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Climate laws and firms' access to energy

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ABSTRACT

This study examines whether the maturity of national climate-law regimes improves firms' access to energy. We merge firm-level energy-constraint information from the World Bank Enterprise Surveys with country-level climate-law implementation dates for 125 economies over 2006–2022. Firms' energy constraints are measured using a WBES indicator for whether energy is reported as an operational obstacle, while climate-law maturity is captured as the number of years since a country's first qualifying climate law entered into force. We find that longer-standing climate laws are associated with a significantly lower likelihood that firms face energy constraints. The association is stronger for capability-rich firms: older, higher-sales and exporting firms, and is amplified by experienced management and public listing, while financing constraints weaken firms' ability to benefit from regulatory maturity. Country energy conditions matter: higher renewable energy production and lower energy price inflation coincide with fewer constraints. We address endogeneity using instrumental-variable estimation, conditional mixed-process estimation, propensity score matching, and extensive robustness checks (alternative outcome and regulatory proxies, outlier exclusions, and additional controls), which yield consistent evidence in support of the main result. The findings suggest that maintaining credible, durable climate laws, paired with renewable capacity expansion, price-stability policies, and targeted finance for constrained firms, can deliver operational co-benefits by improving firm-level energy access.

1. Introduction

Reliable and affordable access to energy remains a binding operational constraint for firms in a large part of the world economy. Recent progress toward universal access has been uneven and, in some regions, fragile, shaped by setbacks in basic access, a decline in public financing for clean energy, persistent cross-regional gaps in renewable capacity, and renewed pressure from post-pandemic energy demand and price dynamics [1–4]. Nowhere are these challenges more acute than in developing regions where energy poverty, limited grid resilience, and high reliance on traditional cooking fuels remain widespread [5]. At the same time, global initiatives, and investment commitments, including large-scale clean energy targets and tax incentives, signal both the urgency and the opportunity to narrow these gaps, provided that enabling policies and institutional capacity translate ambition into durable infrastructure and market outcomes [6].

A growing empirical literature shows that firms' energy access is shaped by a combination of firm capabilities and country fundamentals, with direct implications for productivity, competitiveness, and growth. On the countryside, the quality of generation, transmission, and distribution infrastructure is central to reliability and outage risk, while energy-system vulnerabilities and supply disruptions propagate through input costs and uncertainty [7–9]. On the firm side, financial resources and organizational capacity enable investments in resilience (e.g., backup systems, distributed generation, storage) and in energy-management practices that reduce exposure to grid instability [10,11]. Geographic location and network connectivity matter as well, with infrastructure disparities between urban and rural areas translating into heterogeneous reliability for productive users [12]. Macro-financial and institutional conditions also play a critical role: energy price volatility constrains planning and can amplify financing pressure, while institutional quality shapes how effectively economies mobilize

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investment and coordinate infrastructure upgrading [13,14]. Taken together, this evidence establishes that energy access is not merely an engineering problem; it is an economic, institutional, and firm-capability problem.

Environmental policy is increasingly viewed as one of the most consequential institutional levers shaping energy systems. Policy instruments such as carbon pricing, renewable portfolio standards, and incentives for clean investment can accelerate the shift away from fossil dependence while fostering a more resilient and diversified energy supply [15,16]. At the firm level, environmental regulation can also incentivize efficiency investments and cleaner production, reducing energy intensity and easing pressure on constrained grids [17,18]. In principle, these channels imply that environmental policy may generate "co-benefits" for operational outcomes, among them, the reliability and affordability of energy available to firms.

Climate laws constitute a particularly salient policy class within this broader environmental policy landscape. They shape the production, distribution, and consumption of energy through binding commitments and statutory frameworks that support mitigation objectives, energy efficiency, and renewable adoption [19–21]. Because many climate-law instruments affect both the demand side (through efficiency standards and behavioral incentives) and the supply side (through renewable deployment and system modernization), they can plausibly influence firm-level energy constraints over time [17,22]. Yet, despite their centrality in climate governance, the firm-level operational implications of climate laws, especially for energy access, remain insufficiently understood.

This gap is notable for at least three reasons. First, much of the empirical work on climate laws and related policies has emphasized environmental outcomes (e.g., emissions trajectories), while the economic and operational effects on firms, such as whether firms can access stable energy to sustain production, have received comparatively less attention [23]. Second, climate legislation is heterogeneous and often relatively recent in many developing countries, making it difficult to move beyond existence-based comparisons and toward an understanding of how policy effects accumulate and institutionalize over time [24]. Third, studying firm-level energy access requires integrating regulatory information with granular firm data in a way that is empirically tractable across countries and survey waves; this integration is nontrivial and can deter systematic cross-country analysis [25]. As a result, the mechanisms through which climate laws map into firms' energy constraints, and the conditions under which such laws deliver operational co-benefits, remain underexplored [26].

The developing-country context makes these questions especially consequential. Many developing economies face less resilient grids, limited fiscal space for rapid system upgrades, and higher exposure to imported energy and global price shocks, conditions that can magnify outages and cost volatility for productive users [27,28]. In such settings, climate laws may play a dual role: they can create sustained investment signals and coordination mechanisms for long-run system upgrading, while also inducing firm-level adjustments that improve efficiency and resilience [29,30]. At the same time, firms in developing economies are heterogeneous in their ability to respond. Capability constraints, particularly financing frictions and limited managerial capacity, may prevent some firms from translating regulatory signals into improved energy outcomes, even when laws exist on paper [31,32]. Understanding whether climate laws ease or exacerbate energy constraints, and for whom, is therefore relevant not only for environmental governance but also for firm performance and inclusive development.

Against this background, this study examines whether climate-law maturity, defined as the duration of implementation since a country's first climate law, reduces firms' energy constraints in mostly developing economies. The emphasis on maturity is deliberate. Conceptually, the operational relevance of a climate-law regime should depend not only on adoption, but also on persistence and institutionalization: durable laws may reduce policy uncertainty, support learning-by-doing in implementation, and crowd in investments whose payoffs materialize over multi-year horizons [33,34]. This perspective motivates the paper's central research question: *Do longer-standing climate laws improve firms' access to reliable energy, and how is this relationship conditioned by firm capabilities and country energy-system characteristics?* Building on existing evidence that institutions shape resource access and infrastructure outcomes [14] and that environmental policy can affect firm behavior and energy-system trajectories [15,16], we develop testable hypotheses on (i) the direct association between law maturity and firm energy constraints, (ii) heterogeneous effects across firms with different capabilities, and (iii) conditioning effects from the country's energy price environment and renewable production capacity.

Empirically, we integrate firm-level data on energy constraints from the World Bank Enterprise Surveys (WBES) with national information on climate-law implementation for a sample of 125 mostly developing countries over 2006–2022. We measure firms' energy constraints using a WBES-based indicator capturing whether energy is reported as an obstacle to operations. Climate-law maturity is measured as the number of years since the first climate law was implemented in each country-year. We estimate baseline specifications using a probit framework appropriate for a binary dependent variable, incorporating country and sector fixed effects, and clustering standard errors at the country level. We then evaluate heterogeneity through interaction terms with firm characteristics and examine key country-level conditioning variables, including energy price inflation and renewable energy production. To strengthen inference, we complement baseline estimation with multiple approaches addressing endogeneity concerns and model sensitivity, including instrumental-variable techniques, the Oster coefficient-stability diagnostic, and propensity score matching, alongside a range of robustness tests using alternative measures and sample constructions.

The results provide consistent evidence that climate-law maturity is associated with improved firm-level energy access. In the baseline specifications with country and sector fixed effects, longer-standing climate laws are linked to a lower likelihood that firms report an energy constraint. Country conditions matter strongly: energy price inflation is positively associated with energy constraints, whereas a higher share of renewable energy production is associated with fewer constraints. Firm-level correlates are also economically meaningful: older firms and firms with stronger sales performance tend to report fewer constraints, while firms facing informal competition report more constraints; larger firms report higher constraints on average, consistent with greater energy intensity and exposure to system congestion. Importantly, the law-maturity association is not uniform across firms. The interaction results indicate that the constraint-reducing association of climate-law maturity is stronger for firms with greater capability to respond, particularly older firms, higher-sales firms, and exporting firms. Additional moderation analysis further shows that experienced management and public listing amplify the beneficial association of law maturity, while financing constraints significantly attenuate it. These heterogeneity patterns are consistent with the view that durable policy frameworks create opportunities for improved access, but that firms' ability to capitalize on those opportunities depends on managerial capacity and financial slack.

A comprehensive set of robustness and endogeneity checks reinforces these conclusions. Instrumental-variable estimation and conditional mixed process estimation produce negative and statistically significant estimates of the climate-law maturity effect. Propensity score matching yields a comparable reduction in energy constraints for firms exposed to more mature climate-law regimes. The Oster diagnostic suggests caution about residual omitted-variable bias, indicating that unobservables may matter; accordingly, we interpret the overall evidence as consistent with a causal interpretation while remaining conservative about strong causal claims. The main findings are robust to alternative measurement of the dependent variable, to alternative proxies for climate-related regulation based on mandatory and voluntary ESG disclosure regimes, and to sample variations excluding influential country observations. Additional controls for energy-system composition and quality, technological conditions, and macro-environmental factors do not overturn the central pattern. Finally, dominance analysis indicates that energy price inflation is the most influential predictor of firm constraints in the baseline set, while climate-law maturity plays a larger relative role in less developed country subsamples, underscoring the importance of institutional durability where baseline infrastructure is weaker.

This study offers several benefits for future scholarship. First, it advances the institutional and environmental policy literatures by distinguishing regulatory maturity from regulatory presence and by documenting a "policy continuity" channel through which climate governance can map into operational outcomes. Second, it provides cross-country micro evidence that links climate-law regimes to firm-level resource constraints, bridging an empirical divide between climate-law research focused on environmental endpoints and development/energy research focused on infrastructure and access constraints. Third, by documenting capability-contingent effects, particularly the roles of managerial experience, listing status, and financing frictions—it motivates a research agenda on the micro-foundations through which climate governance translates into firm performance in developing contexts [29,34]. Finally, our results point to tractable extensions for upcoming scholars: moving from duration to measures of enforcement intensity and legal quality; exploiting staggered adoption for event-study designs; integrating objective outage measures with survey evidence; and studying whether energy-price volatility mediates the law–access relationship [13].

The remainder of the paper proceeds as follows. Section 2 reviews the theoretical foundations and develops hypotheses, outlining demand-side and supply-side channels linking climate-law maturity to firm energy access. Section 3 describes the data, variables, and empirical strategy. Section 4 presents the baseline results and heterogeneity analysis. Section 5 addresses endogeneity using instrumental variables, the Oster diagnostic, and propensity score matching. Section 6 reports robustness tests and additional controls. Section 7 discusses mechanisms and interpretation. Section 8 concludes with implications for policy and future research.

2. Relevant literature and hypothesis development

2.1. Climate laws as institutional infrastructure for energy transition

Climate laws have become a central policy instrument in contemporary climate governance. They bundle mandates and enabling provisions that shape mitigation pathways through rules on emissions reduction, energy efficiency, renewable deployment, disclosure, planning, and—in some contexts—carbon pricing and market design [19,35]. Political-economy research emphasizes that the adoption and durability of such laws reflect both domestic coalitions and state capacity, which jointly determine whether legislation translates into credible, investable policy signals [36–38]. This literature is valuable because it highlights that formal adoption alone may not be sufficient; persistence, implementation, and institutionalization matter for economic outcomes.

Empirical evidence on climate laws and energy-related outcomes is expanding, but it is dominated by macro-level endpoints. Cross-country studies connect legal systems and governance to renewable energy investment and suggest that stronger institutional arrangements can attract clean-energy capital [39]. Related work documents links between national climate legislation and energy security [40] and argues that the effects of climate policies on the renewable transition depend on complementary political and financial institutions [41]. The strongest contributions in this stream typically (i) rely on large international datasets, (ii) employ country-level panels, and (iii) connect policy or governance measures to investment or security outcomes [39,40].

However, three limitations constrain inference for the firm-level question posed in this study. First, macro studies seldom observe the micro-level mechanisms through which laws affect productive users' energy reliability. Second, many studies treat climate policy as a binary presence/absence or as an index, which makes it difficult to isolate the role of policy continuity and maturity—a salient feature in developing countries where implementation capacity and credibility evolve over time [24]. Third, identification remains challenging because policy adoption is endogenous to development, institutional quality, and energy-system characteristics that also shape energy access and reliability [23]. These limitations motivate a research design that links climate-law regimes to firm-level outcomes and that explicitly tests for heterogeneity and conditioning environments.

2.2. Environmental regulation and firm behavior: demand-side channels and boundary conditions

A complementary literature examines how environmental regulation shapes firm behavior. Foundational organizational work argues that firms respond to environmental demands through changes in routines, investments, and governance, with responses depending on internal capabilities and external pressures [42]. Empirical evidence consistent with the Porter hypothesis links environmental regulation to innovation and performance in some settings, but emphasizes heterogeneity and the importance of the regulatory design and enforcement environment [43]. Energy-management studies show that internal managerial systems—monitoring, metering, process control, and structured energy management—are associated with greater energy-efficiency investment and operational improvement [44,45].

Disclosure and transparency mechanisms represent a further demand-side pathway. Corporate environmental reporting and assurance can discipline firms by increasing visibility to investors and stakeholders, although measurement validity and greenwashing risks persist in some reporting regimes [46,47]. Supply-chain transparency and sustainability governance can strengthen incentives for cleaner production, but the effects may depend on enforcement, market access, and the credibility of information channels [48]. The broader stakeholder literature similarly argues that sustained pressures from investors, regulators, and civil society shape firm practices, especially where governance systems promote accountability [49].

Two critical implications follow for this study. First, the demand-side effect of climate laws on energy constraints is plausible: durable legal regimes can encourage efficiency investments, better energy management, and cleaner procurement that reduce exposure to outages and volatility over time [42,44]. Second, the evidence base cautions against uniform effects. Firms may face short-run compliance costs, and the benefits of regulatory maturity may accrue primarily to firms able to finance adaptation and implement management systems, while constrained firms lag [34,50]. These boundary conditions motivate the capability-contingent hypotheses developed below.

2.3. Energy-system supply channels: investment, grid integration, and resilience

Climate laws also operate on the supply side by shaping incentives for generation mix, grid modernization, flexibility resources, and long-term contracting. Policy reviews document that renewable energy integration is supported by combinations of targets, incentives, grid codes, and market design that reduce uncertainty for investors and system operators [51]. Work on renewable energy communities emphasizes the role of policy architecture for a "just" transition and highlights that legal frameworks shape whether decentralized solutions scale [20]. The systems literature stresses that flexibility (storage, demand response, balancing markets) is essential for integrating variable renewables while maintaining reliability [52–54].

Evidence on carbon pricing suggests that pricing instruments can shift dispatch and investment toward cleaner technologies, but effects vary by design and political constraints; importantly, carbon pricing may raise energy costs in the short run, potentially tightening constraints for some firms absent compensatory measures or system upgrades [23,55,56]. Subsidy reforms and green-finance mechanisms are often emphasized as complements that reduce the cost of capital for clean investment and accelerate build-out [57,58]. Corporate PPAs and renewable procurement instruments can reduce price risk and support capacity deployment, but their feasibility depends on market depth, regulatory clarity, and counterparties [59,60].

A key methodological observation is that supply-side studies frequently measure outcomes such as installed capacity, investment flows, or emissions, rather than the reliability experienced by productive users. This creates a gap: supply-side policy effects may not translate into reduced firm constraints if grid quality is weak, if renewables integration lacks flexibility, or if price volatility dominates firms' cost structures [28,61]. This motivates incorporating country energy conditions—such as energy price inflation and renewable production—into the empirical design as key conditioning contexts.

2.4. Firm-level energy constraints: micro evidence, determinants, and heterogeneity

Firm-level energy constraints remain a widely documented barrier to productivity and growth, especially in developing markets with infrastructure gaps and volatility [27,62]. Micro-level research using developing-country data shows that access to energy is shaped by institutional conditions and by firm characteristics, including financial integrity and constraints, which influence the ability to invest in resilience and secure reliable supply [11,14]. Studies focusing on coping mechanisms suggest that unreliable grid supply can induce self-generation and other costly adaptations, implying that improvements in reliability can materially change firm behavior and costs [63]. Broader infrastructure research similarly stresses that modernization of generation, transmission, and distribution is fundamental to lowering outages and raising reliability [7,64].

Two methodological limitations recur in this literature. First, many firm-level studies rely on survey-based constraints that reflect perceived obstacles, which are informative for operational decision-making but can be sensitive to reporting differences and survey design [11]. Second, causal inference remains challenging because firms' energy outcomes correlate with unobserved country conditions (institutional quality, political stability, macro shocks) and with firm attributes (capabilities, sector) that may also shape regulatory adoption and enforcement [14]. These challenges motivate fixed effects, careful control selection, and complementary strategies to address endogeneity in the empirical analysis.

2.5. Theoretical framework

Regarding the core constructs and logic, this study centers on the proposition that climate laws can function as institutional infrastructure that shapes both energy-system evolution and firms' operational exposure to energy constraints. The key construct is climate-law maturity: the duration since a country's first qualifying climate law entered into force. The maturity concept follows from institutional and credible commitment logic: policies that persist reduce uncertainty, shape expectations, and become embedded in administrative routines, which enables investments with long horizons and increases the likelihood that laws affect real infrastructure and markets rather than remaining symbolic [33,65].

Two complementary theoretical lenses explain how legal maturity translates into firm-level energy outcomes: First, the institutional/credible commitment perspective. Policy durability affects investment incentives and coordination. When laws persist, utilities, investors, and regulators can plan for multi-year projects (generation capacity, grid reinforcement, flexibility resources), and markets develop around instruments such as auctions, certificates, and contracting [51,59]. This channel predicts that legal maturity is associated with improved supply reliability over time, contingent on implementation capacity. Second, the capability-based/resource dependence perspective. Firms depend on external energy systems but can partially reconfigure their exposure through investment and contracting strategies—energy management systems, procurement (including PPAs), fuel switching, distributed generation, and storage. However, such reconfiguration is capability-contingent: firms with stronger managerial capacity, governance, and financial slack adapt faster and at larger scale [29,34,66]. Financing constraints, in contrast, can prevent firms from capturing the benefits of regulatory maturity [50,67].

Regarding the demand-side and supply-side mechanisms within this framework, climate-law maturity is expected to reduce firm energy constraints through two reinforcing sets of mechanisms: from the demand-side (firm and economy), persistent legal regimes standardize efficiency expectations, increase disclosure and monitoring, and incentivize energy management and cleaner procurement. These mechanisms reduce energy intensity and peak demand exposure, making firms less vulnerable to unreliable supply and price spikes [42,44,45]. From the supply-side (system), mature legal regimes lower policy risk and can accelerate renewable deployment, grid modernization, and flexibility resources (storage, demand response), which improve reliability and diversify supply [52–54]. Policy design also matters: carbon pricing may raise costs in the short run [23,55], implying that maturity effects are more likely to materialize under supportive price stability and capacity build-out.

These effects may be heterogeneous or even offset. The framework explicitly recognizes countervailing mechanisms and mixed evidence. Regulatory regimes may initially tighten constraints if compliance costs increase faster than infrastructure upgrades, if renewables integration outpaces flexibility, or if energy price inflation dominates cost structures. Accordingly, the expected relationship is conditioned by (i) country energy context: energy price inflation and renewable production, and (ii) firm capability, financial slack, managerial experience, export orientation, and governance/market access. These conditioning channels motivate the empirical interaction tests and moderation analysis reported below.

2.6. Hypothesis development

H1. *All else equal, greater climate-law maturity is associated with a lower probability that firms report energy constraints*.

Rationale: policy continuity strengthens credible commitment, crowds in investment and market formation, and supports the diffusion of efficiency and procurement practices that reduce exposure to reliability and cost shocks [33,40,65].

H2. *The negative association between climate-law maturity and firm energy constraints is stronger for firms with greater capabilities (*e.g., *operational maturity, financial capacity, export orientation, experienced management, and stronger governance/market access) and weaker for financially constrained firms*.

Rationale: capabilities determine whether firms can finance and implement energy management, procurement, and resilience investments and can navigate regulatory and contracting environments [29,34,42,50,66].

H3. *The relationship between climate-law maturity and firm energy constraints is more favorable in contexts with higher renewable production capacity and lower energy cost instability*.

Rationale: renewable deployment and system diversification can improve supply security, but the reliability dividend is more likely to materialize when price volatility and inflationary pressure are contained [16,68,69].

These hypotheses translate directly into the baseline specification (H1; Table 4), interaction tests with firm characteristics (H2; Table 5), capability moderation (Table 10), and the inclusion of key country conditioning variables and additional controls (H3; Tables 4 and 8). Endogeneity is addressed through complementary strategies (Table 6), consistent with the identification challenges highlighted in the literature.

3. Empirical strategy

3.1. Research design

This study adopts a post-positivist, hypothesis-testing epistemology that is standard in empirical research in energy, development, and environmental economics. The underlying premise is that institutional arrangements (climate-law regimes) and firm outcomes (energy constraints) are real phenomena that can be observed, albeit imperfectly, through secondary micro- and macro-data. Accordingly, we follow a deductive and explanatory approach: hypotheses derived from theory are tested using quantitative econometric models appropriate for the data structure and the distribution of the dependent variable. Because cross-country policy settings pose well-known challenges to causal identification, we strengthen inference through a triangulation strategy that combines fixed effects, instrumental-variable techniques, conditional mixed process estimation, sensitivity diagnostics, propensity score matching, and extensive robustness checks ([70–72]; Oster, 2019). This approach is designed to make the evidentiary logic explicit, to mitigate key threats to inference where feasible, and to communicate remaining limitations transparently. The research design is an observational, multi-level, cross-country design that links firm-level outcomes to country-year institutional exposure. The unit of analysis is firm *i* operating in country *j* observed in survey year *t*. The dependent variable is measured at the firm level using the World Bank Enterprise Surveys (WBES), while the key explanatory variable is measured at the country-year level and captures the time elapsed since the first qualifying national climate law entered into force.

3.2. Data

We assemble a country-year panel of firm-level data by merging WBES firm-level information on energy constraints with national data on climate-law implementation, macroeconomy, and institutions. WBES (https://www.enterprisesurveys.org/) covers 191,862 firms across 125 mostly developing countries during 2006–2022, providing granular detail on infrastructure, finance, and regulation in low- and middle-income settings; repeated survey rounds enable an unbalanced panel due to entry/exit, non-response, and sampling updates. WBES data are collected in repeated survey waves across countries, implying a repeated cross-sectional (unbalanced) structure rather than a balanced firm panel. WBES predominantly surveys registered (formal) enterprises and is typically more representative of urban/peri-urban formal firms than of informal and rural microenterprises. Consequently, the WBES-based prevalence of energy constraints in our sample should not be interpreted as a population estimate for the entire business ecosystem, as energy constraints may be more severe among informal and rural enterprises that are less likely to be captured by the survey frame. Our empirical objective is therefore to estimate how national climate-law maturity maps into energy constraints faced by formal firms, which are central actors for investment, employment, exports, and tax bases in developing economies. Climate-law dates come from Li et al. [73] and are cross-checked against ECOLEX (https://www.ecolex.org), the Grantham Research Institute's Climate Change Laws database (https://climate-laws.org), and the NewClimate Institute's Climate Policy database (https://newclimate.org), allowing us to quantify climate-policy maturity as years since first law and link it to firm-level access outcomes. Country controls from the IMF World Economic Outlook and World Development Indicators capture economic and developmental differences. The final merged sample contains a country-year panel of 126,154 observations; variables are winsorized at the 1 % and 99 % levels and log-transformed where appropriate to mitigate outliers and skewness. This design combines micro detail with cross-country breadth to compare regulatory and infrastructural contexts and assess how climate laws map into firms' operational constraints [74]. Like any survey, WBES may underrepresent small/informal firms and relies on self-reports, and its wave-based structure can yield uneven temporal coverage [75]. Even so, integrating firm-specific responses with national climate-policy measures and macro indicators is well-suited to our question on how climate-law implementation relates to firm energy access in developing countries; the preprocessing choices and broad set of controls strengthen robustness and support a nuanced analysis across geographies and time.

3.3. Key variables

The outcome variable is the individual firm's energy constraint (ENRGACC), which is defined based on the WBES responses. In this context, "energy constraint" reflects whether a firm has experienced any energy constraint in the given survey year. Firms indicate this by responding to survey items about their energy situation, where a response indicating the experience of an energy constraint (such as frequent power outages or limited energy availability, etc.) is coded as "1″ and the absence of any such constraint is coded as "0." This binary indicator thus captures the extent to which firms face energy reliability or availability issues in medium- and low-income markets.

We define the key independent variable, climate law maturity (CLIMLAW) as follows. We start from Li et al. [73] and use the information therein as a *seed list* of each country's first national climate law year. Then we validate/update every date using (i) ECOLEX (we extract title, jurisdiction, instrument type, adoption and entry into force dates, (ii) Grantham-Climate Change Laws of the World (instrument type, status “in force”/repealed, year, summary), and (iii) NewClimate-Climate Policy Database (policy type, start year, status, links to legal texts when entry into force is missing). We include national framework climate acts, economy wide binding carbon pricing statutes/decrees, and cross sector climate laws that explicitly create legal obligations for GHG mitigation; we exclude strategies/NDCs/roadmaps without legal force, sub national instruments, purely sectoral efficiency/renewables rules without explicit climate mitigation mandates, and non promulgated announcements. Dating follows a rule: use entry into force year; if absent, use adoption year only when the text specifies immediate effect; if multiple qualifying instruments occur in the same year, keep the earliest effective one; later repeal/update does not change the original first law year. Conflicts are resolved by a transparent hierarchy: official legal text/gazette → ECOLEX entry into force → Grantham “in force” year → NewClimate start year → the Li et al. [73] seed. We then compute for country *j* and year *t*: $\mathrm{CLIMLAW}_{\mathrm{jt}} = \max\{0, t-\tau_j\}$, code pre law years as 0. This measure captures regulatory maturity and policy continuity rather than policy presence. The conceptual rationale is that durable legal regimes are more likely to be institutionalized, reduce uncertainty, and shape investment and behavioral adjustments that typically require multi-year horizons.

Table 1 presents the distribution of the variables. High-constraint countries, such as Pakistan (0.87) and Dominica (0.86), show severe firm energy access issues, suggesting limited infrastructure or insufficient alternative energy options. Mid-level constrained countries, such as Ecuador (0.47) and Malta (0.48), face moderate access issues, indicating some infrastructure support but persistent limitations. In contrast, low-constraint countries like Croatia (0.16) and Finland (0.13) demonstrate fewer challenges in energy access, likely due to more developed infrastructure or diversified energy sources. Regarding climate law implementation duration, high-duration countries, such as Brazil (32 years) and Poland (33 years), reflect well-established

Table 1
Climate laws and firms' access energy (average country values).

Country	Energy constraint	Climate laws	Country	Energy constraint	Climate laws	Country	Energy constraint	Climate laws
Albania	0.57	9	Greece	0.50	20	Nicaragua	0.65	24
Argentina	0.54	32	Grenada	0.29	16	Niger	0.75	11
Austria	0.18	21	Guatemala	0.55	14	Nigeria	0.76	11
Bahamas	0.41	18	Guinea	0.77	4	Pakistan	0.87	11
Bangladesh	0.74	14	Guyana	0.59	22	Panama	0.47	16
Barbados	0.58	11	Honduras	0.57	13	Papua New Guinea	0.78	9
Belarus	0.27	13	Hungary	0.30	18	Paraguay	0.54	22
Belgium	0.37	13	India	0.36	15	Peru	0.41	20
Belize	0.68	9	Indonesia	0.33	18	Philippines	0.32	14
Benin	0.78	20	Iraq	0.81	10	Poland	0.39	33
Bhutan	0.22	11	Ireland	0.06	23	Portugal	0.51	19
Bolivia	0.44	24	Israel	0.11	15	Romania	0.52	10
Brazil	0.60	32	Italy	0.47	25	Russia	0.35	10
Bulgaria	0.30	9	Jamaica	0.60	8	Rwanda	0.36	12
Burundi	0.80	10	Jordan	0.40	10	Samoa	0.64	16
Cambodia	0.47	10	Kazakhstan	0.44	11	Sierra Leone	0.70	8
Cabo Verde	0.72	6	Kenya	0.54	11	Slovakia	0.42	19
Chile	0.58	9	Kosovo	0.80	9	Slovenia	0.29	27
China	0.09	10	Kyrgyz Rep	0.52	16	Solomon Isls	0.49	11
Colombia	0.56	11	Lao PDR	0.34	13	South Africa	0.36	19
Costa Rica	0.69	14	Latvia	0.30	19	Spain	0.56	25
Croatia	0.16	10	Lesotho	0.54	5	Sri Lanka	0.46	13
Cyprus	0.48	3	Liberia	0.70	5	St Lucia	0.82	18
Czech Rep	0.60	19	Lithuania	0.39	11	Suriname	0.40	8
Côte d'Ivoire	0.67	9	Luxembourg	0.35	23	Sweden	0.02	32
Denmark	0.36	31	Madagascar	0.63	13	Tajikistan	0.41	20
Dominica	0.86	21	Malawi	0.55	11	Tanzania	0.79	11
Dominican Rep	0.66	12	Malaysia	0.38	13	Thailand	0.36	16
Ecuador	0.48	24	Mali	0.61	12	Timor-Leste	0.52	12
Egypt	0.44	12	Malta	0.49	14	Tonga	0.48	13
El Salvador	0.47	10	Mauritius	0.52	3	Trinidad & Tobago	0.28	17
Estonia	0.22	23	Mexico	0.52	16	Tunisia	0.40	16
Eswatini	0.32	9	Micronesia	0.53	14	Türkiye	0.35	13
Ethiopia	0.68	13	Moldova	0.41	9	Ukraine	0.42	12
Fiji	0.38	11	Mongolia	0.27	23	Uruguay	0.53	18
Finland	0.13	33	Montenegro	0.29	8	Vanuatu	0.53	8
France	0.52	19	Morocco	0.54	14	Venezuela	0.56	15
Gabon	0.74	11	Mozambique	0.40	13	Vietnam	0.23	17
Gambia	0.85	7	Myanmar	0.44	14	Zambia	0.56	17
Georgia	0.50	2	Namibia	0.24	13	Zimbabwe	0.60	8
Germany	0.22	23	Nepal	0.80	12			
Ghana	0.83	11	Netherlands	0.15	16	Total average	0.46	15.03

Note. Authors' calculations.

regulatory frameworks that could support energy access through long-term infrastructure planning. Mid-duration countries, including Sri Lanka (13) and Tonga (13), display mixed outcomes; while they have had climate laws in place for over a decade, they still experience high energy constraints, indicating possible gaps in infrastructure or policy enforcement. Low-duration countries, such as Cyprus (3 years) and Mauritius (3 years), show the least regulatory maturity, which, coupled with high energy constraints, suggests a need for strengthened regulatory frameworks and infrastructure investment.

3.4. Controls

We include a compact set of firm- and country-level controls that theory and prior evidence link to energy access. At the firm level: FAGE (log years since founding; mean 3.22), capturing organizational maturity and resilience [30,76]; FSIZE (employees: 1 = small, 2 = medium, 3 = large; mean 1.77), reflecting scale, bargaining power, and backup options [11,77]; FOWNPR (% privately owned; mean 89.17 %), a proxy for financial flexibility [14,78]; FSALES (log sales; mean 16.52), indicating capacity to finance reliability [29]; FEXPRT (=1 if > 50 % exports), capturing standards and resources tied to export orientation [14]; and FINFORC (=1 if the firm faces informal competitors), representing competitive pressure that can exacerbate access issues [79]. At the country level: ENRGINFL (IMF; mean 4.98 %, range −5.36 %–41.30 %), capturing cost volatility that tightens constraints [69], and ENRGPRD (renewables share; mean 6.62 %, range 0 % to > 70 %), proxying system diversity and sustainability [80,81]. Descriptives (Tables 2 and 3): ENRGACC mean 0.45; CLIMLAW averages 15.24 years (range 2–33); correlations: CLIMLAW–ENRGPRD = 0.30, CLIMLAW–ENRGINFL = −0.12, FAGE–FSIZE = 0.22; the mean VIF = 1.07, indicating negligible multicollinearity. Detailed definitions remain in the Appendix.

3.5. Estimation methodology

To estimate the effect of climate laws on firms' energy access, where the outcome variable is binary, a probit model using a maximum likelihood estimator offers a more appropriate approach than OLS regression [70]. The probit model specifically addresses binary dependent variables by estimating the probability of an outcome using a cumulative normal distribution, which ensures that predictions remain bounded between 0 and 1. To enhance the accuracy and reliability of the estimates, the country-year model incorporates sector and country fixed effects, where firm effects are unavailable. These fixed effects account for unobserved, time-invariant factors that vary across sectors and countries, such as differences in energy policies, regulatory frameworks, and industry-specific characteristics. Sector fixed effects control for variations within specific industries, while country fixed effects address differences in national energy infrastructures and regulatory environments. By controlling for these factors, the model reduces some omitted variable bias and isolates the impact of climate laws on energy access. In

Table 2
Summary statistics.

Variable	Count	Mean	SD	Min	P25	P50	P75	Max
ENRGACC	126154	0.45	0.50	0.00	0.00	0.00	1.00	1.00
CLIMLAW	126154	15.24	6.04	2.00	11.00	14.00	18.00	33.00
FAGE	126154	3.22	0.54	0.01	2.89	3.22	3.50	5.86
FSIZE	126154	1.77	0.77	1.00	1.00	2.00	2.00	3.00
FOWNPR	126154	89.17	29.12	0.00	100.0	100.0	100.0	100.0
FSALES	126154	1.65	3.05	0.00	1.44	1.62	1.83	3.55
FINFORC	126154	0.39	0.49	0.00	0.00	0.00	1.00	1.00
FEXPRT	126154	0.07	0.26	0.00	0.00	0.00	0.00	1.00
ENRGINFL	126154	4.98	4.75	−5.36	1.91	4.63	6.14	41.30
ENRGPRD	126154	6.62	10.75	0.00	0.26	2.60	6.90	72.26

Note. The table reports the summary statistics of the variables.

Table 3
Correlation matrix.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ENRGACC (1)	1.00									
CLIMLAW (2)	−0.07***	1.00								
FAGE (3)	0.03***	0.14***	1.00							
FSIZE (4)	−0.02***	0.04***	0.22***	1.00						
FOWNPR (5)	−0.01**	−0.02***	−0.02***	−0.15***	1.00					
FSALES (6)	−0.01	−0.01	0.01***	0.01***	−0.01	1.00				
FINFORC (7)	0.05***	−0.04***	−0.01	−0.08***	0.03***	0.01*	1.00			
FEXPRT (8)	−0.01***	0.03***	0.03***	0.19***	−0.15***	0.01	−0.09***	1.00		
ENRGINFL (9)	0.09***	−0.12***	0.04***	−0.01***	−0.01***	−0.01	0.01**	−0.05***	1.00	
ENRGPRD (10)	−0.05***	0.30***	0.07***	0.02***	−0.01***	−0.01	−0.05***	0.07***	−0.03***	1.00
VIF	1.07									

Notes. The table reports the pairwise correlations between variables as well as the mean variance inflation factor (VIF) value for the regression.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

this cross-country analysis, clustering standard errors at the country level further ensures robustness [82]. Firms within the same country often face similar conditions and respond similarly to climate laws and energy policies, creating within-country correlation in error terms. Together, the probit model, fixed effects, and clustered standard errors form a rigorous baseline framework for estimating the relationship in this cross-country setting. The probit model can be expressed as follows:

$$P\big(Y\_(ijt) = 1|X\_(ijt)\big) = \Phi\Big(\beta\_(0) + \beta\_(1)\ \text{CLIMLAW\_(jj)} + \beta\_(2)\ \text{X\_(ijt)} + \beta\_(3)\ \text{Z\_(jt)} + \alpha\_(\text{s}) + \gamma\_(\text{c}) + \epsilon\_(\text{ij})\Big) \quad (1)$$

In this model, $P(Y_{ijt} = 1|X_{ijt})$ represents the probability that firm *i* in country *j* in year *t* experiences an energy constraint, with $\mathbf{\Phi}$ as the cumulative distribution function of the standard normal distribution. The dependent variable, $ENRGACC_{ijt}$ is binary, where 1 indicates that a firm reported an energy constraint. The key predictor $CLIMLAW_{jj}$ measures the years since a country's first climate law, hypothesized to affect firms' energy access. The vector X_{ijt} includes firm-level controls: firm age (log years since establishment) for maturity, firm size (small, medium, large by employee count), private ownership (percentage privately owned), sales performance (log sales as a financial health measure), competition with informal firms (1 = yes, 0 = no), and exporter status (1 if over 50 % of sales are exported). These variables capture resource flexibility and external pressures impacting energy access. Country-level controls vector Z_{jt} includes energy price inflation (annual price changes) and extent of renewable energy production (renewable energy percentage), both influencing energy stability and cost. Sector fixed effects (α_s) and country fixed effects (γ_c) control for unobserved, time-invariant industry and country factors, with the error term (ϵ_{ijt}) capturing unexplained variance. Probit model coefficients indicate changes in the latent z-score rather than direct probabilities, with marginal effects often calculated for interpretation [83]. Given causality challenges, we interpret results as associations, cautiously using terms like "impact" and "predict" to describe the observed statistical relationships.

4. Results

4.1. Baseline effects

Table 4 presents the baseline effects of climate laws and controls on the probability of firms facing energy constraints, estimated using various fixed effects models. Across all specifications, the duration of climate law implementation shows a negative and statistically significant relationship with energy constraints. In Model (4), the most comprehensive model, the coefficient for climate law implementation duration (CLIMLAW) is −0.123 ($p < 0.01$). This indicates that for each additional year of climate law maturity, the likelihood of firms experiencing energy constraints decreases. This finding supports H1, confirming that longer-established climate laws significantly improve firms' access to reliable energy. The results highlight that mature climate laws foster regulatory stability, infrastructure development, and alignment with sustainability goals, reducing firms' energy constraints. Over time, these laws introduce efficiency standards, carbon pricing mechanisms, and incentives that promote renewable energy adoption and innovation [80,84]. Firms respond by investing in energy-efficient technologies and adopting sustainable practices, which lower operational constraints and enhance energy reliability [85]. Furthermore, climate laws encourage infrastructure upgrades, decentralized energy solutions, and energy storage systems, which improve grid stability and support the integration of renewable energy sources [54]. Mechanisms like power purchase agreements and renewable energy certificates provide financial incentives that expand clean energy availability, stabilize supply chains, and ensure firms benefit from sustainable and reliable energy systems in the long term [59]. These outcomes align with H3, as countries with greater renewable energy production and lower energy costs experience fewer constraints on firms' energy access.

Several firm-specific factors also influence energy constraints, with

Table 4
Baseline direct effects.

Variable	(1)	(2)	(3)	(4)
CLIMLAW	−0.012	−0.012*	−0.158***	−0.123***
	(0.008)	(0.008)	(0.021)	(0.021)
FAGE	0.044	0.030	−0.036	−0.051**
	(0.036)	(0.036)	(0.024)	(0.024)
FSIZE	0.001	−0.016	0.060***	0.046***
	(0.028)	(0.028)	(0.013)	(0.013)
FOWNPR	−0.001	−0.001	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)
FSALES	−0.001	−0.001	−0.001*	−0.001*
	(0.001)	(0.001)	(0.001)	(0.001)
FINFORC	0.110**	0.115***	0.061*	0.068**
	(0.043)	(0.043)	(0.032)	(0.031)
FEXPRT	−0.054	−0.091**	−0.010	−0.052**
	(0.040)	(0.039)	(0.022)	(0.022)
ENRGINFL	0.027***	0.026***	0.032***	0.032***
	(0.009)	(0.009)	(0.008)	(0.007)
ENRGPRD	−0.002	−0.002	−0.010*	−0.010*
	(0.003)	(0.003)	(0.006)	(0.006)
Pseudo R^2	0.013	0.016	0.098	0.102
Log likelihood	−86900.0	−85670.0	−86987.0	−87213.0
Country FE	No	No	Yes	Yes
Sector FE	No	Yes	No	Yes
N	126154	126154	126154	126154

Notes. The table presents the baseline impact of climate laws on firms' energy constraint, with control variables accounting for economic and environmental factors. The data spans from 2006 to 2022, and the estimation employs a probit model that incorporates both random and fixed effects. Standard errors are indicated in parentheses and are clustered by country. Model (1) exclusively incorporates random effects, while Model (2) solely accounts for sector effects. Model (3) focuses solely on country effects, and Model (4) encompasses both country and sector effects.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

some findings supporting H2. Firm age (FAGE) has a negative coefficient (−0.029, p = 0.043), suggesting that older firms are less likely to face energy constraints, likely due to accumulated resilience and adaptive capacity [86]. Firm size (FSIZE) shows a positive coefficient (0.046, p = 0.004), indicating that larger firms are more likely to encounter energy constraints, possibly due to their higher energy demands. Private ownership (FOWNPR) has a positive coefficient (−0.001, p = 0.008), implying that privately owned firms experience higher energy constraints. Sales performance (SALES) demonstrates a negative relationship (−0.034, p = 0.039), showing that firms with better financial performance are more capable of investing in energy-related infrastructure, reducing constraints [67]. Exporter status (FEXPRT) has a negative coefficient (−0.052, p = 0.027), demonstrating that export-oriented firms benefit from consistent energy access to maintain competitiveness [87]. These results confirm H2, as firms with stronger financial resources, advanced operational capacity, and export-oriented strategies better adapt to climate laws and secure reliable energy access.

Country-level factors further shape energy constraints. Energy price inflation (ENRGINFL) has a positive coefficient (0.032, $p < 0.01$), highlighting the adverse impact of rising energy costs on firms' access to energy, underscoring the importance of economic stability [8]. Conversely, renewable energy production (ENRGPRD) shows a negative coefficient (−0.011, $p < 0.05$), suggesting that higher shares of renewable energy reduce constraints by providing more reliable and sustainable energy sources [68]. These findings reinforce H3, demonstrating that countries with robust renewable energy capacity and stable energy costs create an enabling environment for firms to access reliable energy.

The results emphasize the critical role of climate laws in reducing energy constraints and improving firms' access to sustainable energy. Policymakers should focus on regulatory maturity, economic stability, and renewable energy expansion while addressing firm-level disparities through strategies that enhance financial and technological capacity [40,41].

4.2. Indirect effects

Table 5 explores the indirect effects of climate laws on firms' energy access by analyzing interactions with firm-level characteristics, revealing how these attributes influence energy constraints under varying regulatory maturity. The primary variable, climate law implementation duration (CLIMLAW), remains a significant and negative predictor across all models. Interaction terms provide additional insights: CLIMLAW x FAGE (−0.005, $p < 0.10$) indicates that older firms benefit more from maturing climate laws due to their operational stability and adaptability [74]. CLIMLAW x FSALES (−0.001, $p < 0.05$) suggests firms with higher sales performance leverage regulatory stability to improve energy access. In contrast, CLIMLAW x FOWNPR (0.001, $p > 0.05$) shows that firms with high private ownership do not significantly benefit, possibly due to prioritizing profitability over compliance or investment in infrastructure [29]. Lastly, CLIMLAW x FEXPRT (−0.007, $p < 0.10$) reveals that export-oriented firms encounter fewer energy constraints under mature climate laws, likely due to their strategic importance and resilience in international markets [51]. These results highlight the moderating role of firm-specific characteristics in shaping the relationship between climate laws and energy access. These results show that while longer climate law implementation duration generally reduces energy constraints, the benefits are greater for older firms, as well as for firms with strong sales and export performance. In contrast, large firms and firms with high private ownership may not experience the same level of advantage. Policymakers should consider firm-level heterogeneity when designing and implementing energy policies to maximize their effectiveness [5].

5. Endogeneity

Endogeneity is a frequent challenge in econometric estimation, occurring when an explanatory variable is correlated with the error term in a regression model [70]. Endogeneity can significantly affect the quality of results when estimating the causal effect of climate laws on firms' energy constraint. If unobserved factors simultaneously impact both the likelihood of energy constraints and the implementation of climate laws, the estimated effects of climate laws might capture these confounding influences rather than the true relationship, leading to over- or underestimation of the effects. This endogeneity can arise from omitted variable bias, measurement errors, reverse causality, or adverse selection. To address endogeneity concerns, the study employs instrumental variable (IV) methods, the Oster test for coefficient stability, and propensity score matching. Table 6 provides the results.

5.1. Instrumental variables

Instrumental variables are employed to isolate the exogenous variation in climate law implementation, independent of firms' energy constraints. For this purpose, we utilize the Environmental Democracy Index (EDI) as an external instrumental variable. EDI is a comprehensive metric developed by the World Resources Institute and The Access Initiative, designed to evaluate and compare the extent to which national laws promote environmental democracy. It assesses countries across three interrelated rights: the right to freely access information regarding environmental quality and issues, the right to engage meaningfully in decision-making processes, and the right to seek enforcement of environmental laws or compensation for damages [88]. These rights are fundamental to ensuring transparent, inclusive, and accountable environmental governance. The EDI evaluates these rights through 75 legal indicators, aligned with the United Nations Environment Program's (UNEP) Bali Guidelines, which assess the robustness of national laws in safeguarding and promoting procedural environmental rights.

In the context of this research, EDI meets both the relevance and exclusivity conditions for addressing potential endogeneity when examining the impact of climate laws on firms' energy access in

Table 5
Indirect effects.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
CLIMLAW	−0.088***	−0.118***	−0.125***	−0.123***	−0.120***	−0.128***
	(0.032)	(0.023)	(0.021)	(0.021)	(0.023)	(0.022)
CLIMLAW x FAGE	−0.005*					
	(0.002)					
FAGE	0.021	−0.051**	−0.051**	−0.051**	−0.051**	−0.051**
	(0.053)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
FSIZE	0.046***	0.073**	0.046***	0.046***	0.046***	0.046***
	(0.013)	(0.033)	(0.013)	(0.013)	(0.013)	(0.013)
CLIMLAW x FSIZE		−0.002				
		(0.002)				
FOWNPR	0.001**	0.001**	−0.001	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CLIMLAW x FOWNPR			0.001			
			(0.001)			
FSALES	−0.001*	−0.001*	−0.001*	0.001*	−0.001*	−0.001*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CLIMLAW x FSALES				−0.001*		
				(0.001)		
FINFORC	0.068**	0.068**	0.068**	0.068**	0.086	0.068**
	(0.031)	(0.031)	(0.031)	(0.031)	(0.061)	(0.031)
CLIMLAW x FINFORC					−0.001	
					(0.003)	
FEXPRT	−0.052**	−0.052**	−0.053**	−0.053**	−0.053**	0.062
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.067)
CLIMLAW x FEXPRT						−0.007*
						(0.004)
ENRGINFL	0.031***	0.032***	0.032***	0.032***	0.032***	0.032***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
ENRGPRD	−0.010*	−0.010*	−0.010*	−0.010*	−0.010*	−0.010*
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Pseudo R^2	0.102	0.102	0.102	0.102	0.102	0.102
Log likelihood	−86,900.0	−86,900.0	−86,900.0	−86,900.0	−86,900.0	−86,900.0
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
N	126154	126154	126154	126154	126154	126154

Notes. Notes. The table presents the interaction effects of climate law with the firm-specific characteristics on firms' energy constraint, with control variables accounting for economic and environmental factors. The data spans from 2006 to 2022, and the estimation employs a probit model that incorporates both random and fixed effects. Standard errors are indicated in parentheses and are clustered by country.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

developing countries. First, the EDI, which measures a country's commitment to transparency, public participation, and access to justice in environmental governance, is strongly relevant to the enactment and longevity of climate laws. Countries with higher EDI scores are likely to have regulatory frameworks that support and uphold climate legislation, reflecting an environment that promotes mature, effective climate laws [89]. This governance support is essential to ensure that climate laws remain robust and impactful over time, thus indirectly influencing the conditions that affect firms' energy access. Therefore, a higher EDI score suggests a greater likelihood of climate law maturity and continuity, directly connecting environmental democracy with our research focus on the efficacy of climate laws. Secondly, EDI is exclusive in that it is unlikely to directly impact individual firms' energy access in a manner other than through the regulatory climate it supports. EDI is a measure of procedural rights—access to information, public participation, and access to justice—specifically within the environmental governance sphere. These rights facilitate the development and sustainability of environmental regulations but do not directly alter firms' energy infrastructure or pricing. Thus, while EDI scores reflect an environment conducive to stronger, more sustainable climate laws, they do not directly influence the energy constraints firms experience. This makes EDI a credible instrument, as its effects on firms' energy access are mediated through its support for climate law development and enforcement, rather than through direct interventions in energy supply or pricing. We argue that EDI meets the relevance condition by indicating a supportive environment for climate law maturation and the exclusivity condition by affecting energy access only indirectly through regulatory governance, rather than through direct influence on energy markets.

In Model (1), the first stage results show that EDI is highly significant as an instrument for CLIMLAW, with a positive coefficient (5.638, $p < 0.01$), indicating a strong correlation between the instrument and the allegedly endogenous variable, CLIMLAW. Additionally, the Kleibergen-Paap LM statistic is significant at the 10 % level (3.077, $p = 0.079$), supporting the relevance of EDI as an exogenous predictor of CLIMLAW. The large heteroskedasticity-corrected Kleibergen-Paap F statistic (3144.6) confirms the strength of EDI as an instrument, exceeding the conventional threshold of 10, which indicates robustness against weak instrument concerns. These statistics suggest that EDI is a valid and strong instrument, effectively isolating the exogenous variation in CLIMLAW necessary for inference. In the second stage, the coefficient for CLIMLAW is −0.053 ($p < 0.01$), indicating that a longer duration of climate laws is associated with a lower probability of firms experiencing energy constraints. The large F statistic (12.207 > 10) confirms the regression's overall significance.

Model (2) employs the Conditional Mixed Process (CMP) estimation, which is useful for addressing endogeneity by allowing for instrumental variables within a simultaneous equations framework, capturing unobserved factors that may influence the endogenous regressor and the outcome variable [71]. The first stage results (3.928, $p < 0.01$) also show that the EDI serves as a strong instrument for CLIMLAW effectively capturing the exogenous variation needed in CLIMLAW. The model provides a Chi-squared statistic of 2.29e+06, which is highly significant, indicating a good fit and suggesting that the model accounts for a substantial portion of the variance in firms' energy access. The insignificant Atanhrho value (0.072, $p = 1.36$) provides additional insights into the

Table 6
Endogeneity analysis.

Variable	(1)	(2)	(3)	(4)
CLIMLAW	−0.053***	−0.061***	−0.048***	
	(0.002)	(0.008)	(0.008)	
FAGE	−0.040*	−0.013	−0.018**	
	(0.022)	(0.008)	(0.009)	
FSIZE	0.052***	0.021***	0.016***	
	(0.017)	(0.004)	(0.004)	
FOWNPR	0.001	0.001**	0.001**	
	(0.001)	(0.001)	(0.001)	
FSALES	−0.001***	−0.001***	−0.001***	
	(0.001)	(0.001)	(0.001)	
FINFORC	0.041	0.021*	0.024**	
	(0.028)	(0.011)	(0.011)	
FEXPRT	−0.058**	−0.003	−0.018**	
	(0.029)	(0.008)	(0.008)	
ENRGINFL	0.026***	0.012***	0.012***	
	(0.001)	(0.003)	(0.003)	
ENRGPRD	0.002***	−0.004*	−0.004*	
	(0.001)	(0.002)	(0.002)	
TREATED				−0.054***
				(0.003)
First-stage				
CLIMLAW				
EDI	5.638***	3.928***		
	(1.560)	(0.827)		
Kleibergen-Paap F_stat	31.446			
Second stage				
Pseudo R^2				
Kleibergen-Paap LM stat (pv)	3.077			
	(0.079)			
F stat	12.207	.	.	250.067
Chi^2		2.290.02		
Beta			−0.006	
Delta			0.301	
Atanhrho (pv)		0.072		
		(0.36)		
Mean_bias(%)				7.312
N	65247	126471	126154	85296

Notes. The table presents the impact of climate laws on firms' energy constraint after applying endogeneity analysis, with control variables accounting for economic and technological factors. The data spans from 2006 to 2022, and the estimation employs IV models. Standard errors are indicated in parentheses and are clustered by country. Model (1) employs an instrumental variable (IV) approach utilizing the 2SLS estimator. Model (2) also applies an IV method, but this time employing the CMP estimator. In the IV analysis, the external instrument utilized is the degree to environmental democracy in the country (EDI). Model (3) uses the Oster (2019) coefficient stability test to address potential omitted variable effects.
*p < 0.1, **p < 0.05, ***p < 0.01.

residual correlation, suggesting this correlation is not significant. This implies that unobserved heterogeneity between the endogenous regressor and the outcome variable is adequately controlled, reducing the risk of bias from endogeneity. In the second stage, CLIMLAW shows a negative and statistically significant coefficient (−0.061, $p < 0.01$), indicating that a longer history of climate laws reduces the probability of energy constraints for firms. This aligns with the research hypothesis that mature climate laws facilitate better energy access, likely by promoting improved infrastructure and stability in energy policies.

5.2. *The Oster test of coefficient stability*

Model (3) applies the coefficient stability approach of Oster (2019) to gauge sensitivity of our estimates to omitted variables. As a rule of thumb, $\delta \geq 1$ is interpreted as evidence that unobservables would need to be at least as important as observables to overturn the result. In our case, the estimated $\delta = 0.301$ indicates limited robustness: relatively modest selection on unobservables could attenuate the effect toward zero. We therefore treat this diagnostic as cautionary rather than confirmatory and avoid causal claims based on the Oster test alone. Notwithstanding, within the Oster framework the CLIMLAW coefficient remains negative and significant (−0.048, $p < 0.01$), consistent with the broader pattern in our IV, CMP, and PSM analyses, and with prior evidence that policy frameworks can accompany improved energy reliability [5,37,51,90]. We thus interpret the Oster results as a sensitivity check, i.e., one that tempers the strength of the inference from selection on observables models, while relying on the quasi-experimental evidence for more credible identification.

5.3. *Propensity score matching*

Finally, Model (4) uses propensity score matching (PSM) to create a balanced comparison group of firms with similar characteristics, except for exposure to mature climate laws. By matching firms in countries with long-standing climate laws to similar firms in countries with shorter or less comprehensive climate regulations (separated by the CLIMLAW median value), this method reduces bias from observable differences across groups, providing a more reliable estimate of the effect of climate laws on energy access constraints. The study uses PSM with a nearest-neighbor matching process to address potential endogeneity by creating comparable groups of firms that differ primarily in their exposure to mature climate laws [72]. This approach aims to reduce selection bias by matching firms based on similar observable characteristics, allowing for a clearer interpretation of the impact of climate law maturity on energy access. The TREATED variable in this model represents firms in countries with mature climate laws—defined as countries where climate laws have been established for a longer period. The coefficient for TREATED is negative and significant (−0.054, $p < 0.01$), indicating that firms exposed to longer-standing climate laws are significantly less likely to experience energy constraints. This aligns with the hypothesis that mature climate regulations improve conditions for energy access by promoting more stable and supportive infrastructure and regulatory environments. The significance and negative direction of the TREATED coefficient suggest a robust effect of climate law maturity on reducing energy access constraints for firms. Moreover, the mean bias of 7.312 % (<10 %) reflects the success of the PSM process in creating balanced treatment and control groups with minimal differences in observable characteristics. This low bias percentage indicates that the matching process effectively reduces selection bias, enhancing confidence that differences in energy access constraints can be attributed to the presence of mature climate laws rather than underlying firm characteristics. The PSM results reinforce the interpretation of the robust effect of climate law maturity on firms' energy access.

6. Robustness

6.1. *Sensitivity analysis*

The sensitivity tests evaluate the robustness of our primary findings regarding the impact of climate laws on firms' energy access by utilizing alternative metrics and modifications to the baseline model. Table 7 presents the results. In Model (1), an alternative ordinal variable, derived from WBES data, is employed to assess firms' energy access, with values ranging from 0 to 4, where 4 represents a severe constraint (ENRGACC1). Using the ordinal variable provides richer insights of firms' energy constraint since their decisions may be less accurately captured by the binary bifurcation [91]. Following the new measurement, the coefficient for CLIMLAW remains negative and significant (−0.551, $p < 0.01$), indicating that the baseline relationship holds even with a more refined measure of energy constraints. This supports the finding that longer-standing climate laws reduce the likelihood of severe energy constraints for firms.

Model (2) introduces an alternative measure of climate regulation (CLIMLAW2) based on the presence of 'mandatory' ESG disclosure requirements by country, using data from Krueger et al. [92]. The CLIMLAW2 coefficient remains significantly negative (−0.086, $p < 0.01$),

Table 7
Sensitivity tests.

Variable	(1)	(2)	(3)	(4)	(5)
CLIMLAW	−0.551***			−0.123***	−0.121***
	(0.022)			(0.021)	(0.022)
CLIMLAW2		−0.086***			
		(0.008)			
CLIMLAW3			−0.097***		
			(0.001)		
FAGE	−0.068***	−0.051**	−0.051**	−0.050**	−0.049**
	(0.023)	(0.024)	(0.024)	(0.024)	(0.025)
FSIZE	0.065***	0.046***	0.046***	0.045***	0.045***
	(0.014)	(0.013)	(0.013)	(0.013)	(0.013)
FOWNPR	0.001**	0.001**	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
FSALES	−0.001***	−0.001*	−0.001*	−0.001*	−0.001*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
FINFORC	0.089***	0.068**	0.068**	0.068**	0.068**
	(0.030)	(0.031)	(0.031)	(0.031)	(0.031)
FEXPRT	−0.063**	−0.052**	−0.052**	−0.051**	−0.053**
	(0.025)	(0.022)	(0.022)	(0.022)	(0.022)
ENRGINFL	0.029***	0.032***	0.032***	0.032***	0.031***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
ENRGPRD	−0.006	−0.010*	−0.010*	−0.010*	−0.010*
	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
Pseudo R^2	0.108	0.102	0.102	0.096	0.102
Log likelihood	−82500.0	−86900.0	−86900.0	−86200.0	−86000.0
Country FE	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes
N	125567	126154	126154	125009	124732

Notes. The table presents the impact of climate laws on firms energy constraint after applying alternative sensitivity tests, with control variables accounting for economic and technological factors. The data spans from 2006 to 2022, and the estimation employs a probit model that incorporates fixed effects. Standard errors are indicated in parentheses and are clustered by country. Model (1) employs an alternative metric of firms' energy constraint based on a wider differentiation of responses (ENRGACC1). Model (2) utilizes an alternative metric of climate laws based on the number of years since mandatory ESG disclosure is established (CLIMLAW2). Model (3) employs an alternative metric of climate laws based on the number of years since voluntary ESG disclosure is encouraged (CLIMLAW3). Model (4) adopts a distinct sample framework that omits the country whose firms experience the lowest energy constraint, namely Sweden. Model (5) operates with an alternative sample structure that that omits the country with the longest implementation of climate laws, namely Poland.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

showing that mandatory ESG frameworks, independently from climate law provisions, also help alleviate firms' energy constraints. This test is important as it demonstrates that regulatory mechanisms promoting transparency and sustainability positively affect firms' energy access.

In Model (3), 'voluntary' ESG disclosure, again from Krueger et al. [92], is used as an alternative climate regulation measure (CLIMLAW3). The coefficient for CLIMLAW3 remains negative and significant (−0.097, $p < 0.01$), suggesting that even voluntary ESG practices can create conditions favorable for firms' energy access, likely by encouraging firms to adopt energy-efficient behaviors that reduce dependency on traditional energy sources.

Model (4) excludes Sweden, the country whose firms experience the highest energy access, to determine if outliers impact the results. The CLIMLAW coefficient is still negative and significant (−0.123, $p < 0.01$), indicating that the main findings are not driven by countries with unusually high energy access. Finally, Model (5) excludes Poland, which has the longest history of climate law implementation, to assess the impact of countries with extensive regulatory experience and to contain large spender bias [93]. The coefficient for CLIMLAW remains negative and significant (−0.121, $p < 0.01$), affirming the robustness of the results across varying climate regulation histories.

These sensitivity tests are crucial as they confirm that the observed relationship between climate law implementation duration and improved energy access for firms holds across different definitions of variables, country exclusions, and regulatory contexts. This robustness reinforces the conclusion that mature climate laws positively impact firms' energy security, supporting the hypothesis that regulatory continuity contributes to more stable energy environments.

6.2. Additional controls

The regression estimates in Table 8 evaluate the robustness of the effect of climate laws on firms' energy access by adding various groups of additional control variables to account for energy, technological, and economic conditions, each addressing potential omitted variable biases that could influence the baseline results.

Model (1) incorporates additional controls to capture the impact of specific energy conditions, including the share of electricity generated from fossil fuels (ENRFOS), sourced from the Energy Institute (https://www.energyinst.org), and the quality of electricity supply (ENRQUL), using data from the World Economic Forum. Energy infrastructure quality and reliance on fossil fuel-based electricity generation significantly affect energy access, particularly in developing countries [94]. The coefficient for Climate Law Implementation Duration (CLIMLAW) remains negative and significant (−0.257, $p < 0.01$), confirming that mature climate laws reduce the likelihood of firms experiencing energy constraints, independent of energy infrastructure specifics. Additionally, ENRFOS shows a negative and significant coefficient (−0.005, $p < 0.05$), indicating that higher reliance on fossil fuels decreases energy constraints, while ENRQUL exhibits a significant negative coefficient (−0.198, $p < 0.01$), demonstrating that better electricity supply quality mitigates energy constraints. These results highlight that while mature climate laws independently enhance energy access, strategic energy production choices and investments in superior energy infrastructure further improve energy stability for firms.

In Model (2), we assess the influence of a country's technological environment on energy access by incorporating technological factors such as the availability of the latest technologies (TECHAVL), and sourced from the World Economic Forum, and the Digital Adoption Index (DIGITAD), sourced from the World Bank database. The

Table 8
Additional controls.

Variable	(1)	(2)	(3)
CLIMLAW	−0.257***	−0.212***	−0.007***
	(0.091)	(0.020)	(0.001)
FAGE	−0.082***	−0.089	−0.051
	(0.021)	(0.061)	(0.049)
FSIZE	0.048***	0.050**	0.039
	(0.014)	(0.020)	(0.031)
FOWNPR	0.001*	0.001***	−0.001
	(0.001)	(0.001)	(0.001)
FSALES	−0.001**	−0.001***	−0.001
	(0.001)	(0.001)	(0.001)
FINFORC	0.077**	0.051	0.152*
	(0.032)	(0.069)	(0.086)
FEXPRT	−0.057***	−0.056	−0.099**
	(0.022)	(0.040)	(0.046)
ENRGINFL	0.019**	−0.482***	0.030***
	(0.008)	(0.010)	(0.006)
ENRGPRD	−0.006	−0.618***	0.317***
	(0.006)	(0.160)	(0.007)
ENRFOS	−0.005*		
	(0.003)		
ENRQUL	−0.198***		
	(0.045)		
TECHAVL		2.225***	
		(0.033)	
DIGITAD		−0.239***	
		(0.902)	
ENRGIMP			−0.040***
			(0.001)
ENVHLT			−0.009***
			(0.001)
Pseudo R^2	0.106	0.103	0.088
Log likelihood	−85000.0	−25400.0	−12600.0
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
N	123351	36654	18454

Notes. The table presents the impact of climate laws on firms energy constraint after adding new control variables. The data spans from 2006 to 2022, and the estimation employs a probit model that incorporates fixed effects. Standard errors are indicated in parentheses and are clustered by country. Model (1) introduces adjustments to account for the effect of energy conditions (ENRFOS, ENRQUL). Model (2) introduces adjustments to account for the effect of technological conditions (TECHAVL, DIGITAD). Model (3) introduces adjustments to account for the effect of economic and environmental conditions (ENRGIMP, ENVHLT).
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

coefficient for Climate Law Implementation Duration (CLIMLAW) remains negative and significant (−0.212, $p < 0.01$), confirming that the beneficial impact of mature climate laws on energy access persists even when accounting for technological readiness and digital integration [68]. Among the new controls, TECHAVL displays a positive and significant coefficient (2.225, $p < 0.01$), suggesting that greater availability of advanced technology increases energy constraints. This seemingly counterintuitive result aligns with Kajikawa et al. [95], who argue that integrating innovative technologies can initially heighten energy demands and create infrastructure challenges, exacerbating energy constraints in the short term. Conversely, DIGITAD has a negative and significant coefficient (−0.073, $p < 0.05$), indicating that higher digital adoption reduces energy constraints. This finding is consistent with Voumik et al. [96], who emphasize the role of digital technologies in improving energy efficiency, thereby mitigating overall energy constraints. Together, these results underscore the independent role of climate laws in enhancing energy access, with technological advancements further amplifying this positive effect.

In Model (3), we introduce energy and environmental controls to further examine their impact on energy access. These include the value of energy imports as a percentage of total energy use (ENRGIMP), sourced from the World Development Indicators, and the Environmental Health Index (ENVHLT) from Yale's Environmental Performance Index database. The coefficient for CLIMLAW remains negative and significant (−0.007, $p < 0.01$), demonstrating a persistent, albeit smaller, effect of climate law maturity in reducing energy constraints even after accounting for economic and environmental factors. ENRGIMP shows a negative and significant effect (−0.040, $p < 0.05$), suggesting that higher availability of imported energy decreases the likelihood of energy constraints [97]. In contrast, ENVHLT has a negative and significant effect (−0.049, $p < 0.05$), indicating that better environmental health conditions reduce energy access [98]. These findings reaffirm the role of climate laws in easing energy constraints while underscoring the importance of economic resilience and environmental quality in ensuring stable energy access for firms.

These additional controls validate the robustness of our primary findings, emphasizing that the observed effects of climate law implementation duration on firms' energy access are not solely due to specific conditions in energy, technology, or broader economic factors. The results reinforce the evidence that climate law maturity plays an independent role in easing energy constraints, supporting the research hypothesis that regulatory stability through climate policies facilitates a more accessible energy environment for firms across developing countries.

6.3. *Dominance analysis*

Leveraging Luchman's [99] recent methodology for conducting dominance analysis, we evaluate the relative importance of each regressor in predicting energy constraint. Drawing on the Shapley value decomposition from game theory, this approach examines the collective fit statistic to assess the individual contributions of each independent variable [100]. Dominance analysis serves as a valuable tool to pinpoint the most influential predictors and enhance our understanding of their collective impact on energy access of firms. The analysis is conducted for the entire sample, as well as separately for distinct groups of countries, in line with recent empirical studies [101].

Table 9 presents the results, illustrating the relative importance of each variable in explaining firms' energy access and offering a nuanced understanding of the relative predictive power of climate laws and control variables. In Model (1), which considers all countries, the dominance statistic for CLIMLAW is rather small at 0.0037. This indicates a meaningful but smaller relative contribution of climate laws to explaining firms' energy constraints, within the context of other more influential factors such as energy price inflation (0.0104) and less influential ones such as informal competition (0.0021). The moderate fit

Table 9
Dominance analysis.

Variable	(1)	(2)	(3)
CLIMLAW	0.0037	0.0013	0.0110
FAGE	0.0013	0.0012	0.0019
FSIZE	0.0011	0.0012	0.0011
FOWNPR	0.0011	0.0011	0.0011
FSALES	0.0011	0.0011	0.0014
FINFORC	0.0021	0.0026	0.0015
FEXPRT	0.0012	0.0016	0.0011
ENRGINFL	0.0104	0.0059	0.0146
ENRGPRD	0.0019	0.0011	0.0025
Fit-stat	0.018	0.010	0.030
N	126154	68773	57381

Notes. The table displays the outcomes of dominance analysis, examining the influence of each individual regressor on firms' energy constraint. The dataset covers the period from 2006 to 2022, and the estimation utilizes a Shapley value decomposition method to evaluate the contributions of each independent variable to the overall predictive performance. Model (1) illustrates the primary impact of each baseline regressor within the entire dataset. Model (2) showcases the dominant influence of all regressors within the subset of relatively more developed countries. Model (3) showcases the dominant influence of all regressors within the subset of relatively less developed countries.

Table 10
Moderation effects – capability contingencies.

	(1)	(2)	(3)
CLIMLAW	−0.114***	−0.124***	−0.068***
	(0.022)	(0.021)	(0.021)
CLIMLAW x MANGEXP	−0.010**		
	(0.001)		
CLIMLAW x EXLISTED		−0.015**	
		(0.002)	
CLIMLAW x FINACC			0.029***
			(0.003)
FAGE	−0.040	−0.049**	−0.038*
	(0.026)	(0.024)	(0.022)
FSIZE	0.045***	0.049***	0.050***
	(0.013)	(0.012)	(0.012)
FOWNPR	0.001**	0.001*	0.001
	(0.001)	(0.001)	(0.001)
FSALES	−0.001*	−0.001*	−0.001*
	(0.001)	(0.001)	(0.001)
FINFORC	0.074**	0.068**	0.041
	(0.031)	(0.031)	(0.031)
FEXPRT	−0.051**	−0.053**	−0.043*
	(0.022)	(0.022)	(0.022)
ENRGINFL	0.031***	0.032***	0.030***
	(0.008)	(0.008)	(0.007)
ENRGPRD	−0.010*	−0.010*	−0.009
	(0.006)	(0.006)	(0.006)
Pseudo R^2	0.103	0.102	0.120
Log likelihood	−86600.0	−86900.0	−86900.0
Country FE	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes
N	125675	126154	126154

Notes. The table shows the effects of climate laws on firms' energy constraint while accounting for the impact of moderating factors and their interactive effects. The dataset covers the period 2006 to 2022, and the estimation utilizes a probit model with fixed effects. Standard errors are presented in parentheses and are clustered by country. Model (1) reveals the additional climate law-mediated impact of the firm's top manager experience (MANGEXP). Model (2) shows the added climate law-mediated effect of whether the firm is publicly listed on an exchange (EXLISTED). Model (3) shows the additional climate law-mediated influence of the firm's financing constraints (FINACC).
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

statistic (0.018) suggests that while CLIMLAW is significant, its influence is part of a broader interplay of factors shaping energy access.

Model (2) focuses on relatively more advanced developing countries, classified by median GDP per capita. Here, the dominance statistic for CLIMLAW decreases to 0.0013, reflecting a smaller relative role for climate laws in explaining energy access constraints in these contexts. Instead, energy price inflation (0.0059) and informal competition (0.0026) exhibit greater dominance, suggesting that energy costs and market competition are more significant barriers to energy access in these economies. The lower fit statistic (0.010) implies that other, potentially omitted, factors may play a more substantial role in explaining energy access in relatively developed contexts, where baseline infrastructure is stronger, and regulatory interventions may have less pronounced effects.

Model (3) examines relatively less advanced developing countries, where CLIMLAW exhibits a relatively high dominance statistic (0.0110), signaling a prominent role for climate laws in these settings. The fit statistic of 0.030 indicates higher explanatory power, underscoring that in less developed countries, mature climate laws are critical for addressing energy constraints. The importance of energy price inflation (0.0146), which has the highest dominance statistic, further highlights the dual significance of regulatory maturity and energy price stability in shaping firm-level energy access. These findings suggest that in less developed countries, where energy infrastructure is weaker, climate laws are relatively more effective tools in alleviating energy access issues.

In summary, the dominance analysis reveals that the relative importance of climate laws in influencing energy access varies across contexts. While climate laws play a meaningful role universally, their impact is strongest in less developed countries, where regulatory frameworks can significantly enhance weak energy infrastructure. Conversely, in more advanced developing countries, energy costs and competitive dynamics overshadow the influence of climate law maturity, reflecting the differing priorities and challenges across development contexts.

7. Moderation analysis: capability contingencies

We examine whether the association between climate-law maturity (CLIMLAW) and firm energy constraints varies with firm capabilities and financing conditions. Using probit models with interaction terms CLIMLAW $\times$ Z for three moderators: top-manager experience (MANGEXP), public-listing status (EXLISTED), and financing constraints (FINACC). We report interaction effects (average cross-partials) with country-clustered standard errors (Table 10). In all specifications, the main effect of CLIMLAW remains negative and statistically significant (e.g., −0.114 to −0.124 to −0.068), indicating that longer-standing climate laws are associated with fewer firm-reported energy constraints, a pattern consistent with evidence that climate legislation supports energy security [40]. We focus on the cross-partial estimates and their significance [83].

Model (1) shows that CLIMLAW $\times$ MANGEXP is negative and significant (−0.010, $p < 0.05$). Firms led by more experienced top managers benefit more from regulatory maturity, plausibly because seasoned leaders navigate permitting, contracting, and incentive regimes more effectively, and are better at prioritizing investments in efficiency, procurement, and resilience under persistent rules [14]. The result is consistent with a capability-contingent reading of institutional effects: when credible policies endure, managerial human capital improves a firm's ability to translate those policies into tangible access gains.

Model (2) indicates that CLIMLAW $\times$ EXLISTED is negative and significant (−0.015, $p < 0.05$). Listed firms appear to extract greater reliability gains from mature climate laws, likely due to easier capital access, stronger disclosure/compliance systems, and earlier uptake of energy-management and clean-procurement practices (e.g., PPAs), all of which lower exposure to outages and price spikes [39,102]. When the policy signal is stable, financial market access and governance discipline help firms act on it faster and at larger scale.

Model (3) finds CLIMLAW $\times$ FINACC positive and significant (+0.029, $p < 0.01$), implying that financing frictions erode the benefits of legal maturity. Constrained firms struggle to fund retrofits, storage, or long-term renewable procurement, so the reliability dividends of stable policy do not fully materialize for them [67]. This asymmetry emphasizes that policy credibility is necessary but not sufficient: access to finance remains a binding complement for converting legal rules into reliability.

Across models, CLIMLAW is associated with fewer energy constraints, but who benefits most depends on firm capabilities: experienced management and public listing amplify the association, while financing constraints dampen it. These moderation patterns align with our baseline results and suggest that pairing legal continuity with targeted finance and capability support (e.g., concessional credit, guarantees, EMS investments) can broaden the reliability gains from mature climate laws.

8. Discussion

This study examines whether the maturity of national climate-law regimes, measured as years since the first qualifying climate law, relates to firms' reported energy constraints across 125 mostly developing countries over 2006–2022, and whether this relationship varies by firm capabilities and country energy conditions (H1–H3). The results provide consistent micro-level evidence that policy continuity is associated with improved firm energy access, while also showing that the benefits are conditional: they are shaped by firms' capabilities and by country-level price and infrastructure environments.

The baseline estimates support H1. Climate-law maturity (CLIMLAW) is negative and statistically significant in the preferred fixed-effects specification, indicating that longer-standing climate-law regimes coincide with a lower probability that firms report energy constraints. This result is consistent with the climate-governance literature that emphasizes credible commitment and durability as central to translating legislation into investment and system change [37,38,65]. It also extends prior empirical work that mostly links climate laws and policy frameworks to macro-outcomes (e.g., investment and energy security) by demonstrating a relationship with a directly operational, firm-level constraint [39–41]. In the same baseline models, energy price inflation is strongly positive, while renewable energy production is negative and marginally significant, reinforcing the interpretation that institutional maturity is not operating in isolation: macro energy affordability and system composition matter for what firms actually experience.

The heterogeneity results clarify how this association maps into firm behavior and capabilities, supporting H2. Interaction models indicate that the beneficial association between CLIMLAW and energy constraints is stronger for firms with greater operational and market capacity: older firms (CLIMLAW × FAGE), higher-performing firms (CLIMLAW × FSALES), and exporters (CLIMLAW × FEXPRT). This is consistent with the broader view that firms translate regulatory signals into operational outcomes when they have the routines, resources, and incentives to invest in efficiency, procurement, and resilience [29,34, 42]. The capability-contingency models sharpen this conclusion: firms with more experienced management and publicly listed firms benefit more from climate-law maturity, whereas firms facing financing constraints benefit less. These patterns align closely with evidence that managerial capacity and governance facilitate adoption of energy/environmental practices, while financing frictions constrain the ability to invest—even when the policy environment improves [44,50, 67]. A key implication is distributional: climate-law maturity may reduce constraints on average, but the gains are not automatically broad-based unless financing and capability gaps are addressed.

Several baseline firm-level correlates also merit interpretation, including two that may appear counterintuitive and therefore require explicit explanation. First, firm size is positively associated with energy constraints. While SME-focused accounts often expect smaller firms to be more constrained, in weak-grid environments larger firms can be more exposed because their production is more energy intensive and interruption costs are higher; they may also be more likely to classify energy as a binding obstacle given higher continuity requirements. Second, private ownership share is positively associated with constraints in the preferred baseline model. This pattern is consistent with an allocation and political-economy interpretation in systems where state participation may confer preferential access or priority during rationing or connection processes, whereas fully private firms face more market exposure in fragile networks. Finally, informal competition is associated with higher constraints, which is consistent with the idea that competitive pressure compresses margins and reduces the scope for reliability-enhancing investments in constrained settings [11]. These results collectively reinforce that firm-level constraints reflect both capability and exposure/allocation mechanisms.

The evidence remains robust across multiple identification and sensitivity exercises, supporting H3 as a conditional proposition rather than a universal one. Endogeneity checks show that the negative CLIMLAW relationship persists using IV (2SLS) and CMP approaches with EDI as an instrument and is corroborated by propensity score matching. At the same time, the Oster diagnostic yields δ large enough, indicating that omitted variables could attenuate the estimate under that framework; accordingly, the strongest defensible claim is that results are consistent with a causal pathway, but causal language should remain appropriately conservative given the observational design. Sensitivity tests confirm stability using an ordinal energy-constraint outcome, alternative regulation proxies, and influential-country exclusions. Extended-control models show that CLIMLAW remains negative across specifications, while the signs and magnitudes of some contextual variables vary in reduced samples, consistent with the energy-systems literature's emphasis that reliability gains from transition depend on integration readiness and infrastructure conditions rather than renewables alone [52–54]. Dominance analysis further shows that energy price inflation is the most influential predictor overall, while the relative importance of CLIMLAW rises in less developed country subsamples, indicating that institutional maturity may matter most where baseline constraints are more severe.

Three deductions follow. First, the results point to a "law-continuity" channel: sustained climate-law regimes are associated with fewer firm energy constraints, suggesting that durable governance frameworks can generate operational co-benefits alongside environmental objectives. Second, institutional maturity appears to work best when paired with enabling energy-system conditions, especially price stability and grid quality, so that legal signals translate into physical reliability. Third, the benefits are capability-contingent: financing constraints blunt the gains, implying a need for complementary instruments (targeted credit, guarantees, support for energy management and clean procurement) so that constrained firms can convert regulatory maturity into reliability improvements. These deductions connect directly to the study's contribution: by linking climate-law maturity to firm-level constraints, the paper advances the discussion beyond what is already known from macro policy outcomes and from firm constraint studies that do not explicitly incorporate climate-law regimes.

Finally, the results also define a focused agenda for future research. The maturity measure (CLIMLAW) captures duration but not law strength or enforcement, and ENRGACC is survey-based; future studies could incorporate enforcement intensity and objective outage/quality metrics, and exploit staggered legal changes or enforcement shocks for sharper causal identification. These extensions would further clarify the mechanisms through which climate governance translates into firm-level energy access and the conditions under which these benefits become inclusive.

9. Conclusions

Our empirical evidence shows that climate-law maturity is consistently associated with fewer firm-reported energy constraints across 125 countries over 2006–2022. This association is robust to alternative definitions of the dependent variable, alternative policy proxies (mandatory and voluntary ESG disclosure regimes), influential-country exclusions, and a battery of endogeneity checks. The results also reveal meaningful heterogeneity: older, financially stronger, and export-oriented firms appear better positioned to translate regulatory maturity into improved energy access, while larger firms and firms facing informal competition remain more exposed to energy constraints. Capability contingencies are salient: the benefits of regulatory maturity are amplified when firms are led by more experienced top managers and when they are publicly listed, but they are significantly weakened when firms face financing constraints. At the country level, the findings underscore complementarity between institutions and energy-system fundamentals, particularly renewable production capacity and energy price stability, suggesting that regulatory maturity is most consequential when the broader system environment supports reliability and affordability. Taken together, these patterns position climate-law maturity as a meaningful institutional determinant of firm energy access, rather than solely an environmental policy lever.

This study advances theory in three primary ways. First, it isolates regulatory maturity as a distinct dimension of institutional quality, a law-continuity premium, through which persistent climate-law regimes can strengthen credible commitment and progressively align incentives on both the demand side (efficiency investments, disclosure, and cleaner procurement/contracting) and the supply side (clean capacity additions, grid upgrades, storage, and demand response), thereby easing firm-level energy constraints over time. Second, the evidence integrates institutional and resource-dependence perspectives by showing that the access benefits of persistent rules are capability-contingent: firms with stronger governance and managerial capacity, and those with better capital-market access, are more able to convert policy signals into tangible reliability gains, while financing frictions prevent many firms from capturing the institutional dividend. Third, the study addresses an explicit gap in the energy access literature by moving beyond infrastructure-only and macro correlates of access and treating climate laws as a form of institutional infrastructure that accumulates; critically, duration and continuity, rather than the mere presence of legislation, matter. These contributions yield a tractable framework linking law maturity → investment and compliance responses → energy-system reliability → firm energy access, with testable heterogeneity by firm resources and national energy conditions.

For policymakers and regulators, the findings imply that improving firm energy access requires both institutional continuity and system enablers. First, governments should preserve and deepen continuity around core instruments (e.g., standards, carbon pricing, renewable portfolio standards, and certificate markets) to reduce policy risk and crowd in long-horizon private investment. Second, climate-law maturity should be paired with energy-system complements, renewables integration, grid modernization, storage, and demand response, so that regulatory signals translate into physical reliability rather than remaining aspirational. Third, policy design should explicitly target capability and finance gaps: concessional lending, guarantees, and tax measures aimed at SMEs and financially constrained firms can enable adoption of energy management systems, retrofits, and distributed renewables, widening the access gains from regulatory maturity. Fourth, given the outsized role of energy price dynamics in shaping constraints, regulators should prioritize mechanisms that reduce price volatility and uncertainty (e.g., competitive procurement, transparent tariff design, and carefully sequenced subsidy reform). Finally, credibility depends on implementation: institutionalizing disclosure, monitoring, and enforcement capacity is essential so that the benefits of legal continuity are not diluted by weak compliance.

For managers, the results imply that regulatory durability creates a predictable environment in which firms can justify longer-horizon reliability investments and contracting. Practical steps include developing energy-risk playbooks that combine long-term PPAs (or virtual PPAs), on-site generation, and storage; investing in energy management systems, metering, and process optimization to reduce peak loads and outage exposure; strengthening regulatory-navigation and sustainable-finance capabilities (e.g., green loans/bonds, blended finance) to exploit incentives; and hardening supply chains against upstream energy shocks through diversification and supplier engagement on renewables and efficiency. In capability-rich firms, these actions help convert policy continuity into measurable reliability and cost predictability at the plant level; for constrained firms, external finance and targeted support become decisive.

Four directions appear most promising. First, future work should exploit quasi-experimental variation, staggered adoptions, legal thresholds, enforcement shocks, and event-study designs, to sharpen causal inference and trace dynamic effects as regimes mature. Second, researchers should move beyond duration alone by indexing law quality, scope, and enforcement intensity, and by merging firm surveys with objective, high-frequency reliability, and price data (including geospatial proxies such as nighttime lights or grid-quality indicators) to observe constraints more directly. Third, the financing channel warrants deeper investigation, particularly why efficiency and resilience investments do not always relax capital constraints, and how this shapes the distribution of access gains across firm size, location, and sector—including energy justice outcomes. Fourth, it is important to test robustness under extreme weather events, energy crises, and commodity price spikes, and to examine interactions with trade policy, subsidy reform, and digitalization. Extending the analysis to advanced economies and to more granular settings (e.g., industrial parks and export zones) would further clarify generalizability and boundary conditions of the law-continuity premium.

CRediT authorship contribution statement

Charilaos Mertzanis: Supervision, Methodology, Conceptualization. **Apostolos Vetsikas:** Writing – original draft, Data curation. **Athanasios Pavlopoulos:** Methodology, Investigation. **Mohamed Shaker Ahmed:** Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

The authors declare no known conflicts of interest in conducting this research.

Appendix. Definition of variables

Code	Definition	Source
ENRGACC	Binary indicator (firm-level): 1 if the firm reports an energy-related constraint in the survey year; 0 otherwise.	World Bank Enterprise Surveys (WBES)
CLIMLAW	Years since first climate law (country-year): elapsed years from the first climate-related law's entry into force to the survey year.	Li et al. [73]; ECOLEX; Grantham Research Institute; NewClimate Institute
FAGE	Natural log of firm age (firm-level): log(years since establishment).	WBES
FSIZE	Categorical firm size (firm-level): 1 = Small, 2 = Medium, 3 = Large (WBES size bands based on employee count).	WBES
FOWNPR	Private ownership share (firm-level): percentage (%) of equity privately owned.	WBES
FSALES	Natural log of total sales (firm-level).	WBES
FEXPRT	Binary indicator (firm-level): 1 if exports exceed 50 % of output; 0 otherwise.	WBES
FINFORC	Binary indicator (firm-level): 1 if the firm faces competition from informal (unregistered) firms; 0 otherwise.	WBES
MANGEXP	Top manager experience (firm-level): years of experience of the top manager.	WBES
EXLISTED	Binary indicator (firm-level): 1 if the firm is publicly listed; 0 otherwise.	WBES
FINACC	Binary indicator (firm-level): 1 if the firm reports being financially constrained; 0 otherwise.	WBES
ENRGINFL	Energy price inflation (country-year): annual % change in energy prices.	IMF World Economic Outlook
ENRGPRD	Renewable energy production share (country-year): % of total energy produced from renewable sources.	World Development Indicators (WDI)
ENRFOS	Fossil-fuel electricity share (country-year): % of total electricity generation from fossil fuels.	Energy Institute
ENRQUL	Quality of electricity supply index (country-year); higher values indicate better quality/reliability.	World Economic Forum (WEF)
TECHAVL	Availability of latest technologies index (country-year); higher values indicate greater availability.	WEF

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(*continued*)

Code	Definition	Source
DIGITAD	Digital Adoption Index (country-level): country-level digital technology adoption; higher values indicate greater adoption.	World Bank
ENRGIMP	Energy imports (country-year): energy imports as % of total energy use.	WDI
ENVHLT	Environmental Health Index (country-level): component of Yale's Environmental Performance Index; higher values indicate better environmental health.	Yale EPI
EDI	Environmental Democracy Index (country-level): composite of access to information, public participation, and access to justice in environmental matters.	World Resources Institute; The Access Initiative
ENRGACC1	Ordinal energy-constraint severity (firm-level): WBES-based 0–4 scale, where higher values indicate more severe constraints.	WBES
CLIMLAW2	Years since mandatory ESG disclosure (country-year): elapsed years since adoption of mandatory ESG reporting.	Krueger et al. [92]
CLIMLAW3	Years since voluntary ESG disclosure (country-year): elapsed years since introduction/encouragement of voluntary ESG reporting.	Krueger et al. [92]

Data availability

Data will be made available on request.

References

[1] International Energy Agency. World energy outlook 2022. IEA Publications; 2022. https://www.iea.org/reports/world-energy-outlook-2022. [Accessed 2 November 2024].

[2] United Nations Conference on Trade and Development. The least developed countries report 2021: the energy challenge in least developed countries. United Nations; 2021. https://unctad.org/publication/trade-and-development-report-2021.

[3] International Renewable Energy Agency. Renewable capacity statistics 2023. IRENA; 2023. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf. [Accessed 2 November 2024].

[4] World Bank. Global economic prospects. World Bank Publications; 2023. https://documents1.worldbank.org/curated/en/099060723202024954/pdf/BOSIB03b0337cf0dd096470ad6bbabb2581.pdf. [Accessed 2 November 2024].

[5] African Development Bank Group. African economic outlook 2022: supporting climate resilience and a just energy transition in Africa. African Development Bank Group; 2022. https://www.afdb.org/en/documents/african-economic-outlook-2022. [Accessed 2 November 2024].

[6] International Energy Agency, and International Renewable Energy Agency. Renewable energy Investment report 2023. https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf. [Accessed 2 November 2024].

[7] Benayed W, Awijen H, Bousnina R, Chroufa MA. Infrastructure for sustainable energy access in Sub-Saharan Africa: leveraging social factors and natural capital. J Clean Prod 2024;470:143304. https://doi.org/10.1016/j.jclepro.2024.143304.

[8] Goodell JW, Gurdgiev C, Paltrinieri A, Piserà S. Global energy supply risk: evidence from the reactions of European natural gas futures to nord stream announcements. Energy Econ 2023;125:106838. https://doi.org/10.1016/j.eneco.2023.106838.

[9] Xia L, Wan L, Wang W, Luo J, Yan J. Energy accessibility via natural resources: do natural resources ensure energy accessibility in low income countries? Resour Policy 2023;86:104145. https://doi.org/10.1016/j.resourpol.2023.104145.

[10] Mishra S, Anderson K, Miller B, Boyer K, Warren A. Microgrid resilience: a holistic approach for assessing threats, identifying vulnerabilities, and designing corresponding mitigation strategies. Appl Energy 2020;264:114726. https://doi.org/10.1016/j.apenergy.2020.114726.

[11] Mertzanis C, Garas S, Abdel-Maksoud A. Integrity of financial information and firms' access to energy in developing countries. Energy Econ 2020;92:105005. https://doi.org/10.1016/j.eneco.2020.105005.

[12] Huang R, Yao X. The role of power transmission infrastructure in income inequality: fresh evidence from China. Energy Policy 2023;177:113564. https://doi.org/10.1016/j.enpol.2023.113564.

[13] Shahbaz M, Sheikh UA, Tabash MI, Jiao Z. Shock transmission between climate policy uncertainty, financial stress indicators, oil price uncertainty and industrial metal volatility: identifying moderators, hedgers, and shock transmitters. Energy Econ 2024;136:107732. https://doi.org/10.1016/j.eneco.2024.107732.

[14] Mertzanis C. Institutions, development, and energy constraints. Energy 2018;142:962–82. https://doi.org/10.1016/j.energy.2017.10.073.

[15] Du J, Shen Z, Song M, Vardanyan M. The role of green financing in facilitating renewable energy transition in China: perspectives from energy governance, environmental regulation, and market reforms. Energy Econ 2023;120:106595. https://doi.org/10.1016/j.eneco.2023.106595.

[16] Hassan Q, Viktor P, Al-Musawi TJ, Ali BM, Algburi S, Alzoubi HM, Jaszczur M. The renewable energy role in the global energy transformations. Renew Energy Focus 2024;48:100545. https://doi.org/10.1016/j.ref.2024.100545.

[17] Hoang AT, Nižetić S, Olcer AI, Ong HC, Chen WH, Chong CT, Nguyen XP. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: opportunities, challenges, and policy implications. Energy Policy 2021;154:112322. https://doi.org/10.1016/j.enpol.2021.112322.

[18] Chen WA, Chen CF, Tomasik S. Investigating intentions and barriers in adopting decentralized home energy management systems: a justice dimension of demand flexibility. Energy Build 2024;318:114458. https://doi.org/10.1016/j.enbuild.2024.114458.

[19] Du Q, Sun Z, Goodell JW, Du AM, Yang T. Ecological risk and corporate sustainability: examining ESG performance, risk management, and productivity. Int Rev Financ Anal 2024;96:103551. https://doi.org/10.1016/j.irfa.2024.103551.

[20] Hoicka CE, Lowitzsch J, Brisbois MC, Kumar A, Camargo LR. Implementing a just renewable energy transition: policy advice for transposing the new European rules for renewable energy communities. Energy Policy 2021;156:112435. https://doi.org/10.1016/j.enpol.2021.112435.

[21] Chang RD, Zuo J, Zhao ZY, Zillante G, Gan XL, Soebarto V. Evolving theories of sustainability and firms: history, future directions, and implications for renewable energy research. Renew Sustain Energy Rev 2017;72:48–56. https://doi.org/10.1016/j.rser.2017.01.029.

[22] Opoku EEO, Kufuor NK, Manu SA. Gender, electricity access, renewable energy consumption and energy efficiency. Technol Forecast Soc Change 2021;173:121121. https://doi.org/10.1016/j.techfore.2021.121121.

[23] Jenkins JD. Political economy constraints on carbon pricing policies: what are the implications for economic efficiency, environmental efficacy, and climate policy design? Energy Policy 2014;69:467–77. https://doi.org/10.1016/j.enpol.2014.02.003.

[24] Olujobi OJ, Okorie UE, Olarinde ES, Aina-Pelemo AD. Legal responses to energy security and sustainability in Nigeria's power sector amidst fossil fuel disruptions and low carbon energy transition. Heliyon 2023;9(7):e17912. https://doi.org/10.1016/j.heliyon.2023.e17912.

[25] Mallaband B, Wood G, Buchanan K, Staddon S, Mogles NM, Gabe-Thomas E. The reality of cross-disciplinary energy research in the United Kingdom: a social science perspective. Energy Res Social Sci 2017;25:9–18. https://doi.org/10.1016/j.erss.2016.11.001.

[26] Wu D, Xie Y. Unveiling the impact of public data access on collaborative reduction of pollutants and carbon emissions: evidence from open government data policy. Energy Econ 2024;138:107822. https://doi.org/10.1016/j.eneco.2024.107822.

[27] Kaygusuz K. Energy for sustainable development: a case of developing countries. Renew Sustain Energy Rev 2012;16(2):1116–26. https://doi.org/10.1016/j.rser.2011.11.013.

[28] Jasiūnas J, Lund PD, Mikkola J. Energy system resilience-A review. Renew Sustain Energy Rev 2021;150:111476. https://doi.org/10.1016/j.rser.2021.111476.

[29] Backman CA, Verbeke A, Schulz RA. The drivers of corporate climate change strategies and public policy: a new resource-based view perspective. Bus Soc 2017;56(4):545–75. https://doi.org/10.1177/000765031557845.

[30] Zhang J. Energy access challenge and the role of fossil fuels in meeting electricity demand: promoting renewable energy capacity for sustainable development. Geosci Front 2024;15(5):101873. https://doi.org/10.1016/j.gsf.2024.101873.

[31] Zahraee SM, Shiwakoti N, Stasinopoulos P. Agricultural biomass supply chain resilience: COVID-19 outbreak vs. sustainability compliance, technological change, uncertainties, and policies. Clean Logist Supply Chain 2022;4:100049. https://doi.org/10.1016/j.clscn.2022.100049.

[32] Wang Y, Zhao Z, Shi M, Liu J, Tan Z. Public environmental concern, government environmental regulation and urban carbon emission reduction-analyzing the regulating role of green finance and industrial agglomeration. Sci Total Environ 2024;924:171549. https://doi.org/10.1016/j.scitotenv.2024.171549.

[33] Gao Y, Gu J, Liu H. Interactive effects of various institutional pressures on corporate environmental responsibility: institutional theory and multilevel analysis. Bus Strat Environ 2019;28(5):724–36. https://doi.org/10.1002/bse.2276.

[34] Tyler BB, Lahneman B, Cerrato D, Cruz AD, Beukel K, Spielmann N, Minciullo M. Environmental practice adoption in SMEs: the effects of firm proactive orientation and regulatory pressure. J Small Bus Manag 2024;62(5):2211–46. https://doi.org/10.1080/00472778.2023.2218435.
[35] Segger MCC, Voigt C, editors. Routledge handbook of climate law and governance: courage, contributions and compliance. Taylor & Francis; 2024.
[36] Rossi J. The political economy of energy and its implications for climate change legislation. Tulsa Law Rev 2009;84:379.
[37] Fankhauser S, Gennaioli C, Collins M. The political economy of passing climate change legislation: evidence from a survey. Glob Environ Change 2015;35:52–61. https://doi.org/10.1016/j.gloenvcha.2015.08.008.
[38] Nachmany M, Abeysinghe A, Barakat S. Climate change legislation in the least developing countries. Trends Clim CHange Legislat 2017:59–82. https://doi.org/10.4337/9781786435781.00012.
[39] Liu J, Zhang D, Cai J, Davenport J. Legal systems, national governance, and renewable energy investment: evidence from around the world. Br J Manag 2021;32(3):579–610. https://doi.org/10.1111/1467-8551.12377.
[40] Hu G, Yang J, Li J, Cheng X, Feng C. National climate legislation and policymaking and energy security: international evidence. Appl Energy 2024;375:124157. https://doi.org/10.1016/j.apenergy.2024.124157.
[41] Omri A, Jabeur SB. Climate policies and legislation for renewable energy transition: the roles of financial sector and political institutions. Technol Forecast Soc Change 2024;203:123347. https://doi.org/10.1016/j.techfore.2024.123347.
[42] Delmas MA, Toffel MW. Organizational responses to environmental demands: opening the black box. Strateg Manag J 2008;29(10):1027–55. https://doi.org/10.1002/smj.701.
[43] Ramanathan R, He Q, Black A, Ghobadian A, Gallear D. Environmental regulations, innovation, and firm performance: a revisit of the Porter hypothesis. J Clean Prod 2017;155:79–92. https://doi.org/10.1016/j.jclepro.2016.08.116.
[44] Cooremans C, Schönenberger A. Energy management: a key driver of energy-efficiency investment? J Clean Prod 2019;230:264–75. https://doi.org/10.1016/j.jclepro.2019.04.333.
[45] Gunarathne N, Lee KH. The link between corporate energy management and environmental strategy implementation: efficiency, sufficiency, and consistency strategy perspectives. J Clean Prod 2021;293:126082. https://doi.org/10.1016/j.jclepro.2021.126082.
[46] Braam GJ, De Weerd LU, Hauck M, Huijbregts MA. Determinants of corporate environmental reporting: the importance of environmental performance and assurance. J Clean Prod 2016;129:724–34. https://doi.org/10.1016/j.jclepro.2016.03.039.
[47] Semenova N, Hassel LG. On the validity of environmental performance metrics. J Bus Ethics 2015;132:249–58. https://doi.org/10.1007/s10551-014-2323-4.
[48] Gardner TA, Benzie M, Börner J, Dawkins E, Fick S, Garrett R, Wolvekamp P. Transparency and sustainability in global commodity supply chains. World Dev 2019;121:163–77. https://doi.org/10.1016/j.worlddev.2018.05.025.
[49] Freeman RE, Dmytriyev SD, Phillips RA. Stakeholder theory and the resource-based view of the firm. J Manag 2021;47(7):1757–70. https://doi.org/10.1177/01492063219935.
[50] Brutscher PB, Ravillard P, Semieniuk G. Do energy efficient firms have better access to finance? Energy J 2021;42(6):171–98.
[51] Abdmouleh Z, Alammari RA, Gastli A. Review of policies encouraging renewable energy integration & best practices. Renew Sustain Energy Rev 2015;45:249–62. https://doi.org/10.1016/j.rser.2015.01.035.
[52] Huang YW, Kittner N, Kammen DM. ASEAN grid flexibility: preparedness for grid integration of renewable energy. Energy Policy 2019;128:711–26. https://doi.org/10.1016/j.enpol.2019.01.025.
[53] Dranka GG, Ferreira P, Vaz AIF. Integrating supply and demand-side management in renewable-based energy systems. Energy 2021;232:120978. https://doi.org/10.1016/j.energy.2021.120978.
[54] Wang W, Yuan B, Sun Q, Wennersten R. Application of energy storage in integrated energy systems-A solution to fluctuation and uncertainty of renewable energy. J Energy Storage 2022;52:104812. https://doi.org/10.1016/j.est.2022.104812.
[55] Narassimhan E, Gallagher KS, Koester S, Alejo JR. Carbon pricing in practice: a review of existing emissions trading systems. Clim Policy 2018;18(8):967–91. https://doi.org/10.1080/14693062.2018.1467827.
[56] Lilliestam J, Patt A, Bersalli G. The effect of carbon pricing on technological change for full energy decarbonization: a review of empirical ex?post evidence. Wiley Interdiscip Rev: Clim Change 2021;12(1):e681. https://doi.org/10.1002/wcc.681.
[57] Qadir SA, Al-Motairi H, Tahir F, Al-Fagih L. Incentives and strategies for financing the renewable energy transition: a review. Energy Rep 2021;7:3590–606. https://doi.org/10.1016/j.egyr.2021.06.041.
[58] Madaleno M, Dogan E, Taskin D. A step forward on sustainability: the nexus of environmental responsibility, green technology, clean energy, and green finance. Energy Econ 2022;109:105945. https://doi.org/10.1016/j.eneco.2022.105945.
[59] Gabrielli P, Aboutalebi R, Sansavini G. Mitigating financial risk of corporate power purchase agreements via portfolio optimization. Energy Econ 2022;109:105980. https://doi.org/10.1016/j.eneco.2022.105980.
[60] Ghiassi-Farrokhfal Y, Ketter W, Collins J. Making green power purchase agreements more predictable and reliable for companies. Decis Support Syst 2021;144:113514. https://doi.org/10.1016/j.dss.2021.113514.
[61] Chen CF, Dietz T, Fefferman NH, Greig J, Cetin K, Robinson eC, Fu R. Extreme events, energy security and equality through micro-and macro-levels: concepts, challenges, and methods. Energy Res Social Sci 2022;85:102401. https://doi.org/10.1016/j.erss.2021.102401.
[62] Cook P. Infrastructure, rural electrification, and development. Energy Sustain Dev 2011;15(3):304–13. https://doi.org/10.1016/j.esd.2011.07.008.
[63] Oseni MO. Get rid of it: to what extent might improved reliability reduce self-generation in Nigeria? Energy Policy 2016;93:246–54. https://doi.org/10.1016/j.enpol.2016.03.013.
[64] Bridge G, Özkaynak B, Turhan E. Energy infrastructure and the fate of the nation: introduction to special issue. Energy Res Social Sci 2018;41:1–11. https://doi.org/10.1016/j.erss.2018.04.029.
[65] Stern PC, Sovacool BK, Dietz T. Towards a science of climate and energy choices. Nat Clim Change 2016;6(6):547–55. https://doi.org/10.1038/nclimate3027.
[66] Pfeffer J, Salancik G. External control of organizations-resource dependence perspective. In: Organizational behavior 2. Routledge; 2015. p. 355–70.
[67] He G, Liu Y, Chen F. Research on the impact of environment, society, and governance (ESG) on firm risk: an explanation from a financing constraints perspective. Finance Res Lett 2023;58:104038. https://doi.org/10.1016/j.frl.2023.104038.
[68] Hafner M, Luciani G. The palgrave handbook of international energy economics. Springer Nature; 2022.
[69] Batten JA, Mo D, Pourkhanali A. Can inflation predict energy price volatility? Energy Econ 2024;129:107158. https://doi.org/10.1016/j.eneco.2023.107158.
[70] Wooldridge JM. Econometric analysis of cross section and panel data. MIT press; 2010.
[71] Roodman D. Fitting fully observed recursive mixed-process models with cmp. STATA J 2011;11(2):159–206. https://doi.org/10.1177/1536867X1101100202.
[72] Rosenbaum PR, Rubin DB. The central role of the propensity score in observational studies for causal effects. Biometrika 1983;70(1):41–55. https://doi.org/10.1093/biomet/70.1.41.
[73] Li T, Tang DY, Xie F. Climate laws and cross-border mergers and acquisitions. University of Hong Kong; 2022. Unpublished Working Paper, https://litong17.github.io/home/papers/LiTangXie.pdf.
[74] Adbi A, Shukla D. Registration at founding and firm performance: generalization and extension replication from global data. J Int Bus Stud 2023;54(2):365–84. https://doi.org/10.1057/s41267-022-00532-8.
[75] Bertrand J, Klein PO, Pasiouras F. National culture of secrecy and firms' access to credit. J Bank Finance 2024;168:107277. https://doi.org/10.1016/j.jbankfin.2024.107277.
[76] Tashman P. A natural resource dependence perspective of the firm: how and why firms manage natural resource scarcity. Bus Soc 2021;60(6):1279–311. https://doi.org/10.1177/0007650319898811.
[77] Urmee T, Harries D, Schlapfer A. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. Renew Energy 2009;34(2):354–7. https://doi.org/10.1016/j.renene.2008.05.004.
[78] Warren CR, McFadyen M. Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland. Land Use Policy 2010;27(2):204–13. https://doi.org/10.1016/j.landusepol.2008.12.010.
[79] Himri Y, Stambouli AB, Draoui B, Himri S. Techno-economical study of hybrid power system for a remote village in Algeria. Energy 2008;33(7):1128–36. https://doi.org/10.1016/j.energy.2008.01.016.
[80] Sovacool BK, Del Rio DF, Zhang W. The political economy of net-zero transitions: policy drivers, barriers, and justice benefits to decarbonization in eight carbon-neutral countries. J Environ Manag 2023;347:119154. https://doi.org/10.1016/j.jenvman.2023.119154.
[81] Mutezo G, Mulopo J. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. Renew Sustain Energy Rev 2021;137:110609. https://doi.org/10.1016/j.rser.2020.110609.
[82] Hsu PH, Tian X, Xu Y. Financial development and innovation: cross-country evidence. J Financ Econ 2014;112(1):116–35. https://doi.org/10.1016/j.jfineco.2013.12.002.
[83] Zelner BA. Using simulation to interpret results from logit, probit, and other nonlinear models. Strateg Manag J 2009;30(12):1335–48. https://doi.org/10.1002/smj.783.
[84] Ciccarelli M, Marotta F. Demand or supply? An empirical exploration of the effects of climate change on the macroeconomy. Energy Econ 2024;129:107163. https://doi.org/10.1016/j.eneco.2023.107163.
[85] Jakob M, Flachsland C, Steckel JC, Urpelainen J. Actors, objectives, context: a framework of the political economy of energy and climate policy applied to India, Indonesia, and Vietnam. Energy Res Social Sci 2020;70:101775. https://doi.org/10.1016/j.erss.2020.101775.
[86] Govindan K, Hasanagic M. A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. Int J Prod Res 2018;56(1–2):278–311. https://doi.org/10.1080/00207543.2017.1402141.
[87] Liu Y, Feng C. Promoting renewable energy through national energy legislation. Energy Econ 2023;118:106504. https://doi.org/10.1016/j.eneco.2023.106504.
[88] de Castro-Pardo M, Martín JMM, Azevedo JC. A new composite indicator to assess and monitor performance and drawbacks of the implementation of Aichi biodiversity targets. Ecol Econ 2022;201(107553). https://doi.org/10.1016/j.ecolecon.2022.107553.
[89] Ahmadi A, Garraoui M, Bouri A. Environmental performance, indicators, and environmental democracy: a cross-national study. Environ Pol Law 2019;48(6):354–61. https://doi.org/10.3233/EPL-180100.
[90] Agostino M. Extreme weather events and firms' energy practices. The role of country governance. Energy Policy 2024;192:114235. https://doi.org/10.1016/j.enpol.2024.114235.
[91] Greene WH, Hensher DA. Modeling ordered choices: a primer. Cambridge: Cambridge University Press; 2010.

[92] Krueger P, Sautner Z, Tang DY, Zhong R. The effects of mandatory ESG disclosure around the world. J Account Res 2024;62(5):1795–847. https://doi.org/10.1111/1475-679X.12548.
[93] Hadi AS. Identifying multiple outliers in multivariate data. J Roy Stat Soc B Stat Methodol 1992;54(3):761–71. https://doi.org/10.1111/j.2517-6161.1992.tb01449.x.
[94] Panos E, Densing M, Volkart K. Access to electricity in the world energy Council's global energy scenarios: an outlook for developing regions until 2030. Energy Strategy Rev 2016;9:28–49. https://doi.org/10.1016/j.esr.2015.11.003.
[95] Kajikawa Y, Yoshikawa J, Takeda Y, Matsushima K. Tracking emerging technologies in energy research: toward a roadmap for sustainable energy. Technol Forecast Soc Change 2008;75(6):771–82. https://doi.org/10.1016/j.techfore.2007.05.005.
[96] Voumik LC, Ghosh S, Rashid M, Das MK, Esquivias MA, Rojas O. The effect of geopolitical risk and green technology on load capacity factors in BRICS. Util Policy 2024;88:101757. https://doi.org/10.1016/j.jup.2024.101757.
[97] Butt MM, Khalid M, Jabeen N, Ashraf MA. The impact of energy imports and natural gas resource rents on energy vulnerability: evidence from developing countries. Environ Sci Pollut Res 2024. https://doi.org/10.1007/s11356-024-33854-1.
[98] Fan Y, Liang J, Zhou Y. A literature review of the effects of energy on pollution and health. Environ Res Lett 2020;15(10):103002. https://doi.org/10.1088/1748-9326/abac91.
[99] Luchman JN. Determining relative importance in stata using dominance analysis: domin and domme. STATA J 2021;21(2):510–38. https://doi.org/10.1177/1536867X211025837.
[100] Azen R, Budescu DV. Comparing predictors in multivariate regression models: an extension of dominance analysis. J Educ Behav Stat 2006;31(2):157–80. https://doi.org/10.3102/10769986031002157.
[101] Mertzanis C. Central bank policies and green bond issuance on a global scale. Energy Econ 2024;133:107541. https://doi.org/10.1016/j.eneco.2024.107541.
[102] Gielen D, Boshell F, Saygin D, Bazilian MD, Wagner N, Gorini R. The role of renewable energy in the global energy transformation. Energy Strategy Rev 2019;24:38–50. https://doi.org/10.1016/j.esr.2019.01.006.