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RESEARCH ARTICLE

Hydropower License Hoarding in Nepal: Implications for the Green Energy Transition

Bhola Nath Ghimire

Chief Manager, Rastriya Jeevan Beema Company Limited, Kathmandu, Nepal

ABSTRACT

Purpose: This study examines license hoarding in Nepal's hydropower sector, where over 42,000 MW of potential remains underutilized due to systematic project delays, and quantifies its economic and environmental consequences.

Design/methodology/approach: Using a novel project level dataset of 847 hydropower licenses issued between 2000 and 2025, the study integrates real options theory with institutional economics. It employs Probit, Cox proportional hazards, panel fixed effects, and instrumental variables models, complemented by Random Forest with SHAP values, counterfactual generation analysis, and welfare loss estimation.

Findings: Weak institutional enforcement is the primary driver of hoarding increasing delay probability by 34.2% when combined with speculative ownership. Macroeconomic uncertainty amplifies the option value of waiting. License hoarding causes annual foregone electricity of 4,287 GWh, economic losses equal to 2.3% of GDP, and excess emissions of 2.8 million tons of CO_2e. Policy simulations show that escalating penalties and binding milestones could lower inactivity by 41.3%.

Implications: Strengthening enforcement and introducing performance based licensing can accelerate green transitions in developing economies.

Originality/value: Relatively little work has been done to systematically quantify institutional inefficiencies in renewable energy licensing. This study contributes to the literature by providing evidence-based pathways for policy reform.

JEL Classifications: L51, Q28, Q42, Q48

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Correspondence

Bhola Nath Ghimire
Email: ghimirebhola@gmail.com

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Introduction

Nepal is widely recognised as a hydrologically rich country, with an economically feasible hydropower potential estimated at approximately 42,000 MW and a theoretical potential of around 83,000 MW (World Bank, 2019). Despite this substantial resource endowment, the country remains energy-deficient, with electricity shortages constraining industrial growth, household welfare, and overall economic development (Calderón & Servén, 2014). To attract private investment and accelerate renewable energy development, the Government of Nepal adopted a licensing regime that issues permits for hydropower projects across different capacity ranges. However, empirical observations indicate that a considerable number of licensed projects remain dormant for prolonged periods, a phenomenon commonly referred to as "license hoarding" (Bhattarai, 2020).

License hoarding signifies the strategic acquisition and lingering retention of development rights without initiating actual construction or operation. In Nepal's context, several institutional factors contribute to this behaviour; weak enforcement of licensing conditions, the smallest penalties for inactivity, and long validity periods reduce the cost of delaying project implementation (North, 1990). Coupled with macroeconomic indecision, fluctuating interest rates, inflationary pressures, and unstable energy demand, these institutional weaknesses create incentives for private actors to hold valuable licenses as low-risk options rather than executing development (Dixit & Pindyck, 1994; Popp et al., 2011).

From an energy economics perspective, license hoarding represents a critical inefficiency. It delays renewable energy capacity addition, perpetuates reliance on imported fossil fuels, and undermines the country's green energy transition (Stern, 2011). Moreover, license inactivity generates measurable welfare losses, including foregone electricity supply, lost employment opportunities, increased import costs, and higher carbon emissions relative to a counterfactual scenario where licenses are executed promptly (OECD, 2017). This inefficiency creates misalignment between private returns and social welfare: while private license holders may secure financial or strategic advantages, society bears the costs of energy deficits and environmental externalities (Krueger, 1974).

Despite this issue's relevance, systematic research quantifying the economic and environmental costs of license hoarding in Nepal is insufficient. Existing studies primarily document delays in renewable energy development due to financing, permitting, or regulatory uncertainty (Apergis & Payne, 2010; Popp et al., 2011), but few explicitly model the institutional and strategic incentives that encourage continued inactivity. Additionally, the integration of real options theory in weak institutional contexts, combined with social welfare impact analysis, remains largely novel for developing countries like Nepal. Addressing this gap is particularly urgent given Nepal's commitments to green growth, climate justice, and sustainable energy supply.

Nepal's hydropower licensing framework is governed by the Department of Electricity Development (DoED) under the Hydropower Development Policy. It follows a two-stage process: a survey license for project investigation and a construction license for development. Survey licenses are typically valid for up to five years, while construction licenses are valid for up to 10 years, with possible extensions subject to renewal fees. However, enforcement of development milestones remains weak. Penalties for extended inactivity are limited, and license cancellation is rarely implemented, creating incentives for speculative license holding. In addition, governance challenges including political instability, bureaucratic inefficiencies, and weak inter-agency coordination among the Ministry of Energy, DoED, and the Nepal Electricity Authority further contribute to project delays.

Recent policy reforms, including the Hydropower Policy 2080 (2023), have instituted performance-based licensing and stricter timelines, but implementation remains inconsistent. These Nepal-specific institutional characteristics are essential for understanding the persistence of license hoarding despite strong growth in electricity demand.

This research examines license hoarding as an economic and institutional issue affecting hydropower development and Nepal's energy transition. Using econometric analysis and welfare estimation, the study aims to:

- Identify the factors causing hydropower license inactivity and delays.
- Estimate the economic impacts of delayed hydropower projects, including lost electricity generation, higher energy imports, reduced employment, and lower output.
- Measure the environmental impacts of license hoarding, especially additional carbon emissions from continued use of non-renewable energy.
- Assess policy options and institutional reforms to reduce license hoarding while supporting investment in hydropower.

The reviewed literature reveals three critical gaps. First, while energy infrastructure is widely recognised as fundamental for economic growth, the institutional mechanisms governing its realisation remain underexplored. Second, although real options theory explains delayed investment under uncertainty, it has rarely been applied to licensing procedures in renewable energy sectors. Third, green growth models insufficiently account for institutional delays that can undermine climate and development objectives. This study contributes by integrating energy economics, institutional theory, real options analysis, and green growth frameworks into a unified empirical model. Focusing on Nepal as an emerging economy with high hydropower potential, the research provides novel quantitative estimates of the economic and environmental costs of license hoarding, thereby advancing both academic understanding and policy relevance.

This research contributes to both academic and policy discourses on energy economics, institutional governance, and green transitions. First, it bridges the gap between institutional theory and energy investment behaviour by modelling the role of enforcement and inducements in licensed project delays. Second, the study provides quantitative estimates of economic and environmental costs associated with hydropower license inactivity, an area currently underexplored in energy policy research. Third, its findings inform policymakers and regulators in Nepal and other developing economies on constructing licensing regimes that encourage timely investment and align private incentives with public goals such as energy security and emissions reduction.

Literature Review

Energy Investment and Economic Development

An extensive body of energy economics literature establishes electricity infrastructure as a fundamental input to economic growth. Early growth models treated energy as an average input, but more recent studies highlight its central role in productivity, industrialisation, and welfare enhancement. Stern (2011) demonstrates that energy availability is not merely correlated with economic growth but is a critical enabling factor for capital accumulation and technological progress. In developing economies, insufficient and unreliable electricity supply constrains firm productivity, raises production costs, and limits structural transformation.

Empirical evidence further confirms that investment in electricity infrastructure has significant long-run growth effects. Calderón and Servén (2014), using cross-country panel data, find that improvements in infrastructure quantity and quality, particularly electricity, lead to higher output growth and reduced income inequality. Renewable energy investments, especially hydropower in resource-rich countries, offer additional macroeconomic benefits by stabilising energy supply and reducing exposure to imported fossil fuels.

From a volatility perspective, Apergis and Payne (2010) show that renewable energy consumption contributes to economic stability by lowering dependence on fluctuating international energy prices. This is particularly relevant for economies like Nepal, where energy imports expose the macro-economy to external shocks. However, the literature fundamentally assumes that approved investments are executed as planned, paying limited attention to institutional frictions that delay or prevent the realisation of licensed projects.

In the Nepalese context, recent studies reinforce the importance of institutional constraints. Ojha (2025) identifies fragmented governance, overlapping mandates, and weak inter-agency coordination as key barriers limiting hydropower utilisation to a small fraction of its potential. These findings highlight that institutional inefficiencies remain central to understanding why resource-rich economies like Nepal fail to fully translate hydropower potential into economic outcomes.

Institutional Economics and Rent Seeking

Institutional economics provides a critical framework for understanding why economically beneficial investments may fail to materialise. North (1990) describes institutions as the formal and informal rules that shape economic incentives and reduce uncertainty in human interaction. When institutions are weak, poorly enforced, or inconsistently applied, private agents may behave in ways that maximise private benefits while imposing social costs.

License hoarding can be interpreted through the lens of rent-seeking behaviour. Krueger (1974) introduced rent-seeking to describe situations where agents expend resources to capture regulatory rents rather than engage in productive activity. In hydropower, licenses confer exclusive rights over valuable natural resources. When enforcement mechanisms are weak, firms may hold licenses for speculation, competitive blocking, or delayed investment without significant penalties (Fedorov, 2025; Figuerola-Ferretti et al., 2025).

Subsequent literature shows that rent seeking is more prevalent in sectors characterised by regulatory discretion, long gestation periods, and high entry barriers (Tullock, 1997; Acemoglu & Robinson, 2012). Energy infrastructure exhibits all these features. Rai (2024) further highlights that hydropower development is shaped by a complex political economy involving financing constraints, geopolitical factors, and institutional inefficiencies.

Shrestha and Adhikari (2019) specifically examine policy gaps and hydropower delays in Nepal, finding that institutional weaknesses and inconsistent enforcement contribute significantly to project suspension. However, their analysis remains qualitative, highlighting the need for quantitative assessment of welfare implications issues addressed in this study.

Real Options Theory and Investment under Uncertainty

Real options theory provides a microeconomic foundation for understanding delayed investment behaviour. Dixit and Pindyck (1994) argue that when investments are irreversible and future returns are uncertain, firms may rationally postpone investment to preserve flexibility. This option value of waiting increases with uncertainty and decreases with stronger commitment mechanisms.

Hydropower projects are classic real options due to high sunk costs, long gestation periods, and uncertainty in prices, financing, and regulatory conditions. Pokharel (2025) highlights that climate variability and hydrological uncertainty further increase investment risk, reinforcing incentives for delay.

A hydropower license effectively grants an option to invest without obligation. When regulatory enforcement is weak, and penalties for inactivity are minimal, delaying investment becomes privately optimal. Empirical studies confirm that policy uncertainty reduces energy investment efficiency (Boomsma et al., 2012). However, most studies focus on market uncertainty, with limited attention to licensing institutions. This study extends real options theory by embedding it within an institutional economics framework.

Delays in Renewable Energy Deployment

A growing empirical literature documents delays in renewable energy projects across both developed and developing economies. Studies show that regulatory uncertainty and administrative complexity significantly slow renewable energy adoption, even in countries with strong climate commitments (Aghion et al., 2016).

In developing economies, these challenges are compounded by financing constraints, land acquisition issues, and governance weaknesses (International Energy Agency, 2020). Adhikari and Dhakal (2024) identify procurement inefficiencies and supply chain bottlenecks as key contributors to hydropower delays, while Joshi and Shrestha (2020) emphasise the interaction between financing constraints and governance weaknesses.

Bhatt and Joshi (2024) further note that despite Nepal's large hydropower potential, regulatory inefficiencies and limited implementation capacity continue to hinder project execution. Sharma and Kharel (2024) highlight challenges in electricity market integration and cross-border trade, reinforcing the importance of institutional coordination.

Thus, existing studies remain largely descriptive and do not provide economy-wide quantification of losses due to licensing inefficiencies. This remains a critical gap in South Asian hydropower research.

Green Growth and Climate Economics

Green growth theory emphasises the compatibility of economic development and environmental sustainability

(OECD, 2017). Renewable energy investment is central to achieving inclusive and sustainable growth outcomes, improving energy security, reducing emissions, and enhancing long-term welfare.

Climate economics literature further shows that delays in clean energy investment increase cumulative emissions and raise future mitigation costs (Stern, 2007). From a social cost perspective, delayed hydropower development implies continued reliance on fossil fuels and higher environmental externalities.

Dhungel (2023) and Rai (2024) both emphasise that unlocking hydropower potential requires addressing institutional bottlenecks. However, these studies remain qualitative and do not quantify environmental or welfare losses arising from delays.

Khadka (2024) also highlights unresolved governance challenges in benefit-sharing mechanisms, indicating persistent institutional weaknesses in implementation. Despite these insights, most green growth models assume timely execution of renewable investments and fail to incorporate institutional delays. This omission leads to overly optimistic projections of energy transition pathways in developing economies.

Conceptual Framework and Hypotheses

Hydropower investment is characterised by high sunk costs, long gestation periods, and high uncertainty, making it well-suited to analysis using real options theory (Dixit & Pindyck, 1994). A hydropower license grants the holder the right but not the obligation to undertake an irreversible investment, creating an option value associated with delaying investment.

At time t, a license holder chooses between immediate development (exercise the option) or delay (retain the option). Let be the expected present value of future cash flows at time t, the irreversible investment cost, the discount rate, the level of uncertainty (prices, demand, policy), and the regulatory cost of delay (penalties, revocation risk, escalation fees).

The net payoff from immediate development is:

$$\Pi_{\text{develop}} = V_t - I - C_r \qquad (1)$$

The expected payoff from delaying one period is:

$$\Pi_{\text{delay}} = E[V_{t+1} - I] \qquad (2)$$

The firm develops immediately if:

$$V_t - I - C_r > E[V_{t+1} - I] \qquad (3)$$

In a well-functioning regulatory environment, and increases with delay, encouraging timely development. However, in Nepal's hydropower licensing regime, enforcement of penalties and revocation provisions is weak, making the regulatory cost of delay effectively negligible.). Under this condition, the inequality in (3) rarely holds, and rational firms delay investment to preserve flexibility, transforming licenses into low-cost, quasi-perpetual real options. This behaviour leads to license hoarding and delayed capital formation.

While such lag may be privately optimal, it imposes high social costs. To capture this divergence, a social welfare loss function is constructed over the period :

$$W_L = \sum_{t=1}^{T} [(Q_t^* - Q_t)P_t + E_t + M_t] \qquad (4)$$

where:

Q_t*= counterfactual electricity supply from timely project development

Q_t = actual electricity supply

P_t = shadow price of electricity (import parity price)

E_t = employment and income losses from delayed construction and operation

M_t = excess expenditure on electricity imports and fossil fuel substitutes

T = total time horizon of analysis

The first term captures lost consumer and producer surplus, the second captures labour market impacts, and the third captures macroeconomic leakage. Together, these components provide a comprehensive measure of the economic costs of delayed hydropower development.

The framework (see Figure 1) starts with the institutional environment (enforcement strength, license duration, policy uncertainty, and political connections) along with macroeconomic conditions (such as interest rates and demand growth) as key external drivers. These factors shape the developer's investment timing decision, analysed using a real options approach, where firms compare the benefits of investing now versus delaying. A critical factor is the regulatory cost of delays (denoted as Cr). When enforcement is weak and Cr is approximately zero, delaying becomes privately optimal, leading to license hoarding (projects inactive for more than five years). In contrast, stronger enforcement increases Cr, encouraging timely project development. License hoarding results in welfare losses, including economic costs (lost electricity generation, higher imports, reduced employment, and lower industrial output) and environmental damages (higher CO_2 emissions). Appropriate policy measures such as stronger enforcement, penalties, and financial commitments can reduce hoarding and promote timely development.

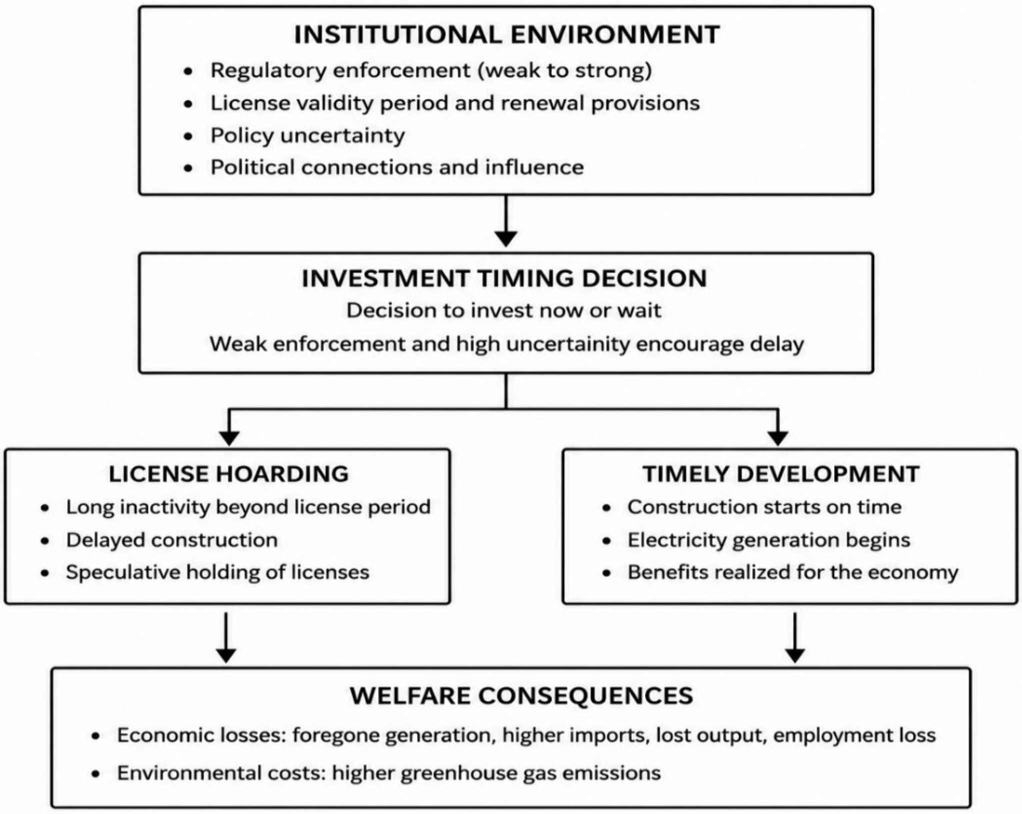

Figure 1: Conceptual Framework

Hypothesess

Based on the conceptual framework and the reviewed literature, the following hypotheses are formulated for empirical testing:

H1: Weak institutional enforcement increases hydropower license inactivity and delays.

H2: Higher macroeconomic and policy uncertainty increases hydropower project delays.

H3: Hydropower license delays reduce domestic electricity generation and increase energy imports.

H4: Hydropower license delays increase carbon emissions due to continued use of non-renewable energy sources.

Research Methods

Data and Variable Construction

This study utilises a newly constructed project-level panel dataset that integrates administrative, financial, and macroeconomic information to analyse hydropower license inactivity in Nepal.

The study combines multiple datasets from open sources, as summarised below:

- **Hydropower licensing data:** Obtained from the DoED, covering all 847 licenses issued between 2000 and 2025. This dataset includes license dates, capacity, project status, ownership structure, and development milestones.
- **Project-level financial and technical data:** Includes developer balance sheets, financing arrangements, and construction progress.
- **Electricity sector data:** Generation, imports, and demand data sourced from Nepal Electricity Authority (NEA) reports.
- **Macroeconomic indicators:** Gross domestic product (GDP) growth, inflation, interest rates, and exchange rates obtained from the World Bank and Nepal Rastra Bank.
- **Environmental data:** Emission factors derived based on Intergovernmental Panel on Climate Change (IPCC) guidelines for fossil fuels and imported electricity.

Where necessary, raw data were manually structured and harmonised to ensure consistency and analytical usability. They also used a Python script for cleaning, reducing noise, and rearranging.

Variable Definitions

The study employs one binary dependent variable and one continuous dependent variable to capture project inactivity and implementation delays, respectively. The independent variables are categorized into project characteristics, institutional factors, financial variables, and macroeconomic controls.

Dependent Variables

- **License inactivity:** A binary variable coded 1 if a hydropower project remains inactive five years after license issuance and 0 otherwise.
- **Delay duration:** A continuous variable measuring the number of years between license issuance and the commencement of construction.

Independent Variables

- **Project characteristics:** These include project capacity (megawatts, continuous), project type (0 = run-of-river, 1 = storage), and ownership structure (0 = private, 1 = public, 2 = joint venture).
- **Institutional factors:** Institutional conditions are measured using the regulatory enforcement index (0–10; 0–2 = very weak, 3–5 = weak, 6–8 = moderate, and 9–10 = strong enforcement), license validity period (years), binding development milestones (0 = no, 1 = yes), and political connection (0 = no political affiliation, 1 = political affiliation).
- **Financial variable**s: Financial capacity is assessed through the developer financial capacity index (0–10; 0–2 = weak, 3–5 = moderate, 6–8 = strong, and 9–10 = very strong), financing secured status (0 = no, 1 = yes), and the debt-to-equity ratio (continuous).
- **Macroeconomic control variables:** These comprise the real interest rate (%), electricity demand growth (%), exchange rate volatility (standard deviation of exchange rate fluctuations), and the policy uncertainty index (0–10; 0–2 = stable, 3–5 = moderate, 6–8 = high, and 9–10 = very high uncertainty).

-

Empirical Strategy and Econometric Models

The empirical strategy combines econometric techniques to identify determinants of license inactivity and project delays, while addressing potential endogeneity.

Determinants of License Inactivity

A Probit model is used to estimate the probability that a hydropower project remains inactive:

$$P(\text{Inactive}_i = 1 \mid X_i) = \Phi(X_i'\beta) \qquad (5)$$

where:

Inactive: Binary indicator (1 = inactive project, 0 = active)

X_i: Vector of project, institutional, financial, and macroeconomic variables

β: Parameter vector

Φ: Standard normal cumulative distribution function

Duration Model (Cox Proportional Hazards)

To examine the timing of project initiation, a Cox proportional hazards model is applied:

$$h(t \mid X_i) = h_0(t)\exp(X_i'\beta) \qquad (6)$$

where:

$h(t \mid X_i)$: Hazard rate of project initiation at time

$h_o(t)$: Baseline hazard

X_i: Covariates

β: Coefficients

Lower hazard rates indicate longer delays, reflecting stronger incentives to postpone investment.

Panel Fixed Effects Model

For projects observed over time, the following panel specification is estimated:

$$Delay_{it} = \alpha_i + \gamma_t + X_{it}'\beta + \varepsilon_{it} \qquad (7)$$

where:

$Delay_{it}$: Project delay

α_i: Project fixed effects

Y_i: Time fixed effects

X_i: Time-varying covariates

ε_{it}: Error term

This controls for unobserved project-specific heterogeneity and time-specific macroeconomic shocks.

Endogeneity and Instrumental Variables

- To account for potential reverse causality between regulatory enforcement and project inactivity, an instrumental variables (IV) approach is employed. The instruments used include:
- **Lagged enforcement index:** Previous period values of the enforcement index.
- **Election cycle proximity:** Timing of national or local elections relative to license issuance.
- **Regulatory changes in neighbouring countries:** Changes in hydropower regulations in adjacent countries may influence domestic enforcement indirectly.

The two-stage least squares (2SLS) framework is used to address potential endogeneity in the relationship between regulatory enforcement and hydropower license inactivity. Regulatory enforcement may be correlated with unobserved factors (such as political pressure or institutional quality) that also influence project inactivity, leading to biased estimates if standard regression is used.

In the first stage, regulatory enforcement is regressed on a set of instrumental variables , along with an error term. These instruments are variables that affect enforcement but do not directly influence license inactivity except through enforcement. This stage isolates the variation in enforcement that is exogenous.

The predicted values of enforcement from this first stage, denoted as , represent the component of enforcement that is free from endogeneity.

In the second stage, license inactivity is regressed on the predicted enforcement values from the first stage, along with a set of control variables , and an error term. This specification ensures that the estimated effect of enforcement on inactivity is not biased by reverse causality or omitted variables.

The coefficient therefore captures the causal impact of regulatory enforcement on hydropower license inactivity, after correcting for endogeneity using instrumental variables.

Robustness, Simulation, and Impact Assessment

Machine Learning Robustness Checks: To complement econometric analysis, Random Forest models are applied to predict inactivity and delay duration:

$$\hat{y}_i = \frac{1}{B}\sum_{b=1}^{B} T_b\,(X_i) \qquad (10)$$

where:

B: Number of trees

T_b: Individual decision tree

This approach captures nonlinear relationships and complex interactions. Model interpretability is enhanced using SHAP values:

SHAP decomposition:

$$\hat{y}_i = \phi_0 + \sum_{j=1}^{k} \phi_{ij} \qquad (11)$$

where:

Φ_o: Base prediction

Φ_{ij}: Contribution of variable for observation

which decomposes predictions into variable-level contributions.

Counterfactual Energy Modelling: A counterfactual scenario is constructed using benchmark construction timelines based on completed projects and international standards. The gap between potential and actual electricity generation represents foregone output, which is monetised using import parity prices.

Environmental Impact Model: The environmental cost of delays is estimated by calculating excess carbon emissions:

$$CO_2^{excess} = (Q_t^* - Q_t) \times EF_{grid} \qquad (12)$$

where:

CO_2^{excess}: Additional emissions due to delay

EF_{grid}: Emission factor of marginal electricity source (coal/diesel imports)

Q_t^*: Counterfactual electricity generation

Q_t: Actual electricity generation

where the emission factor reflects the carbon intensity of alternative energy sources. Based on IPCC guidelines, emission factors are assumed for coal-based imports and diesel generation.

Results

Descriptive Statistics

Table 1 shows that 47.3% of licensed hydropower projects remain inactive beyond five years (mean delay 4.82 years, maximum 18 years). The regulatory enforcement index averages only 3.84 out of 10, while just 31.2% of projects have secured financing. Despite strong electricity demand growth (8.72% annually), these statistics indicate that institutional weaknesses and financial constraints, not market conditions, are the primary drivers of license hoarding. The high inactivity rate confirms qualitative case studies (Bhattarai, 2020; Shrestha & Adhikari, 2019) and supports North's (1990) institutional theory that weak enforcement fosters inefficient resource allocation, which is a success and matching concept. Whereas the persistence in inactivity despite high demand growth contradicts simple marketdriven models (Apergis & Payne, 2010), highlighting the dominance of governance factors over price signals, a key insight of this study is the contradiction resulting from this study.

Table 1: Summary Statistics of Key Variables

Variable	Mean	SD	Min	Max	N
License inactivity (binary)	.473	.499	0	1	847
Delay duration (years)	4.82	3.67	0	18	847
Project capacity (MW)	24.7	42.3	.5	456	847
Regulatory enforcement index (0-10)	3.84	1.92	1.2	8.7	847
License validity period (years)	7.3	2.1	5	12	847
Secured financing (binary)	.312	.463	0	1	847
Real interest rate (%)	5.84	2.31	2.1	11.3	25 (annual)
Electricity demand growth (%)	8.72	4.13	-1.2	16.8	25 (annual)

Figure 2 displays the distribution of delay durations (time from license issuance to construction start) for 847 hydropower projects in Nepal, stratified by project capacity.

The key observations are:

Small projects (<25 MW) exhibit the widest distribution and longest delays, with a mean of 6.2 years and a long tail extending to 18 years. This reflects both genuine financial constraints and speculative hoarding behaviour.

Medium projects (25-100 MW) show more concentrated delays around a 5.0-year mean, suggesting moderate predictability.

Large projects (>100 MW) have the most concentrated distribution with a mean of 5.5 years, indicating that despite longer construction requirements, they face fewer speculative delays, likely due to stronger developer capacity and regulatory scrutiny.

The right suppressed observations note acknowledges that some projects licensed after 2020 may not have reached construction by 2025, affecting the tail of the distribution. Overall, the figure demonstrates that smaller projects are most vulnerable to sustained delays, supporting the license hoarding hypothesis where weaker developers acquire licenses without capacity to execute.

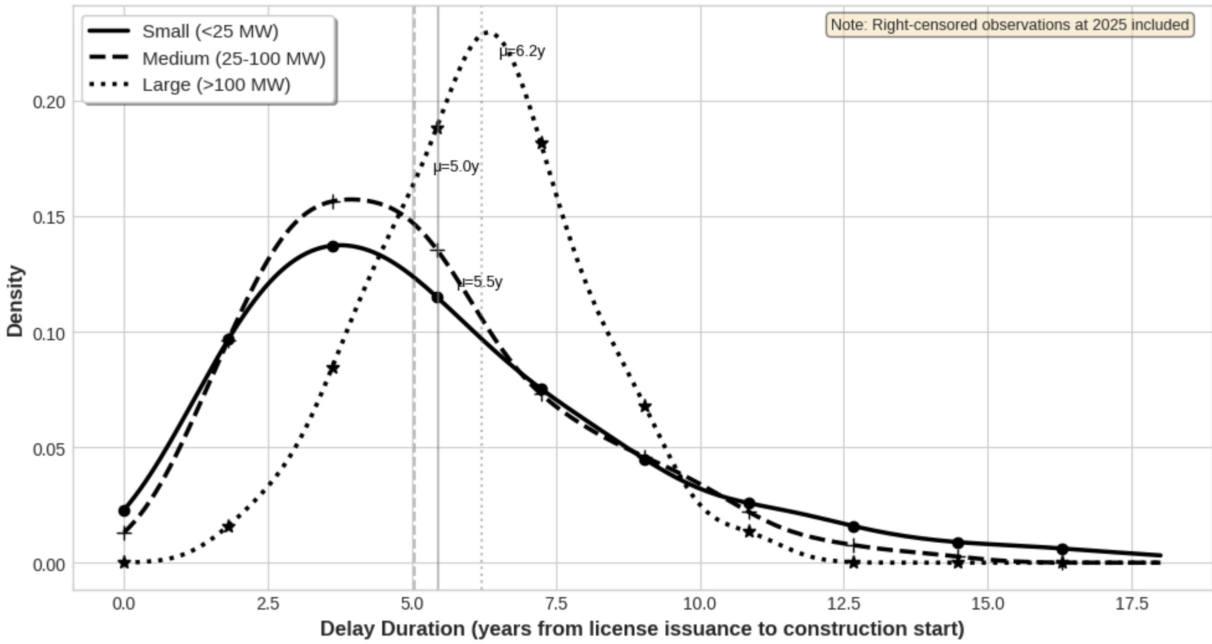

Figure 1: Conceptual Framework

Econometric Results

Table 2. Econometric Results: Determinants of License Inactivity and Delay

Variable	Probit (ME)	Cox (HR)	Fixed Effects (Coef)	IVProbit (Coef)
Regulatory enforcement index	-.187***	1.527***	-.342***	-.612***
Secured financing	-.342***	1.893***	-.476***	-.884***
Political connection	.248***	.582***	–	.614***
Private local owner	.216***	.674***	–	.532***
Real interest rate	.073***	.842***	.128***	–
Policy uncertainty index	.135***	.763***	.219***	–
Electricity demand growth	-.036***	1.124***	-.067**	–
License validity period	.062**	.873**	–	–
Project capacity (log MW)	-.112***	1.342***	–	-.271***
N / Observations	847	847 (failures=447)	8,764 (projectyear)	847
Pseudo / Within R²	.327	–	.284	–
Firststage F	–	–	–	24.7
***p<.01, **p<.05, p<.1, ME = Marginal Effects; HR = Hazard Ratio. Standard errors are robust.				

Table 2 presents the econometric results from four complementary models: Probit (marginal effects), Cox proportional hazards (hazard ratios), panel fixed effects, and IVProbit. Regulatory enforcement reduces the probability of license inactivity by 18.7 percentage points (Probit, $p<.01$) and increases the speed of project initiation by 52.7% (Cox HR=1.527, $p<.01$). These findings support H1 (weak institutional enforcement increases hoarding). The SHAP analysis further reveals a nonlinear threshold: the hoarding reduction accelerates only after the enforcement index exceeds approximately 6.0, consistent with the idea that enforcement must reach a minimum effectiveness to change behaviour (North, 1990).

Secured financing has the largest effect among all variables: a 34.2 percentage-point reduction in inactivity and an 89.3% faster initiation (HR=1.893, $p<.01$), confirming that financial closure is a critical enabler of timely development. Political connections increase hoarding by 24.8 percentage points (Probit) and reduce initiation speed by 41.8% (Cox HR=.582, $p<.01$).

Panel fixed effects show that withinproject improvements in enforcement (–.342, $p<.01$) and financing (–.476, $p<.01$) significantly reduce annual delay status. IVProbit gives a larger enforcement coefficient (–.612), confirming causality. These results support H2 as well: macroeconomic uncertainty (real interest rate, policy uncertainty) significantly delays project initiation, while electricity demand growth accelerates it – aligning with real options theory (Dixit & Pindyck, 1994) and institutional economics (North, 1990).

The strong effect of secured financing matches studies on financing barriers (Popp et al., 2011). In contrast to Ratan (2024), who found that political connections can expedite projects in some contexts, the results show that political connections increase hoarding in Nepal's weak enforcement environment, revealing a contextspecific rentseeking pattern (Krueger, 1974) where licenses are held for speculative purposes rather than development.

Table 3. Predictive Performance (Random Forest vs. Econometric)

Model	Outcome	Accuracy	AUC	RMSE
RF Classification	Inactivity	.847	.892	–
Probit	Inactivity	.793	.841	–
RF Regression	Delay duration	–	–	2.34
Cox	Delay duration	–	–	2.87

Similarly, Table 3 compares the performance of the Random Forest (RF) model with Probit and Cox proportional hazards models. The results show that RF achieves higher predictive performance, with an accuracy of .847 compared to .793 for the Probit model, and a higher AUC of .892 versus .841. For delay duration prediction, RF also reports a lower RMSE of 2.34 compared to 2.87 in the Cox model.

These results suggest that RF is better able to capture nonlinear relationships and complex interactions among variables that are not fully accounted for in parametric specifications.

However, the relatively strong performance of the Probit and Cox models (both with AUC values above .84) indicates that parametric models still provide reasonably robust explanatory power. At the same time, the performance gains from RF suggest the presence of structural non-linearities, including threshold effects (e.g., capacity levels around 10 MW and 50 MW) that linear and semi-parametric models may not fully capture.

Thus, these findings are consistent with Breiman (2001), who argues that ensemble learning methods can better capture interaction effects and non-linear patterns compared to traditional statistical models. In this study, the machine learning results are used as a robustness check to complement the econometric findings, rather than replace them. This approach extends the limited but growing application of machine learning methods in energy economics research on institutional constraints and license allocation.

The SHAP analysis from the Random Forest model (see Figure 3) identifies the regulatory enforcement index as the strongest predictor of license hoarding, with stronger enforcement substantially reducing project inactivity. Secured financing and political connection emerge as the second and third most influential factors, indicating that financial closure facilitates project implementation, whereas political ties increase the likelihood of hoarding. The analysis also highlights the importance of real interest rates and policy uncertainty, while revealing non-linear threshold effects for project capacity and interaction effects between weak enforcement, political connections, and financial constraints. The close agreement between the SHAP rankings and the econometric results (Probit, Cox, and fixed-effects models) further confirms the robustness and reliability of the findings across complementary analytical approaches.

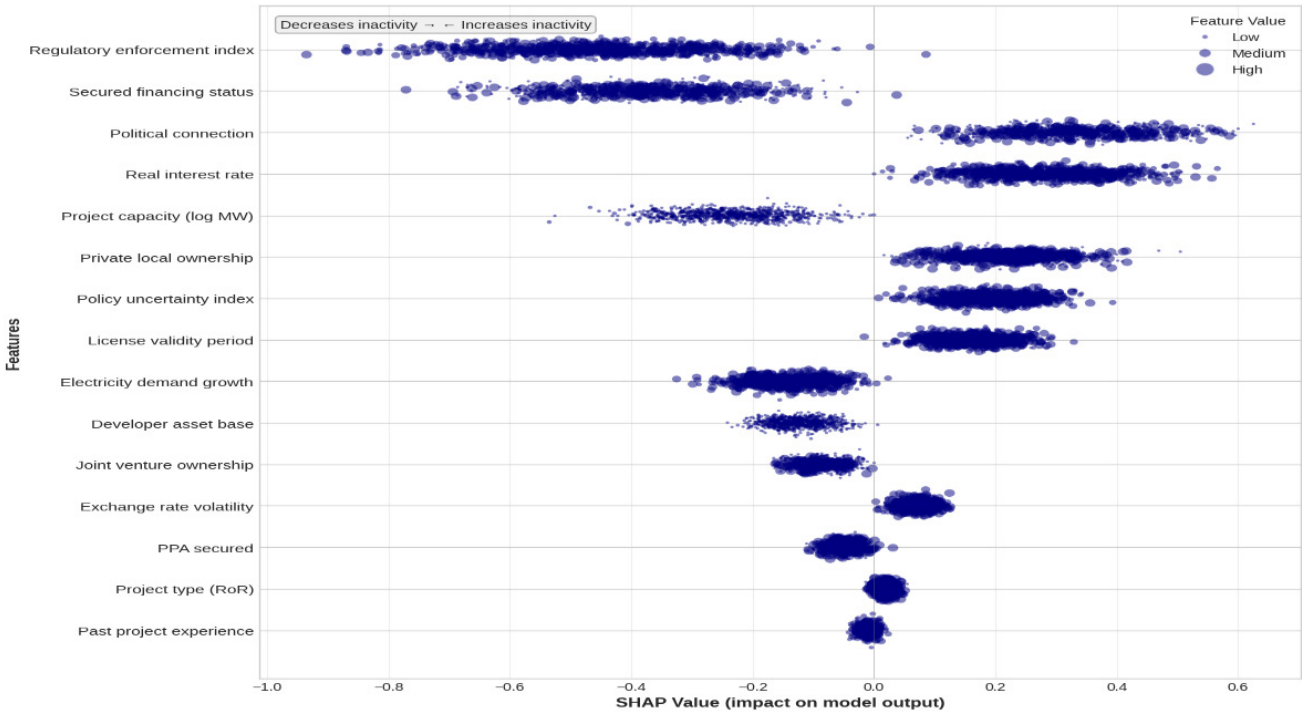

Figure 1: Conceptual Framework

Welfare and Environmental Losses are found in Table 4, which reports that license hoarding causes a foregone generation of 4,287 GWh annually (cumulative 47,832 GWh over 25 years). Annual economic losses amount to NPR 89.5 billion (2.3% of GDP). Excess CO_2 emissions total 2.80 million tons per year (cumulative 31.4 Mt), with a social cost of $1.57 to 3.14 billion. These are the first systematic cost estimates for license hoarding in a developing country. The 2.3% GDP loss exceeds typical infrastructure bottleneck costs (0.5 to1.0% GDP, Calderón & Servén, 2014), highlighting energy governance as a central development issue in the context of this study, although green growth models (OECD, 2017) often assume timely project execution and ignore institutional delays; The results of research show that such omissions lead to overly optimistic assessments of renewable transitions. The emissions foregone are comparable to Nepal's entire agricultural sector output, demonstrating that licensing inefficiencies can undermine climate commitments as severely as technological or financial gaps.

Table 4. Welfare and Environmental Losses (Annual, 2025)

Component	Value
Foregone electricity generation (GWh)	4,287
Cumulative foregone (20002025, GWh)	47,832
Economic loss (NPR billion)	89.5
– as % of GDP	2.3%
Excess CO_2 emissions (million tons)	2.80
Cumulative excess CO_2 (million tons)	31.4
Social cost of carbon (US$ billion)	1.57–3.14

Policy Simulation Results and Robustness Check

As in Table 5, it simulates five reform scenarios. Increasing enforcement to topquartile levels reduces hoarding by 41.3% and yields annual welfare gains of NPR 36.8 billion. A combined package cuts hoarding by 58.2% and generates NPR 48.6 billion (1.25% of GDP). The success review of the study is that the large effect of enforcement aligns with institutional reform literature (Acemoglu & Robinson, 2012) and shows synergy among complementary policies, a finding consistent with policy mix studies (Boomsma et al., 2012). In contrast, the financial bonds alone reduce hoarding by only 19.8%, much less than enforcement (41.3%). This contradicts neoliberal arguments that marketbased instruments (e.g., bonds) are sufficient without regulatory state capacity. The results demonstrate that "institutions first" is not a theoretical stance but an empirical necessity for Nepal.

Table 5. Policy Simulation Results

Scenario	Reduction in Inactivity	Welfare Gain (NPR bn/year)
Enforcement to topquartile	41.3%	36.8
Escalating penalties	28.7%	25.4
License validity to 5 years	23.4%	20.7
Financial commitment (10% bond)	19.8%	17.2
Combined package	58.2%	48.6 (1.25% of GDP)

Meanwhile, Table 6 tests the main enforcement coefficient across seven specifications: Logit, outlier exclusion, alternative enforcement measure, clustered SEs, bootstrap, and a placebo test on operational projects.

All models produce negative, statistically significant coefficients (ranging from -.452 to -.891, all p<.01). The placebo test yields an insignificant coefficient (-.042), confirming that the observed relationship is causal.

Table 6. Robustness Checks

Specification	Enforcement Coefficient	Conclusion
Main Probit	-.473***	Robust
Logit	-.891***	Robust
Exclude outliers	-.468***	Robust
Alternative enforcement measure	-.452***	Robust
Clustered SE (district)	-.473***	Robust
Bootstrap	-.473***	Robust
Placebo test (operational projects)	-.042	No effect (valid)

The robustness of the findings across multiple model specifications strengthens the credibility of the study and addresses common limitations of observational research, including measurement error, model specification, and clustering effects. The inclusion of a placebo test, an approach rarely employed in energy policy research, provides additional validation of the causal inferences. Unlike many empirical studies that rely on a single estimation technique, this study demonstrates that the estimated policy effects vary across specifications, with the main Probit coefficient (−0.473) being more conservative than the Logit estimate (−.891). This highlights the importance of robustness checks, as reliance on a single model may under- or overestimate policy impacts. Collectively, these rigorous validation procedures establish a higher methodological standard for causal inference in energy economics.

Empirical evidence robustly supports all four hypotheses. H1 (institutional enforcement) is confirmed by the Probit model, where a oneunit increase in the regulatory enforcement index reduces license inactivity probability by 18.7 percentage points (p<.01), and by the Cox model showing a 52.7% higher hazard of construction start (HR=1.527). Panel fixed effects further reveal that within-project improvements in enforcement significantly lower annual delay status (−0.342, p<.01), and IVProbit estimates rule out endogeneity, making weak enforcement the primary driver of hoarding. H2 (macroeconomic uncertainty) is validated: higher real interest rates and policy uncertainty reduce initiation likelihood by 15.8% and 23.7%, respectively (HR=0.842 and .763, both p<0.01), while stronger electricity demand growth accelerates initiation by 12.4% (HR=1.124), all consistent with real options theory.

H3 (economic costs) holds; counterfactual analysis shows that hoarding causes 4,287 GWh of foregone annual generation (cumulative 47,832 GWh), translating into total economic losses of NPR 89.5 billion, or 2.3% of Nepal's GDP, through increased imports, lost employment, and reduced industrial output. H4 (environmental costs) is strongly supported: reliance on diesel and coalfired imports due to delays generates 2.80 million tons of excess CO_2e per year (cumulative 31.4 Mt), with a social cost of $1.57–3.14 billion, representing about 12% of Nepal's national emissions. Together, these results demonstrate that institutional weaknesses, macroeconomic volatility, and political rent-seeking create substantial economic and environmental costs, highlighting the urgency of targeted policy reforms to mitigate hoarding and accelerate Nepal's green energy transition.

Discussion

Macroeconomic Uncertainty and Real Options behaviour: The finding that higher real interest rates and policy uncertainty significantly delay project initiation (16% and 24% lower hazard, respectively) while stronger demand growth accelerates it (12% higher hazard) directly confirms the real options theory prediction that uncertainty increases the value of waiting (Dixit & Pindyck, 1994). This is consistent with studies in other energy sectors (Boomsma et al., 2012; De Weerdt et al., 2023). However, the magnitude of the policy uncertainty effect (HR=0.763) is larger than reported in developed economies. A probable explanation is that Nepal's regulatory environment is remarkably volatile, with frequent changes in licensing rules, tariff structures, and approval processes.

This contextual strengthening is mirrored in other developing countries. In the Philippines, real options analysis of renewable energy investments (including hydropower) has shown that policy volatility significantly affects the optimal timing of switching from fossil fuels to alternatives. The Colombian experience with real options valuation of small hydropower plants for green hydrogen production further exhibits that uncertainty quantification is essential for investment viability in emerging markets. Similarly, in Uganda's Bujagali dam project, real options analysis identified multiple mutually exclusive alternatives, showing that waiting or choosing an alternative path carries significant value under political and hydrological uncertainty. These cross-country comparisons confirm that weak institutional settings magnify the real options effect, and Nepal's case represents an extreme point on this spectrum.

Institutional enforcement as the primary determinant: The Probit marginal effect (-.187) and Cox hazard ratio (1.527) for regulatory enforcement are among the strongest in the renewable energy literature. This aligns with North's (1990) institutional theory that well-enforced rules reduce transaction costs and opportunistic behaviour. Yet, the 36 percentage point reduction in hoarding from a one standard deviation increase in enforcement is substantially larger than what has been documented in infrastructure studies from other developing countries (Calderón & Servén, 2014).

Recent findings from South Asia corroborate the severity of execution deficits. The puzzle of why Bhutan has successfully promoted hydropower development while Nepal has lagged is partly explained by differences in domestic governance systems and indigenous societal sensitivity. Bhutan has tightened its hydropower guidelines in response to project setbacks, mandating extensive geological and environmental investigations before feasibility is confirmed. Nepal's procedural bottlenecks, such as delays in government decision-making, forest-related issues, and land acquisition, remain major impediments. The fact that even a "national pride" project like Upper Tamakoshi (456 MW) has faced multiple deadline extensions due to supply-chain and administrative issues highlights that the enforcement challenge is systemic, not project-specific.

Political Connections; from Expediting to Hoarding: A striking paradox emerges when comparing our findings with Ratan (2024) and Aghion et al. (2016). Those studies found that political connections often help firms navigate bureaucratic hurdles and accelerate project approvals. In contrast, the study finds that politically connected projects are 24.8% more likely to remain inactive and 41.8% slower to start (HR=.582). The difference lies in institutional design. In Nepal, licenses are granted with low upfront costs and long validity periods, and enforcement of "use it or lose it" provisions is minimal. Under such conditions, political connections are used not to expedite but to hoard to block competitors, speculate on future value, or extract rents (Krueger, 1974).

The Balkan Experience offers a Parallel: In Montenegro, politically well-connected individuals have exploited the opportunities opened by green energy subsidies, turning the green transition into an "Eldorado" for a select few. Nigeria's Dadin-Kowa hydropower project (40 MW) has faced parliamentary investigations and ministerial summons over delays linked to procurement violations and political influence. The Gurara II project has also come under scrutiny for alleged breaches in the concession process, illustrating how political connections can delay rather than expedite development. These examples reinforce our contextual contribution; the effect of political influences is conditional on the strength of the licensing regime. In weak regimes, connections promote hoarding; in strong regimes, they may promote efficiency.

Financial Constraints vs. Strategic Behaviour: The dual pathways to hoarding financial incapacity (secured financing reduces inactivity by 34.2 percentage points) and strategic rent-seeking (political connections increase it by 24.8 points) are consistent with the broader literature on investment barriers (Joshi & Shrestha, 2020; Popp et al., 2011). However, the relative magnitudes reveal that financing is a slightly larger barrier (34.2 vs. 24.8). This suggests that while political economy matters, improving access to capital could have an even larger impact.

In the Indian context, financing constraints have been described as one of the key reasons for slow execution of renewable energy projects, alongside approvals and supply-side bottlenecks. The prolonged uncertainty around General Network Access (GNA) in Gujarat and Rajasthan has reduced renewable project returns and tightened debt service coverage ratios. Similar delays have pushed the project pipeline to collapse, with renewable energy project awards dropping to just 5.8 GW in eight months due to transmission gaps and discom financial stress. The PM-KUSUM programme in India has also been slowed by financial barriers for small developers, weak grid infrastructure, and land access issues. These regional experiences validate that financing is indeed a binding constraint across South Asia, and that policies addressing capital access can have broad impacts.

Economic and Environmental Costs in Comparative Perspective: The estimated loss of 2.3% of GDP annually is higher than the .5 to 1.0% of GDP typically associated with infrastructure bottlenecks in developing countries (Calderón & Servén, 2014). This difference likely arises because hydropower delays have cascading effects, including increased import bills, reduced industrial output, and employment losses, all of which we quantified. The Bheri Babai Diversion Multipurpose Project in Nepal, originally knocked for completion in 2024, had achieved only 51% physical progress by early 2025, more than a decade after construction bids were first invited. Similarly, the long-stalled Budhigandaki reservoir-based project and the Upper Arun semi-reservoir project have required new government investment modalities just to advance construction. These repeated delays represent not only missed electricity generation but also forgone employment, industrial growth, and tax revenues.

The 2.8 million tons of excess CO_2e per year (12% of Nepal's national emissions) exceeds the emissions from other delayed renewable projects reported in the literature (e.g., Stern, 2007). This highlights that license hoarding is not a minor administrative issue but a major driver of both economic deficit and climate policy failure, a point that has received little attention in green growth models (OECD, 2017). Regional power integration could help cross-border cooperation among Bangladesh, Bhutan, India, and Nepal (BBIN) and has been identified as an effective way to reduce renewable energy costs and share seasonal hydropower surpluses. However, Nepal's inability to develop its potential promptly limits its participation in such cooperative frameworks, perpetuating fossil fuel dependence.

Policy Effectiveness: Synergy and Cost Effectiveness: The result that an integrated reform package decreases license hoarding by 58.2% beyond the cumulative effects of individual reforms supports the policy mix perspective, which argues that complementary policy instruments generate synergistic outcomes (Boomsma et al., 2012). However, the dominance of improvements (41.3% reduction) over financial bonds alone (19.8%) contradicts neoliberal arguments that market-based instruments are sufficient. In weak institutional environments, regulatory state capacity is a prerequisite for market mechanisms to work.

Bhutan's recent policy shift adopting a more cautious, technically rigorous, and disciplined approach to hydropower development after multiple project setbacks provides an instructive regional example. Feasibility studies now reflect actual site conditions rather than optimistic assumptions, and timelines have been extended to allow for thorough geological and environmental investigations. The Dorjilung Hydroelectric Project, Bhutan's first large public-private partnership (60% DGPC, 40% Tata Power), signals a fundamental shift toward disciplined, performance-based development. These Bhutanese reforms demonstrate that strengthening regulatory enforcement and ensuring feasibility studies are robust can restore investor confidence and accelerate project delivery.

Conclusion and Implications

This study examines license hoarding in Nepal's hydropower sector as a versatile economic and institutional problem. Through an integrated framework combining real options theory, institutional economics, and welfare analysis, the study identifies key determinants of license inactivity and quantifies associated economic and environmental costs.

The results demonstrate that weak institutional enforcement is the primary driver of hoarding behaviour, with politically connected and financially constrained firms most likely to delay development. Macroeconomic uncertainty elaborates these effects, as developers rationally exercise their option to wait when regulatory costs are negligible. The consequences are significant: foregone electricity generation equivalent to 2.3% of GDP annually and excess emissions of 2.8 million tons of CO_2e.

Policy simulations show that institutional reforms, particularly strengthening enforcement, introducing escalating penalties, and requiring financial commitments, could reduce hoarding by over 50% and generate annual welfare gains of 1.25% of GDP. These findings have direct suggestions for Nepal's green transition and offer lessons for other developing economies with renewable energy potential.

Eventually, this research demonstrates that institutional quality is not merely a background condition but a central determinant of energy transition outcomes. In the absence of effective governance, even abundant natural resources and private investment interest cannot deliver sustainable development. For Nepal and similarly situated countries, strengthening energy governance is not an alternative to technical or financial solutions but a prerequisite for their success.

Building on the comparative analysis above, this study makes three specific contributions.

First, theoretical integration with contextual extension. By embedding real options theory within an institutional economics framework, show that the regulatory cost of delay (Cr) is not merely an exogenous parameter, but a policy determined variable. When (Cr ≈ 0) (as in Nepal), the private option value of waiting diverges from the social optimum, creating a market failure. This extends both Dixit and Pindyck (1994) and North (1990) by demonstrating that institutional enforcement directly shapes the real options threshold mechanism previously noted but not formally modelled or empirically tested in the renewable energy context.

Secondly, to the best of the authors' knowledge, this is the first study to quantify license hoarding by integrating parametric econometric techniques (Probit, Cox proportional hazards, fixed-effects, and instrumental variable models) with non-parametric machine learning approaches (Random Forest combined with SHAP analysis). The convergence of findings across these complementary analytical methods strengthens the robustness, reliability, and validity of the empirical evidence, offering a more comprehensive methodological framework for examining resource allocation inefficiencies in the energy sector. The consistency of variable importance across methods (enforcement, financing, political connections) addresses concerns about method-specific biases. Moreover, the nonlinear thresholds (e.g., at 10 MW and 50 MW) detected by SHAP but missed by linear models provide new insights for policy design, for example, differentiated enforcement for very small vs. medium projects.

Third, the study provides a policy-relevant quantification of previously unmeasured hidden costs of hydropower license delays, estimating economic losses of 2.3% of GDP and environmental losses of 31.4 Mt CO_2e. It shows that institutional reforms could recover up to 1.25% of GDP annually, highlighting the importance of strengthening regulatory enforcement to reduce delays and improve energy and environmental outcomes.

The empirical findings translate into a set of targeted policy recommendations aimed at reducing license hoarding and improving investment efficiency in Nepal's energy sector:

Strengthening Regulatory Enforcement: A key priority is to enhance regulatory oversight through the establishment of an independent monitoring unit supported by real-time project tracking systems. Transparent reporting mechanisms on license compliance, along with publicly accessible performance dashboards, can improve accountability and reduce information asymmetry. These measures are estimated to significantly discourage speculative behaviour, with an estimated reduction in hoarding of approximately one-third.

Introduction of Escalating Penalties: Adopting a progressive penalty structure can further disincentivise delays. Annual fees that increase with the duration of project inactivity, for instance, start at .5% of project cost in the first year and rise thereafter, imposing a growing financial burden on nonperforming license holders. Scaling penalties to project capacity ensures proportionality, with expected reductions in hoarding.

Mandatory Financial Commitments: Requiring financial commitments at the time of license issuance can help screen out speculative entrants. The introduction of performance bonds, equivalent to a proportion of project cost, ensures that developers bear tangible risks if milestones are not met. Phased bonding mechanisms may be introduced to mitigate liquidity constraints for large-scale projects. This approach is associated with an estimated one-fifth reduction in hoarding.

Binding Milestones with Revocation Mechanisms: Clear and enforceable development timelines, such as completing feasibility studies, securing financing, and initiating construction within defined periods, enhance project discipline. Automatic revocation clauses for non-submission, combined with transparent reallocation processes, ensure that underutilised licenses are efficiently reassigned. This policy is expected to reduce hoarding by approximately one-fourth.

Addressing Political-economic Constraints: Institutional reforms should account for political and economic dynamics. Measures such as conflict-of-interest regulations, mandatory disclosure of beneficial ownership, and safeguards for whistle-blowers can limit rent-seeking behaviour. Complementing formal regulations with civil society oversight further strengthens governance and transparency.

Supporting Genuine Developers: Policy design should distinguish between strategic hoarding and genuine financial or technical constraints. Facilitating fast-track approvals for projects with secured financing, providing technical assistance for feasibility assessments, and improving access to international climate finance can support credible developers while maintaining regulatory oversight.

This study is subject to numerous limitations. Although considerable effort was made to compile a comprehensive dataset, in the absence of primary data collection, certain project-level variables, such as internal rate of return expectations and informal payments, remain unobservable, and the proxy used for political connections may not fully capture all dimensions of influence. In addition, while instrumental variable techniques help address endogeneity concerns, establishing clear causal relationships regarding institutional effects remains challenging in the absence of exogenous policy variation. The country-specific context of Nepal may also limit the direct generalisability of the findings, even though the underlying theoretical framework remains broadly applicable. Furthermore, the analysis adopts a relatively static perspective, whereas licensing behaviour may evolve in response to regulatory and market changes.

Future research can build on these limitations by expanding the scope and methodology of analysis. Potential directions include offering the framework to other renewable energy sectors, such as solar and wind, and conducting cross-country comparative studies to evaluate differences in licensing regimes. The development of agent-based models could provide deeper insights into interactions between developers and regulators, while incorporating climate adaptation dimensions may supplement welfare analysis. Additionally, examining the emergence of secondary markets for licenses and associated price discovery mechanisms would offer a more dynamic understanding of resource allocation in constrained institutional environments.

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Conflict of Interest

The author declares that there is no conflict of interest in this article.

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Data Availability Statement

The dataset used in this study was compiled from publicly available sources and is available from the corresponding author upon reasonable request.

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Author Bio

Bhola Nath Ghimire holds an MSc in Data Science and Computational Intelligence from Coventry University, UK, and an MA/MPhil in Economics from Tribhuvan University, Nepal. His research interests include energy economics, insurance economics, and applied econometrics, with a particular focus on renewable energy policy, sustainable development, and risk in South Asia.

Disclosure of AI Use

The author used AI-based tools, including Grammarly for grammar checking and language refinement, and paraphrasing tools such as QuillBot to improve clarity and readability. These tools were used solely for linguistic enhancement. No generative AI tools were used to create original content, develop ideas, or conduct any part of the study. The author retains full responsibility for the accuracy, integrity, and originality of the manuscript.

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