
LNKS	Intercept and trend	0.1631	0.0358	0.0357	0.1000
LNLS	Intercept	0.8267	0.0100	0.7069	0.0129
LNLS	Intercept and trend	0.2939	0.0100	0.0858	0.1000

Table 5.
Quarterly Phillips–Perron Unit-Root Results.

Variable	Level stat.	p	First-diff. stat.	p	Assessment
LNGDP	0.3140	0.9780	-3.4814	0.0085	I(1)
LNQA	2.3649	0.9990	-3.2916	0.0153	I(1)
LNQI	1.6418	0.9980	-5.6380	0.0000	I(1)
LNQS	-0.8211	0.8129	-3.7608	0.0033	I(1)
LNK	0.9972	0.9942	-4.0601	0.0011	I(1)
LNL	1.6357	0.9980	-2.8790	0.0478	I(1)
LNRE	-0.4212	0.9065	-6.4630	0.0000	I(1)
LNKA	-0.7676	0.8284	-3.4063	0.0107	I(1)
LNLA	-0.7379	0.8367	-4.6119	0.0001	I(1)
LNKI	-2.1762	0.2150	-3.2040	0.0198	I(1)
LNLI	1.0849	0.9951	-4.4394	0.0003	I(1)
LNKS	0.7688	0.9911	-7.6630	0.0000	I(1)
LNLS	1.5986	0.9979	-2.8013	0.0581	Not I(1) at 5%

The PP test provides more convincing evidence of first-difference stationarity for most of the variables, although LNLS is marginally non-stationary at the 5% level. Finally, supplementary empirical output on KPSS results suggests that a number of first-differenced series pass under at least one deterministic specification. To summarise, the tests suggest that only certain care should be taken.

6.1.2. Annual Phillips–Perron Robustness Results

The annual PP tests are reported in full rather than summarized. With only 15 annual observations, test power is limited and isolated classifications should not be overinterpreted. Most variables become stationary after first differencing, whereas LNQS, LNLA, and LNKI appear stationary at level.

Table 6.
Annual Phillips–Perron Robustness Results.

Variable	Level stat.	Level p	First-diff. stat.	Diff. p	Order
LNGDP	-1.0613	0.7302	-10.8381	0.0000	I(1)
LNQA	1.5933	0.9978	-6.0330	0.0000	I(1)
LNQI	0.5501	0.9863	-7.3701	0.0000	I(1)
LNQS	-4.0079	0.0014	-5.7650	0.0000	I(0)
LNK	-0.3655	0.9157	-7.5402	0.0000	I(1)
LNL	1.1434	0.9956	-3.2690	0.0163	I(1)
LNRE	-1.0811	0.7225	-7.7051	0.0000	I(1)
LNKA	-2.1393	0.2290	-5.5876	0.0000	I(1)
LNLA	-2.9729	0.0375	-8.1380	0.0000	I(0)
LNKI	-4.7527	0.0001	-14.2905	0.0000	I(0)
LNLI	-0.5305	0.8859	-6.4471	0.0000	I(1)
LNKS	-1.0521	0.7338	-12.3002	0.0000	I(1)
LNLS	1.0272	0.9945	-3.7399	0.0036	I(1)

6.1.3. Integrated Assessment of Stationarity Evidence

The difference between ADF and PP is interesting. ADF does not reject a unit root after first differencing for many quarterly series. PP yields first-difference stationarity for almost all variables except LNLS at the 5% level. KPSS can often find stationarity after differencing under at least one deterministic specification. The pattern does not lend itself to a simple statement that all variables are $I(1)$, but it does suggest that the main series are more consistent with first-difference stationarity under PP than under ADF.

Labour variables require special care. LNL, LNLI and LNLS reveal that some of the test evidence still presents problems. Smooth employment pathways and measurement procedures could reduce the power of the tests. Capital also offers mixed evidence, with LNKI stationary at level under the quarterly ADF result but $I(1)$ under the quarterly PP. These disagreements are a substantive limitation, not a presentational detail, because Johansen and FMOLS are sensitive to the order of integration.

The annual tests do not eliminate the uncertainty. Their sample is too short to allow high-powered discrimination between $I(0)$, $I(1)$, and near-unit-root processes. The annual evidence is thus used to test whether the broad substantive pattern survives without interpolation, not to determine a better integration classification for each series.

6.2. Quarterly Cointegration

Table 7.

Johansen Cointegration Results.

Model	Trace rank	Max-eigen rank	Conclusion at 5%
GDP	1	1	Supported
Agriculture	1	1	Supported
Industry	0	0	Not supported
Services	1	0	Inconclusive

The Johansen statistics both support one cointegrating vector for GDP and agriculture. Neither supports cointegration in industry. The trace and maximum-eigenvalue tests do not agree for services. The long-run interpretation is most robust for GDP and agriculture, not supported for industry, and inconclusive for services.

6.2.1. Model-by-Model Cointegration Interpretation

For the aggregate GDP model, the concurrence of the two Johansen statistics supports one long-run vector. This is a defensible long-run basis for the aggregate FMOLS equation, but the residual diagnostics remain a limitation for inference. Both statistics also support one vector for agriculture, making this sector the one with the clearest evidence for quarterly equilibrium.

The industrial result is very different. Both statistics show zero cointegrating vectors at the 5% level. Hence, the industrial FMOLS estimate is not used to accept a long-run industrial hypothesis. Although its statistical significance is no substitute for the missing cointegration condition, it is nevertheless shown for the sake of completeness and comparability.

For services, the trace statistic is for one vector, but the maximum-eigenvalue statistic is not. The evidence on the services is therefore mixed. This terminology is used consistently throughout the abstract, results, discussion, and conclusion so that no part of the manuscript gives the impression of providing stronger evidence than another.

6.3. Quarterly FMOLS Estimates

Table 8.
Quarterly FMOLS Estimates: Coefficients (p-values).

Variable	GDP	Agriculture	Industry	Services
Constant	8.0530 (0.0000)	7.3740 (0.0000)	8.7473 (0.0000)	4.5832 (0.0055)
LNRE	0.0342 (0.0000)	0.0485 (0.0000)	0.0412 (0.0000)	0.0260 (0.0007)
Capital	0.2703 (0.2735)	-0.1079 (0.1730)	-0.0666 (0.0441)	0.7089 (0.0033)
Labour	-0.0103 (0.8541)	0.0250 (0.3280)	0.0561 (0.0627)	-0.0708 (0.1471)
R ²	0.9027	0.7576	0.8884	0.9292

For GDP and agriculture, where the Johansen tests agree, a 1% rise in renewable generation is linked to about 0.034% and 0.049% higher output, respectively, when controlling for the included controls. There is no cointegration; hence, the positive coefficient on the industrial variable is not interpreted as a confirmed long-run elasticity. The coefficient on services is also regarded as secondary because of disagreement among the cointegration tests. Statistical significance in a misspecified or non-cointegrated equation does not in itself imply a valid long-run relationship.

6.3.1. Economic Interpretation of the FMOLS Equations

The coefficient on renewables in the GDP equation is small and positive. The estimate is consistent with the view that renewable electricity has started to underpin aggregate activity, but its impact is mitigated by the time taken for firms, infrastructure and financing arrangements to adjust. The reported equation shows that capital and labour are statistically insignificant, a finding that cautions against interpreting the specification as a full structural production function.

The agricultural renewable coefficient is the biggest in the quarterly equations. Its sign is economically feasible, as farms and agricultural supply chains can utilise solar electricity for pumping, irrigation, refrigeration, ventilation and storage. The negative but insignificant coefficient on agricultural capital should not be interpreted literally as a productivity effect, especially given interpolation and possible measurement differences between sectoral capital and output.

The industrial equation produces a positive renewable coefficient, a negative significant capital coefficient, and a positive labour coefficient that is marginal at conventional levels. The signs may be due to multicollinearity, measurement error, common trends or specification issues. The equation does not provide evidence for a stable industrial production relationship because cointegration is not established.

The services equation is characterised by the smallest renewable coefficient and a relatively large positive capital coefficient. The services sector is heterogeneous, with activities that have very different electricity intensities. Thus, a modest mean association is plausible. However, the difference between Johansen statistics indicates that the numerical elasticity is still tentative.

6.4. Quarterly Diagnostics

Table 9.
Summary Quarterly Residual Diagnostics.

Model	JB p	BP p	White p	DW	BG p	RESET p
GDP	0.4096	0.0000	0.0000	0.0521	0.0000	0.0000
Agriculture	0.0008	0.0037	0.0000	0.0486	0.0000	0.0325
Industry	0.2842	0.0002	0.0003	0.1107	0.0000	0.0000
Services	0.3816	0.0038	0.0014	0.1246	0.0000	0.6747

A major limitation is the diagnostic evidence. All equations exhibit heteroscedasticity and very low Durbin-Watson statistics, and Breusch-Godfrey test results suggest serious serial correlation. RESET rejects the correct functional form for GDP, agriculture, and industry but not for services. These results

are in agreement with the smoothing and deterministic local motion imposed by linear interpolation. Even for models that show cointegration, careful inference is required.

Table 10.
Complete Quarterly Diagnostic Results.

Model	R ²	JB p	BP p	White p	DW	BG p	Ljung-Box p	RESET p
GDP	0.9027	0.4096	0.0000	0.0000	0.0521	0.0000	0.0000	0.0000
Agriculture	0.7576	0.0008	0.0037	0.0000	0.0486	0.0000	0.0000	0.0325
Industry	0.8884	0.2842	0.0002	0.0003	0.1107	0.0000	0.0000	0.0000
Services	0.9292	0.3816	0.0038	0.0014	0.1246	0.0000	0.0000	0.6747

6.4.1. Detailed Diagnostic Interpretation

The normality assumption is rejected only for the agricultural residuals and not for the other three equations at the 5% level. More importantly, the Breusch–Pagan and the White tests reject homoskedasticity in each of the models. The Durbin–Watson statistics are very low, and the Breusch–Godfrey and Ljung–Box probabilities indicate widespread serial correlation. These are not small technical imperfections but serious specification problems.

The RESET test rejects the functional form for GDP, agriculture, and industry but not for the services equation. The rejection can be explained by the omission of nonlinearities, structural change, or the smooth deterministic movement of the interpolated data. The problem is not only the estimated standard errors but also whether the conditional-mean specification is adequate. Robust standard errors would not fully address these concerns.

The diagnostic results justify the conservative wording of the manuscript. The evidence of long-run association is generated from the interpolated trajectories, i.e., the quarterly estimates. They are not presented as unbiased causal effects, nor is statistical significance ever used as the sole criterion for substantive acceptance.

6.4.2. Multicollinearity Diagnostics

We keep variance inflation factors because trending interpolated series may have strong common movement. The highest values are for aggregate capital and services capital. These results do not mechanically reject the equations but do increase uncertainty about the coefficients and weaken attempts to assign a separate structural interpretation to each control variable.

Table 11.
Variance Inflation Factors.

Model	Variable	VIF
GDP	LNRE	5.9066
GDP	LNK	15.9351
GDP	LNL	6.6347
Agriculture	LNRE	8.6412
Agriculture	LNKA	5.4418
Agriculture	LNLA	2.5906
Industry	LNRE	1.6220
Industry	LNKI	1.4303
Industry	LNLI	2.0254
Services	LNRE	5.5168
Services	LNKS	9.6841
Services	LNLS	3.3356

6.5. Annual Robustness Analysis

6.5.1. Annual ADF Robustness Results

Full annual ADF evidence is also provided. This is not surprising given the short sample and the mixed results. Under this specification, renewable energy is stationary in levels, and several output series are statistically unresolved. Industry is stationary after first differencing. Thus, the annual ARDL exercise is treated as a layer of robustness rather than a substitute for the quarterly analysis.

Table 12.

Annual ADF Robustness Results.

Series	Level stat.	Level p	First-diff. stat.	Diff. p
GDP	-0.6146	0.8676	-2.0319	0.2728
Agriculture	1.0459	0.9947	-2.4210	0.1359
Industry	0.3170	0.9781	-3.9058	0.0020
Services	-1.6662	0.4486	-1.6705	0.4464
Renewable Energy	-3.4459	0.0095	-1.0068	0.7508

Table 13.

Complete Annual ARDL(1,1,1,1) Robustness Results.

Model	AR(1)	LNRE(t)	p	LNRE(-1)	p	LR mult.	Bounds F	Lower p	Upper p	AIC
GDP	0.9403	0.0095	0.3910	-0.0077	0.3716	0.0304	0.7633	0.7921	0.9599	-77.9157
Agriculture	1.0130	-0.0791	0.0051	0.0424	0.0387	2.8279	8.8311	0.0000	0.0000	-63.2758
Industry	1.1183	-0.0047	0.5807	0.0090	0.3031	-0.0362	2.3905	0.1112	0.3764	-77.8814
Services	0.8755	0.0036	0.7504	-0.0031	0.7652	0.0041	0.4340	0.9372	0.9920	-69.3068

6.5.2. Detailed Annual Robustness Interpretation

The GDP model produces a statistically insignificant positive contemporaneous renewable coefficient and a negative lagged renewable coefficient. Its bounds statistic is below conventional evidence thresholds, with large lower- and upper-bound p-values. Hence, the small positive implied multiplier is not seen as evidence of a stable annual relationship.

The agricultural model is different because both renewable terms are large, and the bounds statistic is large. However, the autoregressive coefficient, 1.013, is greater than one. As a consequence, the determinant used to construct the implied long-run multiplier is close to zero and changes sign, thus magnifying the reported multiplier. The value 2.8279 should not be referred to as a reliable elasticity since there is no stable error-correction coefficient and no dynamic roots inside the unit circle.

The industrial autoregressive coefficient is also above one. The renewable terms are insignificant, and the bounds result is not decisive. Hence, the negative implied multiplier is not structurally interpreted. The statistics for the renewable coefficients and bounds in services do not indicate a durable long-run relationship on an annual basis.

The proper yearly conclusion is comparative, not absolute. The most prominent annual statistical signal is produced by agriculture. Dynamic stability rules out an unqualified long-run claim. The other equations do not support positive quarterly FMOLS coefficients. This frequency difference is stated openly and is part of the substantial conclusion of the study.

Table 14.

Summary Annual ARDL Robustness Results.

Model	AR(1)	LNRE(t)	LNRE(-1)	LR multiplier	Bounds F	Interpretation
GDP	0.9403	0.0095 (0.3910)	-0.0077 (0.3716)	0.0304	0.7633	No bounds evidence
Agriculture	1.0130	-0.0791 (0.0051)	0.0424 (0.0387)	2.8279	8.8311	Bounds evidence; dynamics unstable
Industry	1.1183	-0.0047 (0.5807)	0.0090 (0.3031)	-0.0362	2.3905	Inconclusive
Services	0.8755	0.0036 (0.7504)	-0.0031 (0.7652)	0.0041	0.4340	No bounds evidence

The strongest bounds test is agriculture. The contemporaneous and lagged renewable-energy terms are statistically significant. The estimated autoregressive coefficient, however, is 1.013, only slightly above unity. That outcome presents a problem of dynamic stability and renders the implied long-run multiplier of 2.828 inappropriate for an unqualified economic interpretation. The annual analysis thus provides only relative support for agriculture: it gives better evidence than the other annual equations, but it is not able to justify a stable long-run magnitude without further stability tests, an error-correction representation, alternative lag selection and, preferably, a longer sample. There is no bounds evidence for GDP and services, and the evidence is inconclusive for industry.

7. Discussion

In general, the evidence is more nuanced than a blanket statement that renewable energy increases all components of output. The strongest quarterly long-run relationships are for GDP and agriculture, both supported by Johansen statistics for cointegration. Even here, residual serial correlation, heteroskedasticity, and functional-form issues limit the power of inference. The magnitudes should be interpreted as suggestive elasticities from a time-disaggregated data set, not as causal treatment effects.

The most likely sectoral channel seems to be agriculture. Its quarterly renewable energy elasticity is the highest among the reported FMOLS coefficients, and its annual equation generates the strongest bounds statistic. This is consistent with the economics of renewable electricity supporting pumping, irrigation, refrigeration, and storage in an economy with interdependent water and energy constraints. But the annual coefficient above unity stops the large implied multiplier from being offered as a stable structural estimate.

The industrial FMOLS result is economically plausible, but econometrically unsupported as a long-run equilibrium coefficient, because the Johansen tests do not find cointegration. The result for services is also tentative because the two Johansen statistics are at odds. These differences are important. The coefficients should be left as addenda; presenting them as equally established would exaggerate the evidence.

Descriptive evidence also suggests that renewable generation grew much more rapidly than changes in sector GDP shares. This implies that there is no automatic immediate structural reallocation in the electricity-sector transition. The transmission of renewable energy to production is affected by grid capacity, storage, tariffs, financing, firm-level adoption, and efficiency policies [11, 12, 18–20]. The results are thus in line with recent literature that has considered the renewable-energy–growth nexus as conditional on complementary investment and economic capabilities [1–4].

7.1. Relationship to Previous Studies and Structural Transformation

The overall positive association is generally consistent with Jordanian studies that find a positive relationship between renewable energy and output. The current estimates are smaller and more qualified, because the analysis makes a distinction between evidence of cointegration and the significance of coefficients, and reports explicitly on failure of residuals. Thus, the study supports the direction of much of the previous literature, but with a weaker claim.

A sectoral comparison gives information not provided by aggregate studies. Agriculture shows the clearest quarterly long-run evidence and the strongest relative annual signal. Industry has a positive quarterly coefficient, but no cointegration, and the services sector has a smaller coefficient and inconclusive cointegration. The results shed light on why one should not infer structural transformation from a single GDP coefficient.

The descriptive sectoral shares changed little as renewable generation grew. Structural transformation can take place through within-sector productivity before the emergence of a large reallocation of GDP shares. Financing, grid, storage, and adoption constraints could also limit it. The study thus describes Jordan's transition as economically promising but unfinished.

The results are consistent with recent international work emphasising complementary capital formation and economic capabilities. Renewable electricity can help ease an energy constraint, but it does not substitute for investment in machinery, skills, water efficiency, logistics, storage or institutions. If a policy package increases generation but does not address these complements, the real-economy effects may be weaker than the headline electricity indicators suggest.

7.2. Hypothesis Assessment

For GDP, the null hypothesis is rejected only in the narrow sense that the quarterly cointegrated model suggests a significant positive association. The result is not a causal rejection since the data are interpolated and the diagnostics are weak. The quarterly results challenge the agricultural null most strongly, whereas the annual results do so relatively, but are dynamically unstable.

Johansen tests do not support cointegration, and hence the industrial null cannot be rejected as a long-run equilibrium proposition. However, the null for services cannot be rejected conclusively, as the cointegration tests disagree and the annual model has not been confirmed. The general null of no long-run relationship is rejected for GDP and agricultural systems but not for industry, and is unresolved for services.

The coefficients are different, so the hypothesis of equal sectoral responses is not descriptively supported, but a formal cross-equation equality test is not reported. Hence, the manuscript does not claim a formal statistical rejection of equality, but states that the observed associations are heterogeneous.

8. Conclusions and Policy Implications

Renewable electricity expansion is positively related to economic activity in Jordan, but the size and robustness of this relationship vary across sectors and empirical specifications. Quarterly cointegration is supported for GDP and agriculture, rejected for industry, and inconclusive for services. The FMOLS coefficients in all four equations are positive, but only the coefficients for GDP and agriculture have relatively strong long-run support. The data are interpolated, and residual problems are severe on a quarterly basis, so definitive causal claims are precluded. Annual models identify agriculture as the strongest relative channel, although the agricultural autoregressive coefficient raises a stability concern that precludes an unqualified interpretation of its long-run multiplier.

8.1. Practical Implications

- Target renewable energy applications for irrigation, water pumping, agricultural cooling, and storage, prioritizing projects based on measurable productivity and water-efficiency benefits.
- Modernise transmission and distribution infrastructure and expand economically justified storage to match increased renewable penetration and ensure reliable supply.
- Bundle renewable-energy incentives with energy audits, efficiency standards and demand-side management in industry, services and water-intensive agriculture.
- Develop financial instruments for farms, small and medium-sized enterprises, and energy-intensive service establishments, with clear performance criteria.
- Evaluate the effects of tariff and net-metering reforms on investment incentives, network costs and competitiveness of the productive sector.
- Establish quarterly and monthly databases for direct observation of generation, curtailment, prices, capital formation, employment and sectoral output.
- Require periodic ex post policy evaluations that differentiate between installed capacity and actual generation, and between electricity-sector outcomes and real-economy outcomes.

8.2. Detailed Recommendations

Investment policy should shift from a general objective of increasing renewable capacity to a portfolio approach that identifies productive uses, network needs and measurable results. Agricultural programs should link solar pumping and cooling to standards of water efficiency, maintenance capacity, and indicators of farm productivity. Industrial programs should include generation plus audits, efficient motors, process redesign, and demand-side management. Initiatives in the service sector should distinguish between hospitals, hotels, universities, public buildings, retail facilities and digital infrastructure.

Grid and storage decisions must be viewed as economic infrastructure. Renewable electricity has more productive value when it can be reliably delivered when and where demand occurs. Therefore, planning should consider congestion, curtailment, distribution-system reinforcement, forecasting, flexible demand, and storage economics, and not just installed capacity.

Financing arrangements need to take into account the constraints of farms and small and medium-sized enterprises. Leasing and performance-based finance, as well as concessional credit and guarantees, may be relevant where upfront costs are a barrier to adoption. Public support needs to be transparent, time-limited and linked to verified energy and productivity outcomes, so that it does not subsidise projects that would have gone ahead anyway.

Data reform is essential. Monthly and quarterly data should include renewable generation by technology, consumption by sector, curtailment, tariffs, network constraints, storage, investment, employment and sectoral output on a monthly and quarterly basis. A common public database would allow future researchers to replace interpolation with observed variation, and would improve ex post evaluation of energy policy.

Regulatory assessment should be evidence-based and periodic. Net-metering, wheeling, connection charges, procurement arrangements and tariff changes can bring about changes in incentives across consumer groups. Their effects should be evaluated jointly in terms of investment, fiscal exposure, network cost recovery, competitiveness and distributional effects.

8.3. Consolidated Results

First of all, the evidence on unit roots is mixed. PP supports first-difference stationarity for most quarterly variables, ADF is less supportive, and KPSS results depend on the specification. Second, Johansen tests find evidence of one cointegrating vector for GDP and agriculture, no cointegrating vector for industry, and mixed evidence for services. Third, the FMOLS renewable coefficients are positive in all four equations, but the long-run interpretation is confirmed only in the systems with more explicit evidence of cointegration.

Fourth, the quarterly diagnostics suggest the presence of heteroskedasticity, severe autocorrelation, and functional form problems in a number of equations. Fifth, the annual models do not uniformly support the quarterly findings. Agriculture has the highest bounds statistic and important renewable terms. However, the autoregressive coefficient of agriculture raises a stability concern. Annual data from GDP, industry, and services are softer.

Broadly, the most defensible finding is not that renewable energy leads to uniform growth across the economy. The renewable expansion is related to aggregate GDP and, more consistently, to agricultural activity, while the industrial and services evidence is tentative. The economic value of the transition depends on the existence of complementary productive, financial, infrastructural and institutional conditions.

9. Limitations and Future Research

The main drawback is that the quarterly observations are interpolated from 15 yearly values. Linear interpolation smooths short-run variation, creates strong serial dependence, and may affect the validity of unit-root, cointegration, and residual-based tests. The second limitation is related to the short annual

sample, which restricts the selection of lags and reduces the statistical power of the ARDL bounds tests. Third, renewable electricity generation does not differentiate between solar and wind technologies, installed capacity and realised generation, or utility-scale and distributed systems. Fourth, the estimated relationships could be affected by unaccounted-for variables such as electricity prices, curtailment, storage, tariffs, water conditions, quality of investments, and structural breaks.

Temporal aggregation also makes it more difficult to interpret shocks. Annual benchmark values aggregate movements that may be observed at different points within a year, and linear interpolation imposes a smooth quarterly path between annual observations. This may change the perceived timing of the relationship between renewable generation and output. Thus, the lag coefficients in the interpolated series should not be interpreted as representing true quarter-to-quarter transmission mechanisms.

The 2010–2024 period is relatively short and includes potential structural breaks, such as the acceleration of renewable deployment and the economic contraction in 2020. The conventional unit-root and cointegration tests may have low power or produce distorted results due to structural breaks. Therefore, longer time series should be used in future research to test for endogenous structural breaks and to consider regime-sensitive or nonlinear specifications.

More complete source documentation is needed for the capital and labour controls, including measurement units, constant-price base years and construction methods, especially for the sectoral measures. Future research should ensure full documentation of these variables and consistency with the underlying official data sources and their metadata.

Future research should focus on directly observed high-frequency data, longer annual data series, structural break tests, and model-specific deterministic terms and lag-selection procedures. Sectoral analyses should distinguish between renewable technologies and include other variables, such as electricity prices, storage, curtailment, emissions, employment, exports, and productivity. For annual ARDL models, future studies should report the error-correction coefficients, dynamic roots, CUSUM and CUSUMSQ stability tests, alternative lag-selection criteria, and small-sample critical values. Causal designs should be reserved for cases in which credible identification strategies and exogenous policy or project-level variation exist.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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Appendix A. Original Annual Source Series

Table A1.
Annual Output and Renewable-Energy Series.

Year	GDP	RE (GWh)	RE share (%)	Agriculture	Industry	Services
2010	29447.21	18.00	0.52	1502.44	7674.27	16419.29
2011	30303.33	18.00	0.47	1556.67	7990.12	16949.53
2012	31032.02	18.00	0.44	1415.22	7996.77	17689.63
2013	31877.05	18.00	0.38	1362.66	8158.93	18298.44
2014	32936.29	18.00	0.37	1464.00	8518.84	18799.69
2015	33767.14	153.00	1.21	1532.42	8776.33	19256.17
2016	34480.19	514.00	4.40	1571.24	8887.68	19771.33
2017	35344.86	624.00	6.73	1612.50	9176.33	20211.77
2018	36000.09	1009.00	10.60	1645.94	9252.25	20702.82
2019	36668.37	1588.00	14.41	1663.99	9579.94	21247.59
2020	36245.74	2088.00	18.95	1685.34	9410.68	20901.51
2021	37605.69	2450.00	22.98	1783.00	9717.47	21728.46
2022	38638.66	2597.00	23.13	1851.56	10175.14	22308.84

2023	39847.67	2621.00	23.13	1974.97	10675.51	22926.68
2024	40866.20	2812.50	26.90	2106.34	11005.02	23356.03

Appendix B. Sample of Temporally Disaggregated Quarterly Data

Table B1.

Selected Interpolated Quarterly Observations.

Quarter	GDP	RE	RE share (%)	Agriculture	Industry	Services
2010Q1	29447.2100	18.0000	0.5200	1502.4400	7674.2700	16419.2900
2010Q2	29447.2100	18.0000	0.5200	1502.4400	7674.2700	16419.2900
2010Q3	29447.2100	18.0000	0.5200	1502.4400	7674.2700	16419.2900
2010Q4	29447.2100	18.0000	0.5200	1502.4400	7674.2700	16419.2900
2011Q1	29661.2400	18.0000	0.5075	1515.9975	7753.2325	16551.8500
2011Q2	29875.2700	18.0000	0.4950	1529.5550	7832.1950	16684.4100
2011Q3	30089.3000	18.0000	0.4825	1543.1125	7911.1575	16816.9700
2011Q4	30303.3300	18.0000	0.4700	1556.6700	7990.1200	16949.5300
2023Q1	38940.9125	2603.0000	23.1300	1882.4125	10300.2325	22463.3000
2023Q2	39243.1650	2609.0000	23.1300	1913.2650	10425.3250	22617.7600
2023Q3	39545.4175	2615.0000	23.1300	1944.1175	10550.4175	22772.2200
2023Q4	39847.6700	2621.0000	23.1300	1974.9700	10675.5100	22926.6800
2024Q1	40102.3025	2668.8750	24.0725	2007.8125	10757.8875	23034.0175
2024Q2	40356.9350	2716.7500	25.0150	2040.6550	10840.2650	23141.3550
2024Q3	40611.5675	2764.6250	25.9575	2073.4975	10922.6425	23248.6925
2024Q4	40866.2000	2812.5000	26.9000	2106.3400	11005.0200	23356.0300

The table reproduces the original manuscript's quarterly sample and makes clear that the observations are generated mechanically between annual fourth-quarter benchmarks.

Appendix C. Data-Treatment Statement

The quarterly data are obtained from annual official series by linear interpolation. Annual observations were used as benchmark values for the fourth quarter and the intervening quarters were interpolated linearly. While the interpolation provides a smooth representation of the annual trajectory, it does not provide the informational content of directly observed quarterly data. Thus quarterly results are exploratory and should be confirmed by future research using directly observed high-frequency series or statistical temporal-disaggregation methods.