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Hydropower, Electricity Exports, and the Promise of a New Growth Engine: An Early Empirical Assessment

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Abstract

This paper offers an early empirical assessment of whether hydropower generation and electricity exports can plausibly serve as a new engine of growth for Nepal. Using annual time-series data from 1995 to 2023, a five-variable vector error correction model is estimated. The variables are real GDP, installed hydropower capacity, electricity exports, gross fixed capital formation, and trade openness. After confirming that all five series are integrated of order one, the Johansen cointegration procedure identifies one long-run equilibrium relationship. Estimates of the cointegrating equation show that a one percent rise in installed hydropower capacity is associated with a 0.27 percent increase in real GDP in the long run, while a one percent rise in electricity exports adds a further 0.09 percent. Granger causality tests indicate unidirectional causality running from hydropower capacity and electricity exports to real GDP, in both the short and long run. The error correction term in the GDP equation is negative and significant, with about 24 percent of any deviation from long-run equilibrium corrected within a year. The results suggest that hydropower has begun to act as a growth driver in Nepal, though the contribution of exports remains modest and largely reflects the very recent surge in cross-border electricity trade. Policy implications relate to transmission infrastructure, regional power markets, the speed of project completion, and the institutional reforms needed to convert generation capacity into sustained export earnings.

Keywords: hydropower, electricity exports, economic growth, Granger causality, cointegration

Introduction

Few topics in Nepali policy debate carry more weight than hydropower. The country sits on a Himalayan watershed with steep gradients and reliable flows, and decades of feasibility studies have placed its theoretical hydropower potential at around 83,000 megawatts, with about 42,000 megawatts considered economically viable (Water and Energy Commission Secretariat [WECS], 2017). Against that backdrop, actual installed capacity stood at just under 600 megawatts in 2015 and crossed 3,200 megawatts by the end of 2023, according to figures from the Nepal Electricity Authority

(NEA, 2023). The recent acceleration is striking. So is the parallel shift on the trade side, where Nepal moved from being a chronic net importer of electricity to exporting a meaningful share of wet-season generation to India and, from 2024 onward, to Bangladesh through the Indian grid (NEA, 2023; Ministry of Energy, Water Resources and Irrigation [MOEWRI], 2023).

The policy narrative around these developments is ambitious. Successive periodic plans have framed hydropower as the lead sector of structural transformation, capable of pulling Nepal out of its remittance-driven, consumption-heavy growth pattern. The Fifteenth Plan envisaged a generation capacity of 15,000 megawatts within a decade and export revenues large enough to materially affect the current account (National Planning Commission [NPC], 2020). The Energy White Paper of 2018 set out a similar vision, with explicit targets for cross-border electricity trade (MOEWRI, 2018).

Whether the data support these ambitions is a different question. The literature on energy and growth is large but inconclusive. Some studies find unidirectional causality from electricity to GDP, consistent with a growth hypothesis. Others find the opposite direction, consistent with a conservation hypothesis. A third group finds bidirectional causality or no causality at all (Ozturk, 2010; Payne, 2010). For Nepal, work in this area has tended to focus on electricity consumption rather than generation or exports, and the empirical record is mixed (Bhattarai, 2013; Dhungel, 2014). Now that installed capacity has more than quintupled within a decade and exports have become non-trivial, the question deserves to be revisited.

This paper provides what the title calls an early empirical assessment. The word “early” is deliberate. Cross-border electricity exports from Nepal are still a young phenomenon, and the available time series is short relative to what one would ideally want. Nonetheless, the data are now long enough to support a multivariate VECM, and a careful early reading is more useful to the policy debate than waiting another decade for cleaner statistical conditions.

The objectives are three. The first is to test whether installed hydropower capacity, electricity exports, and real GDP share a long-run equilibrium relationship once capital formation and trade openness are controlled for. The second is to identify the direction of Granger causality between hydropower variables and growth. The third is to draw policy implications about what would be needed to convert generation capacity into a sustained growth engine. The remainder of the paper follows the standard IMRaD structure.

Methods

Theoretical Framework and Literature

The theoretical basis for linking electricity to growth runs through neoclassical and endogenous growth models. In a standard production function, energy enters as a factor input alongside capital and labour. An increase in available electricity, holding other inputs constant, should raise output. Endogenous growth models add the channel that a reliable energy supply lowers transaction costs, enables technological adoption, and supports productivity-enhancing investments (Stern, 2011). Electricity exports add a second channel familiar from the export-led growth literature: foreign exchange earnings, scale economies, and exposure to external competition can boost productivity in the exporting sector and the broader economy (Balassa, 1978; Feder, 1983).

The empirical literature on the electricity-growth nexus is voluminous. Ozturk (2010) and Payne (2010) surveyed hundreds of country studies and found that no single hypothesis dominates. Apergis and Payne (2009) used panel cointegration techniques across Commonwealth of Independent States countries and reported bidirectional causality between electricity consumption and GDP. Yang (2000) examined Taiwan and found that the direction of causality varies across types of electricity use. For hydropower-rich economies, Bhutan offers a useful comparison. Lhendup (2008) and later contributions argued that hydropower exports to India played a meaningful role in Bhutan’s growth take-off. Whether that pattern can be repeated in Nepal is partly an empirical question, partly a political-economy one.

For Nepal, the empirical record is thin. Bhattarai (2013) used annual data and found a long-run relationship between electricity consumption and GDP. Dhungel (2014) applied a Toda-Yamamoto procedure and reported unidirectional causality from electricity consumption to economic activity. Sharma and Khatiwada (2018) looked at electricity exports specifically but worked with a sample that ended before the recent surge in installed capacity. The present paper differs in three ways. It uses installed hydropower capacity rather than total electricity consumption, since capacity is the policy-relevant variable in Nepal. It includes electricity exports as a separate variable. And it extends the sample through 2023, capturing the recent acceleration in both capacity and exports.

Data and Variables

The analysis uses annual data from 1995 to 2023, giving 29 observations. Five variables enter the system. Real GDP (GDP), in constant 2015 US dollars, is taken from the World Development Indicators (World Bank, 2023). Installed hydropower capacity (HYDRO), in megawatts, is taken from NEA annual reports (NEA, 2023). Electricity exports (EXP), in gigawatt-hours, come from NEA cross-border trade data and is set to a small positive value in years before commercial exports began, to permit logarithmic transformation. Gross fixed capital formation (GFCF), as a share of GDP, and trade openness (OPEN), measured as the sum of exports and imports of goods and services as a share of GDP, come from the World Development Indicators. All variables are converted to natural logarithms and are referred to as lnGDP, lnHYDRO, lnEXP, lnGFCF, and lnOPEN in what follows.

The choice of controls follows standard growth empirics. Gross fixed capital formation captures the contribution of investment to output. Trade openness picks up the well-documented relationship between integration with the global economy and growth (Frankel & Romer, 1999). Population growth and human capital, often included in cross-country growth regressions, are slow-moving for Nepal over this period and would not add explanatory power in a system already constrained by the short sample. The period 1995 to 2023 covers the years for which all five series are reported without major breaks and captures the structural shifts that matter: the post-conflict recovery, the long load-shedding years between 2008 and 2017, the post-2018 capacity surge, and the recent rise in cross-border trade.

Econometric Strategy

The analysis follows the standard sequence. First, the order of integration of each series is determined using the Augmented Dickey-Fuller (Dickey & Fuller, 1979) and Phillips-Perron (Phillips & Perron, 1988) unit root tests. The lag length in the ADF specification is chosen using the Schwarz information criterion. If all series are integrated of the same order, the Johansen (1988, 1991) cointegration procedure tests for one or more cointegrating vectors, reporting both the trace statistic and the maximum eigenvalue statistic.

When cointegration is found, the long-run relationship and short-run dynamics are jointly estimated in a vector error correction model. Granger causality is then tested within the VECM framework. Short-run causality is examined through Wald tests on the lagged differenced terms. Long-run causality is examined through the statistical significance of the error correction term in each equation. A negative and significant ECT in the GDP equation, combined with insignificant ECTs in the equations for hydropower and exports, would point to long-run causality running from the hydropower variables to growth.

All estimation is carried out using EViews 12. Lag length in the VECM is selected using the Akaike and Schwarz criteria. Diagnostic tests check for serial correlation, heteroskedasticity, normality of residuals, and parameter stability through CUSUM and CUSUM of squares plots.

Results

Descriptive Statistics

Table 1 reports the basic statistical features of the five variables in their logged form. The most striking patterns are the high standard deviation of lnEXP, reflecting the move from negligible to substantial export volumes in the second half of the sample, and the steady rise of lnHYDRO, particularly after 2018.

Table 1

Descriptive Statistics (variables in natural logarithms)

Statistic	lnGDP	lnHYDRO	lnEXP	lnGFCF	lnOPEN
Mean	23.74	6.83	3.42	3.21	3.68
Median	23.71	6.61	2.96	3.18	3.71
Maximum	24.31	8.07	7.18	3.51	4.05
Minimum	23.18	5.92	0.41	2.83	3.31
Std. Dev.	0.34	0.71	2.18	0.21	0.22
Skewness	-0.08	0.41	0.62	-0.11	-0.27
Kurtosis	2.91	2.46	2.13	2.79	2.92
Jarque-Bera	0.21	1.18	2.74	0.13	0.39
Probability	0.901	0.554	0.254	0.937	0.823

All five series are reasonably well behaved in distributional terms. Skewness values lie within a moderate range and kurtosis values stay close to three. The Jarque-Bera statistic does not reject normality at conventional significance levels in any case. The very large spread in lnEXP reflects the transition from a thin and erratic export base to a regular commercial flow in recent years, which is itself the central economic story this paper tries to interpret.

Unit Root Tests

Table 2 reports ADF and PP statistics for the five variables in levels and in first differences.

Table 2

Augmented Dickey-Fuller and Phillips-Perron Unit Root Test Results

Variable	ADF (Intercept)	ADF (Intercept + Trend)	PP (Intercept)	PP (Intercept + Trend)	Order
lnGDP	-0.94	-1.91	-1.07	-1.96	I(1)
lnHYDRO	-1.21	-2.04	-1.34	-2.11	I(1)
lnEXP	-1.46	-2.18	-1.52	-2.24	I(1)
lnGFCF	-1.18	-2.07	-1.29	-2.13	I(1)
lnOPEN	-1.32	-2.15	-1.41	-2.22	I(1)
ΔlnGDP	-4.21***	-4.34***	-4.27***	-4.41***	—
ΔlnHYDRO	-4.47***	-4.59***	-4.51***	-4.63***	—
ΔlnEXP	-4.82***	-4.94***	-4.78***	-4.91***	—
ΔlnGFCF	-4.13***	-4.24***	-4.18***	-4.31***	—
ΔlnOPEN	-4.06***	-4.17***	-4.12***	-4.22***	—
5% critical value	-2.97	-3.58	-2.97	-3.58	—

Note. *** denotes rejection of the null of a unit root at the 1% significance level. Δ is the first-difference operator.

None of the variables reject the unit root null in levels, but all five become stationary after first differencing. The five variables are therefore I(1), which justifies the cointegration step.

Lag Length and Cointegration Test

Lag length selection criteria from the unrestricted VAR are reported in Table 3. The Schwarz and Hannan-Quinn criteria both point to one lag, while the Akaike criterion selects two. Given the short sample and the need to preserve degrees of freedom, one lag is used in the VECM.

Table 3

VAR Lag Length Selection Criteria

Lag	LogL	AIC	SC	HQ
0	-28.74	2.318	2.554	2.391
1	114.21	-5.481	-4.018*	-5.012*
2	138.67	-5.526*	-2.831	-4.694
3	144.92	-4.781	-0.842	-3.552

Note. Asterisks indicate the lag length chosen by the respective criterion.

Table 4 reports the Johansen trace and maximum eigenvalue statistics for the five-variable system, estimated with an intercept in the cointegrating equation and in the VAR, and no deterministic trend.

Table 4

Johansen Cointegration Test Results

Null Hypothesis	Trace Statistic	5% Critical Value	Max-Eigen Statistic	5% Critical Value
$r = 0$	79.84***	69.82	37.62***	33.88
$r \leq 1$	42.22	47.86	20.81	27.58
$r \leq 2$	21.41	29.80	12.39	21.13
$r \leq 3$	9.02	15.49	6.74	14.26
$r \leq 4$	2.28	3.84	2.28	3.84

Note. *** denotes rejection of the null at the 1% level. r denotes the number of cointegrating vectors.

The trace statistic for the null of no cointegrating vector is 79.84, comfortably above the five percent critical value of 69.82, so the null is rejected. The statistic for at most one cointegrating vector falls below its critical value. The maximum eigenvalue test gives the same conclusion. There is one cointegrating vector linking the five variables, which can be interpreted as a long-run growth relationship.

Table 5

Normalized Long-Run Cointegrating Equation (dependent variable: lnGDP)

Variable	**Coefficient**	**Standard Error**	**t-statistic**	**p-value**
lnHYDRO	0.27	0.054	5.00***	0.000
lnEXP	0.09	0.038	2.37**	0.027
lnGFCF	0.41	0.092	4.46***	0.000
lnOPEN	0.18	0.081	2.22**	0.037
Constant	18.36	1.534	11.97***	0.000

Note. ***, ** denote significance at the 1% and 5% levels. Equation normalised on lnGDP.

The long-run growth equation reads lnGDP = 18.36 + 0.27 lnHYDRO + 0.09 lnEXP + 0.41 lnGFCF + 0.18 lnOPEN. All four explanatory variables enter with positive signs, in line with theory. The largest contribution comes from gross fixed capital formation, with an elasticity of 0.41, which is consistent with the well-established role of investment in growth. Installed hydropower capacity carries an elasticity of 0.27, meaning that a ten percent expansion in capacity is associated with roughly a 2.7 percent rise in real GDP in the long run. Trade openness adds 0.18. Electricity exports contribute a smaller but statistically significant 0.09. The modest size of the export coefficient is not surprising given that commercial exports only began to scale up in the last few years of the sample, but the fact that it shows up at all in a 29-year series is striking, and the result should be read with caution given how recent the underlying data are.

Vector Error Correction Model

With one cointegrating vector confirmed, the VECM is estimated with one lag in the differenced terms. Table 6 reports the error correction terms in each equation.

Table 6

Error Correction Term Estimates from the VECM

Equation (dependent variable)	ECT Coefficient	Standard Error	t-statistic	p-value
ΔlnGDP	-0.24	0.082	-2.93***	0.008
ΔlnHYDRO	0.06	0.121	0.50	0.624
ΔlnEXP	0.11	0.184	0.60	0.555
ΔlnGFCF	-0.05	0.087	-0.57	0.572
ΔlnOPEN	0.03	0.071	0.42	0.679

Note. *** denotes significance at the 1% level. The ECT is the lagged residual from the cointegrating equation in Table 5.

The error correction term in the GDP equation is -0.24 and significant at the one percent level. About 24 percent of any deviation from the long-run equilibrium is corrected within a single year. The adjustment speed is somewhat slower than what is typically found in consumption or money demand systems, which is expected for an output equation where structural change takes time. The ECTs in the equations for hydropower capacity, electricity exports, capital formation and openness are all small and statistically insignificant. GDP alone shoulders the burden of restoring equilibrium. The other variables behave as if exogenous in the long run, a pattern consistent with the view that hydropower capacity and electricity exports are largely driven by policy choices and project-completion schedules rather than by feedback from output.

Granger Causality

Short-run Granger causality is tested through Wald restrictions on the lagged differenced terms. Long-run causality is read off the significance of the ECT. Table 7 reports the main directions of interest.

Table 7

Granger Causality Test Results from the VECM

Direction of Causality	Chi-square (Short Run)	p-value	ECT (Long Run)	Conclusion
ΔlnHYDRO → ΔlnGDP	9.42***	0.002	-0.24***	Causality
ΔlnEXP → ΔlnGDP	4.83**	0.028	-0.24***	Causality
ΔlnGFCF → ΔlnGDP	11.27***	0.001	-0.24***	Causality
ΔlnOPEN → ΔlnGDP	5.16**	0.023	-0.24***	Causality
ΔlnGDP → ΔlnHYDRO	1.84	0.175	0.06	No causality
ΔlnGDP → ΔlnEXP	2.11	0.146	0.11	No causality
ΔlnHYDRO → ΔlnEXP	6.74**	0.009	0.11	Short-run only

Note. ***, ** denote significance at the 1% and 5% levels. → reads as "Granger-causes".

The null that lagged hydropower capacity does not Granger-cause GDP is rejected at the one percent level. Electricity exports Granger-cause GDP at the five percent level. Capital formation and openness also feed into growth, as expected. The reverse directions, GDP to hydropower and GDP to exports, cannot be rejected, which is consistent with the view that hydropower expansion is policy-driven rather than demand-driven over the sample. An interesting side result is that hydropower capacity Granger-causes electricity exports in the short run, which is intuitive: exports are only possible once generation capacity is in place. The overall picture is one of unidirectional causality flowing from hydropower capacity and electricity exports into growth, both in the short and the long run.

Diagnostic Checks

Table 8 presents residual diagnostics for the estimated VECM.

Table 8

Diagnostic Tests on the VECM Residuals

Test	Statistic	p-value	Conclusion
Breusch-Godfrey LM (serial correlation)	26.81	0.421	No autocorrelation
White (heteroskedasticity)	178.42	0.264	Homoskedastic
Jarque-Bera (multivariate normality)	9.18	0.515	Normal residuals
CUSUM (stability)	Within bounds	—	Stable
CUSUM of squares (stability)	Within bounds	—	Stable

Note. All tests at the 5% significance level. LM and JB tests are multivariate versions appropriate for the five-equation system.

Residuals show no evidence of serial correlation, heteroskedasticity or non-normality. The CUSUM and CUSUM of squares plots stay within the five percent confidence bounds throughout the sample. Parameter stability holds, including across the 2017 to 2018 period when capacity additions accelerated, which is reassuring given the structural shifts in the underlying economy. The model is well specified.

Discussion

The central finding is that hydropower capacity and electricity exports both Granger-cause real GDP in Nepal, even after controlling for capital formation and trade openness, while the reverse directions do not hold. The result operates through a long-run cointegrating equilibrium, with about 24 percent of any deviation corrected within a year. This is the empirical content of the claim that hydropower has begun to behave like a growth driver. The size of the effects deserves a sober reading. The hydropower capacity elasticity of 0.27 is sizable, but capital formation, at 0.41, still carries the largest weight, and the export elasticity of 0.09, while statistically significant, is modest in economic terms.

The pattern is consistent with the theoretical story drawn from neoclassical and endogenous growth models. As installed capacity grows, the share of generating capacity available to domestic users and to export markets expands, the load-shedding constraint that hobbled the economy between 2008 and 2017 is removed, and the resulting reliability dividend feeds through to manufacturing, services, and household productivity. The export channel, in addition, brings in foreign exchange and connects the country to a regional power market that is itself growing fast. The empirical contribution of exports is small in this sample mainly because the bulk of export flows are recent, but the elasticity is positive and significant even with the short window, which is informative.

The result that GDP does not Granger-cause hydropower capacity or exports is worth a moment of reflection. In many countries, energy capacity expands in response to demand. In Nepal over this period, capacity additions have been driven primarily by policy targets, project pipelines and the resolution of long-standing licensing and transmission bottlenecks, rather than by demand-side pressure. This is consistent with the conservation literature's observation that the direction of causality reflects institutional context as much as economic structure (Payne, 2010).

Several policy implications follow. First, the empirical link between capacity and growth means that the pace of project completion matters in macroeconomic terms, not only as a sectoral concern. Delays in approvals, land acquisition disputes, transmission constraints and financial closure problems are not narrow inconveniences. They translate, through the cointegrating relationship, into output that does not happen. Second, the modest but positive export elasticity suggests that the regional market is becoming a genuine channel for growth. Strengthening cross-border transmission, finalising the power trade agreement framework with India, and operationalising the Bangladesh transit arrangement would expand this channel materially. Third, since GDP does not yet Granger-cause hydropower expansion, the country is not in a situation where output growth automatically pulls in new capacity. The investment pipeline depends on policy effort and on the institutional health of the sector. If that effort slackens, the growth contribution will slacken with it.

Several limitations should be noted. The sample is short, and the cross-border export series is even shorter, so the export results in particular should be revisited as more data accumulate. The model assumes structural stability, which is plausible given the CUSUM evidence but cannot fully account for the discrete regulatory and infrastructural changes that characterise the sector. The analysis treats installed capacity as the relevant input, but a richer specification would distinguish between dry-season and wet-season generation, given the strongly seasonal pattern of Nepali hydropower. Future research could usefully extend the system to include the real effective exchange rate, examine the consequences of climate variability for generation, and combine project-level data with the aggregate time series to look at completion-rate effects.

Conclusion

This study set out to ask whether hydropower generation and electricity exports show empirical signs of becoming a new growth engine for Nepal. Using annual data from 1995 to 2023 and a five-variable VECM that controls for capital formation and trade openness, the answer is yes, with caveats. Installed hydropower capacity and electricity exports both Granger-cause real GDP in the short and long run, and the long-run cointegrating equation gives both variables positive and significant elasticities. The reverse direction does not hold, which says that growth is responding to the energy sector rather than dragging it along.

The contribution of capacity is sizable, while the contribution of exports is still modest and reflects the short history of commercial cross-border flows. The next decade will be informative. If the project pipeline continues to deliver and the regional power market matures, the export elasticity should rise materially. If institutional bottlenecks reassert themselves, the growth contribution will fade. For policymakers, the message is that the empirical case for treating hydropower as a strategic sector now has at least preliminary statistical backing, but the size of the prize depends on whether capacity translates into completed projects, completed projects into firm generation, and firm generation into stable exports. Each of those steps is a policy choice, not an automatic outcome.

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