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Game-Theoretic Approaches to Multi-Level Governance Conflicts in Renewable Energy Transitions: Equilibrium Analysis and Strategic Incentives

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Abstract

Renewable energy transitions are increasingly shaped by multi-level governance, where national, regional, and local authorities simultaneously pursue decarbonization objectives, fiscal constraints, and political accountability. These overlapping mandates generate strategic conflicts over siting, permitting speed, grid expansion, cost allocation, and distribution of rents from subsidies and congestion revenues. Game-theoretic methods provide a disciplined way to formalize how heterogeneous objectives and institutional veto points translate into observable policy volatility, delay, and underinvestment. This paper develops a family of models for renewable transition conflicts that combine vertical policy delegation, horizontal jurisdictional externalities, and endogenous private investment under uncertainty. The analysis emphasizes equilibrium characterization under limited commitment, incomplete information about local acceptance costs, and intergovernmental fiscal interactions that distort marginal incentives. Static and dynamic equilibria are compared across Nash, Stackelberg, and Markov-perfect formulations to isolate when coordination failures are structural rather than transient. Strategic incentives are studied for common instrument classes including matching grants, revenue sharing, interconnection pricing, and permitting deadlines, with attention to implementability under incentive compatibility and participation constraints. The models also accommodate endogenous opposition and support as strategic actions by communities and developers, allowing conflict to be interpreted as equilibrium behavior rather than an exogenous friction. The result is an equilibrium-based framework that clarifies which institutional adjustments change best responses, which merely shift rents, and how policy packages can be designed to reduce delay without relying on implausible benevolence assumptions.

1. Introduction

Renewable energy transitions require a sequence of coordinated decisions spanning long planning horizons, large fixed costs, and shared infrastructure [1]. Investment in generation, storage, and transmission interacts with land-use regulation, environmental review, grid interconnection queues, public procurement, and local consent. These decisions are rarely centralized. Instead, they are distributed across multiple governmental levels and agencies with partially aligned objectives and distinct constituencies [2]. A national authority may internalize emissions externalities and security-of-supply concerns, while a regional authority may prioritize industrial development and grid reliability within a territory, and a local authority may place higher weight on visual impacts, property values, or short-run employment patterns. The resulting conflicts are not well represented by a single benevolent planner; they are better treated as strategic interactions among actors with different payoff functions, information sets, and commitment capabilities.

Game theory is useful here not because it adds rhetorical structure, but because it forces explicit modeling of incentives and credible actions. Delays in permitting can be interpreted as equilibrium outcomes of a bargaining game over rents and risk transfers [3]. Overbuilding or underbuilding transmission can arise from free-riding in a network public good. Instability in subsidy regimes can be captured as time inconsistency in dynamic political games. Even local opposition can be formalized as an endogenous action that responds to expected compensation and procedural leverage. Once conflicts are modeled as strategic, the policy question shifts from diagnosing a generic lack of coordination to identifying instrument designs that alter equilibrium incentives subject to institutional constraints [4].

This paper focuses on equilibrium analysis and strategic incentives in multi-level governance conflicts. The

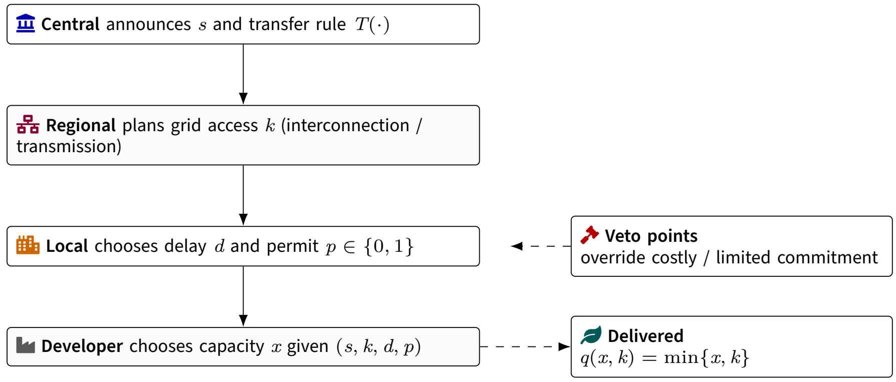

Figure 1. Baseline sequential interaction in multi-level governance: a national support scheme and transfer rule precede regional grid planning, local procedural discretion, and private investment choices.

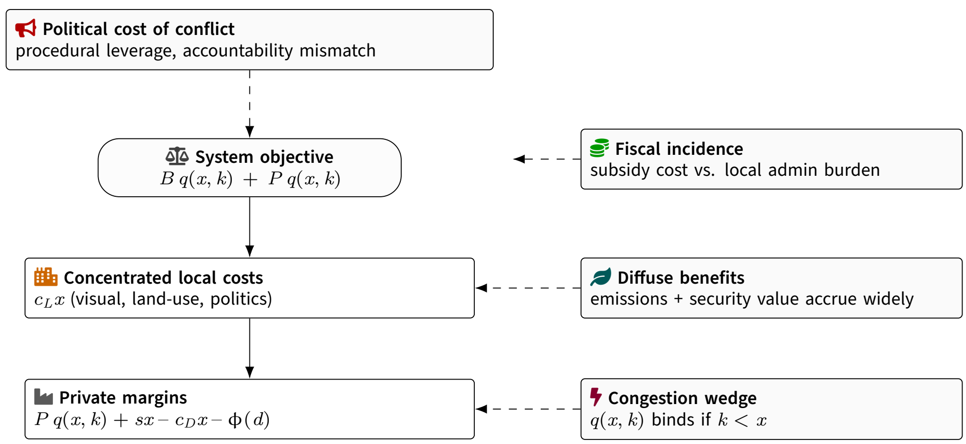

Figure 2. Accountability mismatch as an equilibrium wedge: system-wide benefits are diffuse while costs and procedural power are local; congestion and fiscal incidence further distort marginal incentives across levels.

core modeling choices emphasize three empirical regularities. First, authority is layered, and higher levels frequently cannot perfectly dictate lower-level actions, either due to legal limits or because enforcement is costly and politically constrained [5]. Second, projects create spatially concentrated costs with diffuse benefits, producing systematic wedge problems in local acceptance. Third, investments and policy commitments are intertemporal, so expectations about future policy and future opposition feed back into present actions. The models developed below are intentionally modular. A baseline static game isolates vertical delegation and horizontal spillovers [6]. Mechanism-based extensions incorporate private information about local costs and developer capabilities. Dynamic extensions incorporate uncertainty, learning, and limited commitment, which are central to policy credibility.

The goal is not to claim a universal institutional prescription, but to provide a technically explicit toolkit that can be adapted to different constitutional arrangements. The equilibrium objects of interest include the existence and multiplicity of equilibria, equilibrium comparative statics with respect to intergovernmental transfers and veto power, and implementability of coordination through incentive-compatible contracts [7]. Throughout, the emphasis is on the strategic logic that can explain observed outcomes such as excessive delay, fragmented grid buildout, and volatile support schemes, while also identifying the conditions under which targeted incentive designs can reduce conflict without requiring unrealistically strong central authority.

2. Institutional Architecture and Strategic Environment

A renewable transition within a jurisdiction typically involves at least four classes of actors. A central government sets broad decarbonization targets, carbon pricing rules, or subsidy budgets, and may control national transmission planning or market design. Regional governments manage planning, industrial policy, and sometimes distribution network regulation [8]. Local governments control land-use permissions, community consultations, and elements of environmental review. Private developers choose whether to invest, which technologies to deploy, and how to sequence portfolios. Communities and organized groups influence local authorities through electoral pressure, litiga-

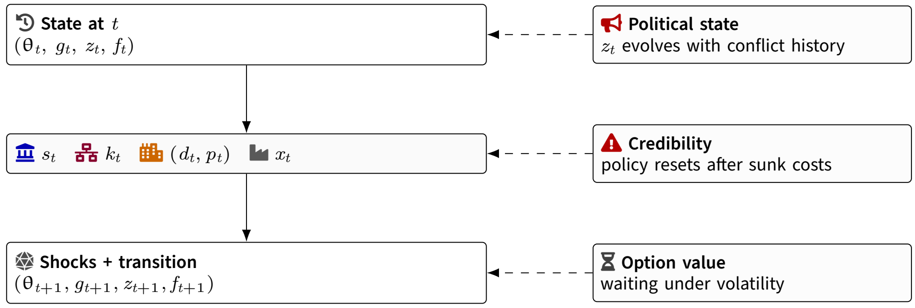

Figure 3. Markov-perfect framing: investment, permitting, and policy are repeated with evolving technology, congestion, political support, and fiscal tightness; limited commitment and volatility generate waiting incentives and persistent conflict.

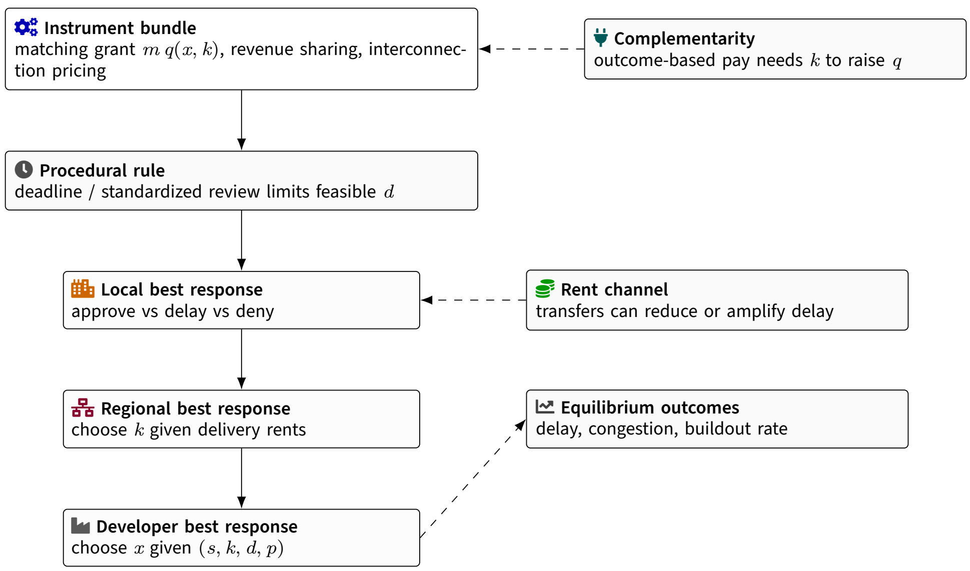

Figure 4. Coupled-instrument logic: outcome-based compensation, procedural constraints, and grid pricing jointly reshape local delay incentives, regional grid investment, and developer entry/scale decisions.

tion, and participation in hearings, and may engage in costly mobilization when they expect adverse impacts [9].

Multi-level governance conflicts are often driven by externalities and accountability mismatches. Benefits from emissions reductions are geographically diffuse, while construction impacts and perceived risks are local. Fiscal systems frequently exacerbate this mismatch when localities bear administrative and political costs but capture limited tax revenue. Conversely, localities may capture certain rents by extracting concessions or imposing delay, particularly when projects are location-specific and developers are sunk-cost sensitive [10]. Regional authorities can become mediators or additional strategic players: they may internalize some spillovers across municipalities, but they may also face their own constituency pressures and budget constraints.

Institutional veto points determine the feasible action sets. Local authorities may have de jure veto power or de facto veto power through procedural delays. Higher authorities may have override mechanisms, but these may be politically costly or legally constrained [11]. The mapping from legal authority to strategic power depends on enforcement costs and on the credibility of threats. For instance, a national authority may threaten to centralize permitting, but if that threat triggers electoral backlash or administrative overload, it may not be credible. These institutional details matter because equilibrium depends on feasible deviations and credible punishments, not merely on stated objectives [12].

Information is also layered. Local authorities and communities may have better information about site-specific impacts and acceptance costs, while national authorities may have better information about system-wide reliability needs and the shadow value of emissions reductions. Developers have private information about costs, learning curves, and financing constraints. This informational asymmetry creates scope for strategic misrepresentation [13]. A locality might exaggerate environmental harms to gain concessions; a developer might overstate cost sensitivity to secure subsidies. Any proposed policy instrument must therefore

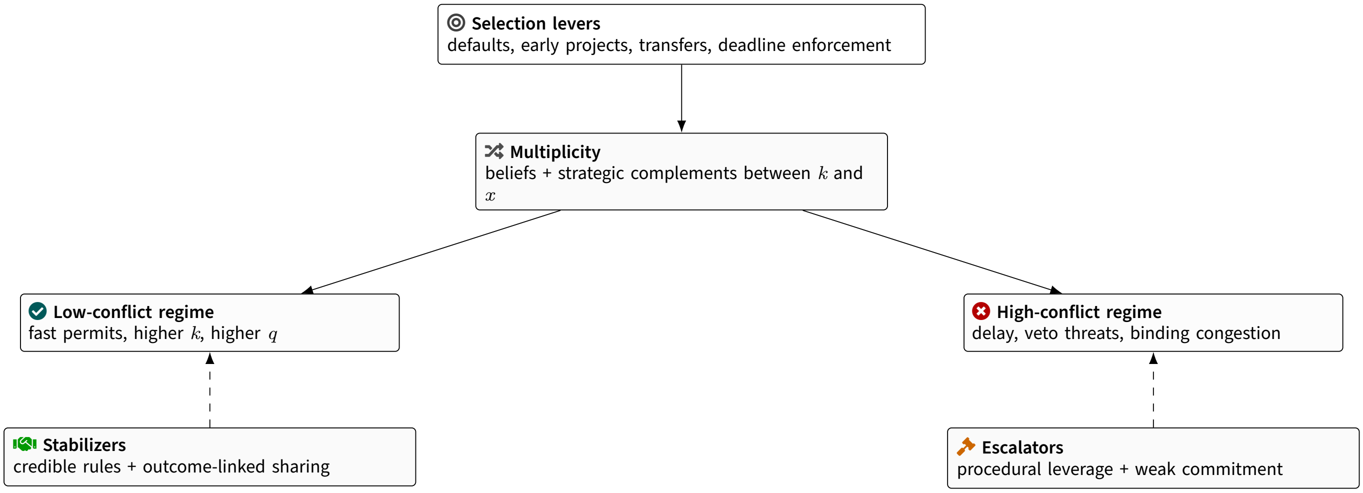

Figure 5. Equilibrium regimes and selection: complementary incentives can support distinct low- and high-conflict equilibria; policy packages matter partly by shifting which regime is risk-dominant or focal.

be evaluated not only for its allocative properties under truthful reporting, but also for its equilibrium properties under strategic reporting.

Finally, time matters. Renewable transitions are sequences of interdependent investments [14]. Transmission upgrades can be lumpy and slow, and generation deployment depends on expectations about interconnection, market prices, and policy durability. Political cycles create periodic opportunities to revise policies, and litigation creates stochastic delays. A static model can identify incentive wedges, but dynamic models are required to analyze credibility and option values. In the following sections, the analysis begins with a tractable baseline game and then adds informational and dynamic structure to capture key strategic phenomena [15].

3. A Baseline Multi-Level Game for Siting, Permitting, and Grid Access

Consider a stylized environment with three governmental levels indexed by $g \in \{C, R, L\}$ for central, regional, and local, and a representative developer indexed by D. The developer chooses an investment scale $x \geq 0$ for renewable capacity at a candidate site. The project requires a local permit decision $p \in \{0, 1\}$, where $p = 1$ grants approval. The project also requires grid access capacity $k \geq 0$ (interpretable as interconnection capacity or complementary transmission investment) chosen by an authority that may be central or regional depending on institutional assignment; for concreteness, let the regional authority choose k. The central authority chooses a subsidy or support parameter $s \geq 0$ and may also set a transfer rule to lower levels [16]. The local authority can impose a delay action $d \geq 0$ that increases developer costs and can also be interpreted as an intensity of procedural scrutiny.

Let system-wide environmental benefit per unit capacity be $B > 0$, valued primarily by the central authority. Let local external cost per unit capacity be c_L, which may be partially internalized by the local authority and community; treat c_L as a site-specific parameter. Let the developer's private marginal cost be c_D, and let delay increase cost via a convex function $\phi(d)$ and reduce the effective net present value through a discount factor that depends on d [17]. Grid access k relaxes a congestion constraint that limits deliverable output to $\min\{x, k\}$, generating an economic value per delivered unit $P > 0$ (market value or avoided cost). For tractability, write delivered quantity as $q(x, k) = \min\{x, k\}$ and approximate with a smooth function when needed, but keep the interpretation that grid capacity can be binding.

Payoffs capture political economy in reduced form. The central authority values decarbonization and reliability, but faces fiscal cost of subsidy and a political cost if local opposition escalates. The regional authority values local economic activity and reliability, but pays a budgetary cost for grid investment. The local authority values local welfare and political support, and can extract concessions through delay [18]. A parsimonious specification is

$$U_C = \alpha_C B\, q(x,k) - \beta_C\, s\, x[19] - \gamma_C \chi(d) \quad (1)$$

$$- \kappa_C \mathbf{1}\{p = 0\}, \quad (2)$$

$$U_R = \alpha_R P\, q(x,k)[20] - \beta_R \psi(k) + \tau_R(s,x) \quad (3)$$

$$- \gamma_R \chi(d), \quad (4)$$

$$U_L = [21] \quad \alpha_L \eta(x) - c_L\, x + T(s,x) + \rho(d,x)[22] - \omega(d), \quad (5)$$

Table 1. Key actors in multi-level renewable governance and their strategic roles

Level / actor	Typical responsibilities	Strategic levers and constraints
Central government (C)	Decarbonization targets, carbon pricing, national support schemes, market design	Subsidy rate s, transfer rules to R and L, potential override powers, but limited commitment and political conflict cost $\chi(d)$
Regional government (R)	Transmission and distribution planning, industrial policy, regional reliability	Grid capacity k, allocation of congestion rents, regional transfers $\tau_R(s,x)$, subject to budget cost $\psi(k)$ and spillovers across jurisdictions
Local government (L)	Land-use permissions, local environmental review, community consultation	Permit p, delay d, local bargaining over $T(s,x)$, political leverage $\rho(d,x)$, exposed to local external cost $c_L x$
Developer (D)	Site choice, technology portfolio, investment scale x	Investment x, project sequencing, litigation or lobbying, responds to s, k, d, and permitting risk in profit Π_D
Communities / groups	Electoral pressure, mobilization, participation in hearings and litigation	Support or opposition campaigns, legal challenges, shaping $\rho(d,x)$ and political cost terms $\chi(d)$ perceived by higher levels

$$\Pi_D \; = \; P\,q(x,k)[23] \; + \; s\,x \; - \; c_D\,x \; - \; \phi(d) \; - \; F, [24] \tag{6}$$

where $\psi(k)$ and $\omega(d)$ are convex cost functions for grid build and administrative effort, $T(s,x)$ is an intergovernmental transfer from the central authority to the locality contingent on observable project characteristics, $\tau_R(s,x)$ is a transfer to the region, $\eta(x)$ captures local economic benefit (jobs, tax base) which may be concave, $\rho(d,x)$ captures local political leverage from delay (for example, delay may increase bargaining power or generate political support from opposition groups), and $\chi(d)$ is an aggregate political cost of conflict perceived by higher levels. The indicator $\mathbf{1}\{p=0\}$ captures an additional central cost when the project is blocked, reflecting missed targets or reputational costs, though it can be omitted when central authority can substitute other sites.

A timing structure determines the game form. A common representation is a sequential game: the central authority chooses s and transfer rule parameters; the regional authority chooses k; the local authority chooses delay d and permit p; the developer chooses x given anticipated approval and grid access. Alternative timing is possible, but this sequence captures the idea that support schemes are announced first, network planning is medium-term, and permitting decisions occur after developers propose projects [25]. The equilibrium concept is subgame perfect equilibrium when actions are observed and commitment is credible within stages.

To avoid degenerate outcomes, impose that the developer invests only if expected profit is nonnegative and permit is granted. One can model p as a best response that compares local payoff under approval to payoff under rejection, recognizing that delay can affect both the developer's proposed scale x and the transfers $T(s,x)$. In many institutions, localities cannot directly set x, but they can shift it through delay and permitting risk, which changes the developer's optimal scale [26]. This is central: local opposition is not merely a binary veto but a continuous strategic lever through timing and compliance burdens.

4. Equilibrium Analysis: Vertical Delegation, Horizontal Externalities, and Credible Commitment

In the baseline sequential game, backward induction begins with the developer's choice of x. For fixed (s,k,d,p) with $p=1$, the developer chooses x to maximize Π_D subject to feasibility and the congestion effect through $q(x,k)$ [27]. In a smooth approximation where $q(x,k)$ is differentiable and increasing in x with marginal delivery $q_x(x,k) \in (0,1]$, the first-order condition is

$$0 \; = \; P\,q_x(x,k) \; + \; s[28] \; - \; c_D \; - \; \partial_x \phi(d,x), \tag{7}$$

where ϕ can be extended to include scale-dependent compliance costs, though the earlier expression treated $\phi(d)$ as separable. When congestion binds, $q_x(x,k)$ falls, reducing the developer's marginal benefit and potentially inducing a corner where $x \approx k$ [29]. This creates strategic complementarity between grid investment and generation investment: higher k raises the

Table 2. Core empirical features motivating the game-theoretic framework

Empirical regularity	Description	Modeling implication
Layered authority	Central, regional, and local authorities share overlapping mandates and veto points	Vertical delegation structure with sequential moves, limited enforcement, and imperfect override options
Spatially concentrated costs	Local visual, environmental, and property value impacts are concentrated, while benefits are diffuse	Local payoff includes $-c_L x$ with limited benefit capture, generating acceptance wedges and strategic delay
Intertemporal investments	Large, lumpy, and irreversible investments in generation, storage, and grid	Dynamic state variables for technology, congestion, and political support; real options and commitment problems
Asymmetric information	Local acceptance costs and developer cost structures are imperfectly observed by higher levels	Mechanism design setting with private types c_L, c_D, incentive compatibility, and strategic misrepresentation

Table 3. Core decision variables in the baseline multi-level game

Choice variable	Interpretation	Primary decision maker
$x \geq 0$	Capacity of renewable investment at the candidate site	Developer D chooses x given s, k, d, and expected permit p
$k \geq 0$	Grid or interconnection capacity that relaxes congestion	Regional authority R chooses k subject to cost $\psi(k)$
$s \geq 0$	Per-unit subsidy or support parameter for capacity or output	Central authority C chooses s and possibly its time path
$p \in \{0, 1\}$	Local permitting decision, with $p = 1$ granting approval	Local authority L chooses p comparing approval and rejection payoffs
$d \geq 0$	Intensity of procedural delay or scrutiny	Local authority L chooses d as both a screening and bargaining instrument
$q(x, k)$	Delivered output, often $q(x, k) = \min\{x, k\}$	Outcome of joint x and k, affects revenue, benefits, and transfers

return to x, and higher x raises the value of k for reliability and congestion rents.

The local authority anticipates the developer's response and chooses (d, p). A central issue is that delay can serve dual roles: it can reduce x by increasing costs, which may improve local welfare if local external cost dominates local benefits; and it can act as a bargaining device if transfers or concessions increase with perceived conflict. In a reduced-form sense, the local problem under approval can be expressed as choosing d to maximize U_L evaluated at $x^\star(s, k, d)$, with $p = 1$ if this exceeds the outside option U_L^{reject}.

When $T(s, x)$ is weakly increasing in x, localities may face a tradeoff: higher x increases transfers and perhaps economic benefit, but also increases local external costs [30]. Delay can reduce x while preserving eligibility for some transfers, which can be attractive if the transfer schedule is not sensitive to delivered output. This can generate an equilibrium with positive delay even when delay is socially inefficient, because it allows the locality to shift the project toward its preferred scale without directly bearing system-wide costs of foregone decarbonization.

The regional authority chooses k recognizing the induced x and the possibility that local permitting fails [31]. If the region benefits from delivered energy or reliability, it has an incentive to invest in k, but it may underinvest if benefits spill over to other regions or if the central authority captures most of the decarbonization value. This resembles a public good problem. In the absence of coordinating transfers, equilibrium k can be below the system-optimal level even when the project is approved, resulting in congestion that depresses x and reduces realized benefits.

Table 4. Selected structural parameters and cost functions

Parameter / function	Economic meaning	Role in the model
$B > 0$	System-wide environmental or decarbonization benefit per unit delivered	Valued mainly by C in U_C, enters social welfare W
$P > 0$	Market value or avoided cost per unit delivered output	Drives revenue $Pq(x, k)$ in U_R and Π_D
c_L	Local external cost per unit capacity (e.g., visual and environmental impacts)	Enters U_L as $-c_L x$; often privately observed by locality
c_D	Developer's marginal cost of capacity	Enters Π_D as $-c_D x$, interacts with subsidy s and delay $\phi(d)$
$\phi(d)$	Additional developer cost induced by delay d	Captures permitting and financing costs, affects $x^\star(s, k, d)$
$\psi(k)$	Cost of grid expansion borne by region R	Drives underinvestment in k when benefits spill over
$\chi(d), \omega(d)$	Political and administrative costs of conflict and effort	Enter U_C, U_R, U_L and shape optimal delay incentives

Table 5. Reduced-form payoff components for central, regional, local, and developer players

Player	Main benefit components	Main cost components
Central authority U_C	Environmental benefit $\alpha_C B q(x, k)$, system reliability, progress toward targets	Fiscal cost $\beta_C s x$, conflict cost $\gamma_C \chi(d)$, penalty $\kappa_C \mathbf{1}\{p = 0\}$
Regional authority U_R	Economic value $\alpha_R P q(x, k)$, regional development, transfers $\tau_R(s, x)$	Grid cost $\beta_R \psi(k)$, political cost $\gamma_R \chi(d)$
Local authority U_L	Local economic gains $\alpha_L \eta(x)$, transfers $T(s, x)$, bargaining returns $\rho(d, x)$	Local external cost $c_L x$, administrative effort $\omega(d)$
Developer Π_D	Market revenue $Pq(x, k)$, subsidy sx	Investment cost $c_D x$, delay cost $\phi(d)$, fixed cost F

The central authority chooses s and transfer parameters anticipating downstream best responses [32]. The central problem is complicated by limited commitment: if subsidies can be revised after local approval, then promises of support may not be credible. A simple way to represent limited commitment is to allow the central authority to reset s after observing (k, d, p), constrained only by political adjustment costs. In such a case, developers anticipate subsidy clawback once sunk costs are incurred, reducing x ex ante. This is an instance of time inconsistency that can be analyzed as a dynamic game; even in the static baseline, it suggests that equilibrium investment depends on policy credibility rather than stated policy [33].

A useful equilibrium decomposition is to isolate the wedge between the marginal social benefit of capacity and the marginal private and local perceived benefits. Define a system welfare function for exposition,

$$W = [34] \quad B\,q(x,k) + P\,q(x,k) + \eta(x) - c_L\,x[35] - c_D\,x \quad (8)$$

$$- \psi(k) - \omega(d) - \phi(d)[36] - F, \quad (9)$$

abstracting from pure transfers and political conflict terms. An efficient allocation (under complete information and full commitment) would choose (x, k, d) with d minimizing real resource costs, typically $d = 0$ unless delay improves information or mitigates real harms. In contrast, the equilibrium allocation incorporates the strategic term $\rho(d, x)$ in U_L and the fiscal incidence of s in U_C [37]. The divergence can be summarized by equilibrium conditions that replace B with an effective valuation distorted by fiscal and political costs and replace c_L with a politically weighted local valuation.

To formalize one comparative static, suppose the local permit is granted when

Table 6. Baseline sequential timing of the multi-level siting and permitting game

Stage	Acting player(s)	Main decision and information structure
0: Policy announcement	Central authority C	Chooses subsidy s and transfer rules (T, τ_R), possibly under limited commitment and anticipating political conflict
1: Grid planning	Regional authority R	Chooses grid capacity k and related investments, observing s and institutional environment
2: Local procedure	Local authority L	Chooses delay d and permit $p \in \{0, 1\}$, observing (s, k) and local type c_L
3: Investment	Developer D	Chooses capacity x conditional on expected approval and anticipated d and k
4: Realization	All players / nature	Delivered output $q(x, k)$ and payoffs realized; conflict and fiscal outcomes feed into future political and fiscal states

$$U_L(p = 1) \;\geq\; U_L(p = 0), [38] \tag{10}$$

and suppose $U_L(p = 0)$ is normalized to zero. Then approval requires that the net local surplus, including transfers and political leverage, is nonnegative. Holding x fixed, an increase in transfer sensitivity $\partial_x T(s, x)$ can relax the constraint and increase the set of parameter values (c_L) for which approval occurs. However, if higher transfer sensitivity also increases the return to delay through $\partial_d \rho(d, x)$, it can raise equilibrium delay [39]. This illustrates an instrument design tension: buying approval through transfers can create rent-seeking incentives that prolong procedures.

Equilibrium multiplicity can arise when expectations about approval affect developer scale and therefore local incentives. If higher expected x raises both local costs and local transfers, the local net surplus may be non-monotone in x. In such cases, there may be a low-investment equilibrium with quick approval and a high-investment equilibrium with intense opposition and delay, or conversely [40]. The selection among equilibria can depend on political narratives, early actions, and institutional default rules. The modeling implication is that policy evaluation should consider equilibrium selection effects, not only local comparative statics around one equilibrium.

5. Strategic Incentives and Mechanism Design for Coordination Under Incomplete Information

Many conflicts in renewable transitions are driven by asymmetric information about local acceptance costs and about developer cost structures. A central authority setting a uniform subsidy s may not observe site-specific c_L and therefore cannot condition support and compensation on true local harm [41]. Localities may strategically exaggerate harms to extract transfers, while developers may strategically choose siting to maximize subsidy capture rather than system value. Mechanism design is relevant because it provides conditions under which a transfer and decision rule can implement a desired allocation in equilibrium given incentive constraints.

Let the locality privately observe $c_L \in [\underline{c}, \overline{c}]$ and report $\hat{c}_L$ to an authority that designs a rule mapping reports into transfers and decisions. The mechanism chooses approval probability or rule $p(\hat{c}_L)$, an allowable capacity $x(\hat{c}_L)$, and a transfer $T(\hat{c}_L)$. The locality's utility under truthful cost is [42]

$$U_L(c_L; \hat{c}_L) \;=\; \alpha_L \eta(x(\hat{c}_L)) - c_L\, x(\hat{c}_L) + T(\hat{c}_L) - \omega(d(\hat{c}_L)) \tag{11}$$

$$+\; \rho(d(\hat{c}_L), x(\hat{c}_L)), \tag{12}$$

where the designer can also specify a delay-reducing administrative package $d(\hat{c}_L)$, interpretable as standardized timelines or centralized review effort. Incentive compatibility requires that truthful reporting maximizes utility:

$$U_L(c_L; c_L) \;\geq\; U_L(c_L; \hat{c}_L) \quad \text{for all} \quad \hat{c}_L. \tag{13}$$

A standard approach is to restrict attention to direct mechanisms and use envelope conditions. When ρ and ω are absent or separable, the locality's incentive constraint typically implies that $x(c_L)$ is non-increasing

Table 7. Policy instruments and their main strategic channels

Instrument class	Direct design target	Strategic effect in equilibrium
Uniform per-unit subsidy s	Aggregate investment incentives	Raises x but can amplify rent extraction and local delay if not paired with local compensation
Matching grants / transfers $T(s, x)$	Local and regional budgets	Can relax local participation constraints but may increase delay when transfers rise with perceived conflict
Revenue sharing on delivered output	Distribution of $Pq(x, k)$ or related rents to L and R	Aligns local incentives with system delivery, especially when congestion is relieved by k
Interconnection pricing and congestion rents	Grid access terms for D and rent distribution	Shapes x and k as strategic complements; allocation of rents influences support at each level
Permitting deadlines and automatic approvals	Feasible space for delay d	Limits delay-based bargaining but may shift conflict to outright rejection or litigation without accompanying transfers
Two-part transfer (A, m)	Participation and marginal incentives for L	Fixed component A supports high-cost sites; marginal component m rewards performance but creates informational rents

in c_L, and transfers must compensate marginally for increased reported costs to prevent misreporting. However, the presence of political leverage from delay complicates monotonicity because a locality may prefer to mimic a higher-cost type if that triggers higher transfers and also grants procedural leverage [43]. Thus, effective mechanism design may need to control not only transfers but also procedural discretion.

A tractable class of instruments in practice is a matching grant and revenue-sharing rule based on delivered energy rather than installed capacity. Suppose the central authority commits to a payment per delivered unit $m \geq 0$ transferred to the locality, so that $T = m\,q(x, k)$. Because q depends on grid capacity, this can induce the region to coordinate on k and can align local incentives with actual system delivery rather than nominal capacity [44]. Under such a rule, the local net marginal benefit of increased delivered output includes m and may partially offset c_L.

To see the strategic effect, consider the local first-order condition for delay in a smooth approximation where x responds to d and delivered output responds through q. A representative condition has the form [45]

$$0 = \partial_d \rho(d, x^\star) - \omega'(d) \tag{14}$$

$$+ \Big([46] \alpha_L \eta'(x^\star) - c_L + m\,\partial_x q(x^\star, k) \Big) \partial_d x^\star [47] - \phi'(d), \tag{15}$$

where $\partial_d x^\star < 0$ when delay raises developer costs.

If transfers are tied to delivered output, the term $m\,\partial_x q$ raises the local marginal return to capacity, reducing the incentive to use delay to shrink x, but only to the extent that delivered output increases with x given k. When congestion binds, $\partial_x q$ falls, and the incentive alignment weakens, indicating that grid investment and transfer design are complements [48].

A second instrument class is a deadline with penalties or automatic approvals, which can be represented as a constraint on feasible d. Such constraints can reduce rent-seeking equilibria by eliminating delay as a bargaining instrument. However, if local costs are genuinely high in some sites, removing delay discretion without alternative compensation can lead to outright permit denial or to increased litigation, shifting conflict rather than resolving it [49]. A mechanism view suggests that procedural constraints should be paired with compensation rules that satisfy participation constraints for high-cost localities.

A third instrument class is a two-part transfer combining a fixed payment for participation and a variable payment for performance. Let $T = A + m\,q(x, k)$ with A conditioned on accepting the project. The fixed component can satisfy participation for high-cost localities, while the marginal component aligns incentives for scale and timely processing [50]. Yet A creates rent-extraction risk if types are unobserved, since low-cost localities also receive A. The designer's problem is therefore to choose (A, m) balancing acceptance probability against informational rents.

When developers also have private information, the

Table 8. Comparison of static and dynamic game-theoretic formulations

Aspect	Static formulations	Dynamic and stochastic formulations
Treatment of time	Single-period game with contemporaneous choices	Multi-period game with evolving states $(\theta_t, g_t, z_t, f_t)$ and Markov strategies
Policy credibility	Subsidy s and transfers assumed fixed within the game	Limited commitment; s_t can be revised after investments, creating time inconsistency
Opposition and support	Captured through d and $\rho(d, x)$ in one-shot interaction	Political state z_t evolves with past conflict, affecting future mobilization and delay costs
Learning about costs	Acceptance costs and technology treated as known or fixed types	Beliefs about c_L and technology evolve; early projects serve as experiments with spillover benefits
Option value of waiting	No explicit real option; delay only as strategic cost	Developers and authorities delay to preserve flexibility under policy and demand uncertainty

mechanism problem becomes multi-dimensional. For example, a developer may privately observe c_D and choose whether to enter [51]. Subsidies that are too generous induce entry and siting that is privately profitable but system-inefficient, while subsidies that are too stingy deter socially valuable projects. A policy-relevant equilibrium analysis therefore treats subsidies, transfers, and interconnection pricing as a coupled mechanism that screens both local acceptance costs and developer costs. Implementability then depends on which variables are verifiable: delivered output is typically verifiable ex post, while local disamenities and developer costs are not. This pushes designs toward outcome-based contracts, though outcome-based contracts must handle congestion and curtailment risk, again linking back to grid investment incentives [52].

6. Dynamic and Stochastic Games: Credibility, Learning, and Real Options in Transition Conflicts

Static games capture incentive wedges but miss two structural features of renewable transitions: policy commitment is limited and information arrives over time. Dynamic game models represent these features by making actions and payoffs time-indexed, with state variables that evolve stochastically. The relevant equilibrium concept is often Markov perfect equilibrium, where strategies depend on payoff-relevant state variables [53].

Let time be discrete $t = 0, 1, 2, \ldots$. Let the state include technology cost index θ_t, congestion state g_t, political support state z_t, and an intergovernmental fiscal state f_t representing budget tightness. Let developer investment be a control x_t, grid investment be k_t, and permitting intensity be d_t with approval decision p_t. State transitions satisfy [54]

$$\theta_{t+1} = \Theta(\theta_t, \varepsilon^{\theta}_{t+1}), \quad (16)$$

$$g_{t+1} = G(g_t, k_t, x_t, \varepsilon^{g}_{t+1}), \quad (17)$$

$$z_{t+1} = Z(z_t, d_t, p_t, x_t, \varepsilon^{z}_{t+1}), \quad (18)$$

$$f_{t+1} = F(f_t, s_t, T_t, \varepsilon^{f}_{t+1}), \quad (19)$$

where ε are shocks. Political support z_t can encode the propensity for opposition mobilization, which may increase if projects impose costs without visible compensation, or decrease if communities observe benefits and credible procedural fairness. This state dependence captures an empirically relevant phenomenon: early conflict can raise the expected cost of future projects by shifting political beliefs and mobilization capacity.

A central dynamic conflict is time inconsistency in subsidy policy [55]. Suppose the central authority chooses s_t each period after observing sunk investments. If subsidizing is politically costly and the central authority cannot commit, then once investment is sunk the central authority may prefer to reduce s_t and save fiscal cost, even though high s_t was necessary to induce investment. Developers anticipate this and invest less, producing a dynamic credibility problem [56].

This can be formalized via Bellman equations. Let the developer's value function be $V_D(\theta, g, z, f)$ and the central authority's value be $V_C(\theta, g, z, f)$. A Markov strategy profile $(\sigma_C, \sigma_R, \sigma_L, \sigma_D)$ is an equilibrium if each player's strategy maximizes its value given others' strategies and the induced transition. For the developer, the control problem can be written as [57]

Table 9. Dynamic state variables and illustrative calibration targets

State variable	Interpretation	Example empirical proxy
θ_t	Technology cost index and learning level	Capital cost indices, auction clearing prices, technology-specific LCOE estimates over time
g_t	Grid congestion and interconnection state	Queue lengths, curtailment rates, congestion price spreads, backlog of connection requests
z_t	Political support and mobilization capacity	Vote shares, survey-based support for projects, counts of organized objections or lawsuits
f_t	Intergovernmental fiscal tightness and budgetary slack	Measured deficits, debt limits, earmarked revenues for energy or infrastructure
Belief state on c_L	Posterior distribution of local acceptance costs	Changes in approval rates and delays after similar projects, inferred from panel data on siting outcomes

Table 10. Selected mechanisms generating deployment inefficiencies and their empirical signatures

Source of inefficiency	Mechanism in the model	Characteristic data pattern
Local acceptance wedge	$c_L x$ is imperfectly offset by local benefits and transfers	High rejection or delay where external cost proxies are low but fiscal returns are weak
Underinvestment in grid	Regional cost $\psi(k)$ with spillover benefits and weak revenue sharing	Persistent congestion, long queues, and curtailment despite strong national targets
Delay-based rent extraction	Positive $\rho(d,x)$ and weak constraints on d	Longer permitting times and larger concessions in settings with generous support schemes
Policy volatility and weak commitment	Time-varying s_t chosen after sunk investments	Investment slowdowns around expected policy revisions and boom–bust deployment cycles
Misaligned instruments	Poorly coordinated s, T, k, and permitting rules	Instruments that raise fiscal cost without materially reducing delay or congestion

$$V_D(\theta, g, z, f) = \max_{x \geq 0} \Big\{ \pi_D(x; \theta, g, \sigma_C, \sigma_R, \sigma_L) \tag{20}$$

$$+ \ \delta \, [58] \mathbb{E}\big[V_D(\theta', g', z', f') \,\big|\, \theta, g, z, f, x \big] \Big\} \tag{21}$$

where $\delta \in (0,1)$ is a discount factor and π_D is the per-period profit depending on current policy and permitting outcomes [59]. The central authority solves an analogous problem, but its action affects future political support z', which in turn affects future conflict costs. This creates an intertemporal incentive to invest in credibility and conflict reduction, but only if current decision makers sufficiently weight future payoffs.

Learning can be incorporated by treating c_L or acceptance costs as unknown and updating beliefs [60]. Suppose local acceptance cost is $c_L = \bar{c} + \nu$, where ν is unknown and communities learn from project experience. Then early projects serve as information experiments. A planner with commitment may tolerate, some early cost to reduce uncertainty and accelerate later deployment. In contrast, multi-level governance can distort experimentation incentives: a locality bears most of the early learning cost while the benefits of improved beliefs may accrue system-wide. This can generate equilibrium under-experimentation, a dynamic free-riding problem distinct from static underinvestment [61].

Real options arise because investment is partially irreversible and future policy is uncertain. If policy volatility is expected, developers delay investment to preserve option value. Localities may also delay decisions to wait for better compensation or clearer political signals. These option values can be represented by convex continuation values in the Bellman equations, which can make delay privately optimal even when it reduces expected social surplus [62]. The model implication is that stabilizing policy rules, even at slightly lower expected subsidy levels, can increase investment by reducing option value of waiting, thereby improving equilibrium deployment.

Dynamic interaction also clarifies why one-time compensation can be insufficient. If political support state z_t evolves based on perceived fairness, then transfer design affects not only immediate acceptance but also the future cost of permitting. Policies that reduce procedural conflict today can lower z_{t+1}, improving future equilibria. Conversely, policies that appear coercive may reduce delay in the short run but increase z_{t+1} through backlash, raising long-run conflict costs. This intertemporal tradeoff is naturally captured in dynamic equilibria but is difficult to see in static models [63].

7. Computational Characterization, Equilibrium Selection, and Empirical Calibration

The practical use of these models often requires computational methods because equilibria can be high-dimensional, non-linear, and potentially multiple. In static games with continuous actions, existence can be established under standard continuity and compactness assumptions, but equilibrium computation may still be challenging due to non-convexities induced by minimum operators in congestion, discrete permit choices, and discontinuities from deadline rules. Smoothing approximations for $q(x, k)$ and probabilistic permitting rules can be used to facilitate computation while preserving qualitative strategic structure [64].

Dynamic Markov-perfect equilibria can be computed via value function iteration, policy iteration, or projection methods, but the presence of multiple governmental players turns the problem into a dynamic stochastic game rather than a single-agent control problem. One approach is to restrict strategies to parametric forms and solve for fixed points in best-response mappings. Another is to compute equilibria on a discretized state space using backward induction when horizons are finite or using algorithms for stationary equilibria when horizons are infinite. The computational burden increases when beliefs are state variables, as in learning models, because the belief distribution must be tracked [65].

Equilibrium selection is particularly important when models admit multiple equilibria corresponding to high-conflict and low-conflict regimes. Selection can be disciplined by introducing small payoff perturbations, by specifying trembling-hand refinements, or by modeling focal points created by institutional defaults. For policy analysis, it is often insufficient to report a comparative static at a single equilibrium; rather, the model should be used to assess whether a policy change shifts the basin of attraction toward low-conflict equilibria by altering best-response slopes and credibility conditions.

Empirical calibration can proceed by mapping model primitives to measurable objects [66]. Grid congestion states can be proxied by queue lengths and curtailment rates. Delay can be proxied by permitting durations and litigation incidence. Transfers and subsidies are observed in budgets and tariff rules [67]. Political support states can be proxied by vote shares, survey measures, or counts of organized interventions. The key identification challenge is that observed outcomes are equilibrium objects, so reduced-form correlations can confound shifts in primitives with shifts in equilibrium selection. Structural approaches attempt to estimate primitives such as acceptance cost distributions and political conflict costs by matching equilibrium predictions to observed patterns across jurisdictions.

A cautious interpretation is warranted because many institutional details matter for mapping the abstract action sets to real policy levers [68]. For example, a local authority's ability to delay may be constrained by statutory deadlines but expanded by litigation channels. A central authority's ability to commit may depend on whether subsidies are legislated with multi-year appropriations or can be revised administratively. These details can be represented as constraints in the model, but doing so requires careful institutional measurement.

Nonetheless, even without full structural estimation, the framework can be used to reason about which data patterns are consistent with which strategic mechanisms [69]. For instance, if increased central subsidies correlate with increased local delay, that may indicate rent-seeking through procedural leverage rather than genuine harm mitigation, especially if delay is concentrated where local external costs are low by observable proxies. Conversely, if delay falls when compensation is tied to delivered output rather than installed capacity, that supports the mechanism-design prediction that outcome-based transfers reduce incentives for strategic shrinkage and bargaining delay under congestion risk. Similarly, if policy volatility correlates strongly with investment slowdowns beyond what market price volatility would predict, that supports the dynamic credibility channel and option value of waiting.

The computational and empirical perspective also highlights a design principle: instruments should be evaluated as coupled systems [70]. A change in interconnection pricing affects developer incentives and also the distribution of congestion rents that can be shared with localities. A change in permitting deadlines affects the feasibility of delay strategies and therefore changes the bargaining environment for compensation. A change in revenue sharing affects the region's willingness to invest in grid capacity, which feeds back into the efficacy of outcome-based transfers [71]. These interdependencies are exactly what equilibrium analysis is intended to capture.

8. Conclusion

Multi-level governance conflicts in renewable energy transitions can be understood as equilibrium outcomes of strategic interaction among authorities, developers, and communities with heterogeneous objectives, asymmetric information, and limited commitment. A baseline sequential game illustrates how local procedural discretion and regional grid investment interact with central subsidy policy to determine investment scale, congestion, and delay. Equilibrium analysis reveals that coordination failures can persist even when all actors prefer a successful transition in aggregate, because incentives are shaped by externalities, fiscal incidence, and the strategic value of delay as a bargaining instrument [72].

Incentive design can mitigate these failures, but implementability depends on what is observable and on the credibility of commitments. Transfers tied to delivered output rather than installed capacity can better align local incentives with system performance, especially when complemented by regional grid investment. Two-part transfers can balance participation with marginal incentives but create informational rents when acceptance costs are private. Procedural constraints such as deadlines can reduce delay-based rent extraction, but without compensation mechanisms they risk shifting conflict into denial or litigation [73]. Dynamic and stochastic game extensions emphasize that credibility and learning are central: policy volatility increases the option value of waiting and reduces investment, while early conflict can raise future opposition through political state dependence.

A computational and empirical lens underscores the importance of equilibrium selection and coupled-instrument evaluation. Many observed outcomes are consistent with multiple mechanisms, so distinguishing channels requires attention to how institutional constraints shape feasible deviations and how policy changes alter best responses. Overall, game-theoretic modeling does not eliminate the institutional complexity of renewable transitions, but it provides a coherent structure for analyzing how that complexity translates into strategic incentives, equilibrium outcomes, and the conditions under which policy packages can reduce conflict while respecting multi-level governance realities [74].

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