https://doi.org/10.33271/nvngu/2026-3/235

M. Sitnicki[*1,2],
orcid.org/0000-0002-0452-0404,
D. Kurinskyi[3,4],
orcid.org/0000-0001-9025-778X,
J. Užík[5],
orcid.org/0000-0001-6678-2285,
S. Podosynnikov[6],
orcid.org/0009-0006-3786-5907

1 – West Virginia University, Morgantown, United States of America
2 – VIZJA University, Warsaw, Republic of Poland
3 – Sumy National Agrarian University, Sumy, Ukraine
4 – Selkat Holding, Singapore, Republic of Singapore
5 – Bratislava University of Economics and Business, Bratislava, Slovak Republic
6 – Sumy State University, Sumy, Ukraine
* Corresponding author e-mail: maksym.sitnicki@mail.wvu.edu

ENERGY POLICY STRINGENCY AND GREEN DIGITAL ENERGY START-UPS

Purpose. The purpose of this article is to determine the impact of energy policy stringency and its individual instruments on the development and financing of green and digital energy start-ups.

Methodology. The study applies panel data analysis for 47 countries over 2000–2023, covering 1,128 country-year observations. The empirical base combines data from the International Energy Agency and the OECD Energy Policy Stringency Index. Two-way fixed-effects models with Driscoll–Kraay standard errors are used to assess the effects of aggregate and disaggregated policy indicators. Dynamic specifications with one- and two-period lags are also estimated, while logarithmic transformations are applied to reduce skewness and zero-inflation in start-up and funding variables.

Findings. The results show that stricter energy policy environments positively affect entrepreneurial activity and investment in green and digital energy sectors. A one-unit increase in the Energy Policy Stringency Index is associated with 8.5 % growth in green start-ups and 11.2 % growth in digital start-ups. The effect on financing is stronger: early-stage green funding increases by 308 %, later-stage green funding by 263 %, while early- and later-stage digital funding rise by 268 and 188 %, respectively. Decomposition results reveal substantial heterogeneity across policy instruments. Feed-in tariffs, renewable auctions and renewable certificates show the strongest positive effects, especially on later-stage financing. Dynamic estimates confirm the persistence of these effects over time.

Originality. The study provides cross-country evidence on how aggregate and individual energy policy instruments affect green and digital energy start-ups. It shows that policy stringency mainly influences investment and scaling rather than start-up entry alone.

Practical value. The findings can help policymakers, regulators and innovation agencies design balanced energy-transition policies that support investment, scaling and sustainable entrepreneurship.

Keywords: *policy stringency, energy start-ups, energy transition, start-up financing, panel analysis*

Received: 07 March 2026
Accepted: 01 June 2026
Available online: 27 June 2026

Introduction. The acceleration of the global energy transition has placed innovation and entrepreneurship at the centre of sustainable development strategies. International organisations such as the European Commission [1], International Energy Agency (IEA) [2], and International Renewable Energy Agency (IRENA) [3] consistently emphasise that achieving climate neutrality requires not only large-scale deployment of existing technologies but also the continuous emergence of new firms capable of developing and scaling breakthrough solutions. Recent reports highlight that innovation ecosystems, particularly start-up-driven innovation, are essential for accelerating clean energy deployment, improving system flexibility, and reducing transition costs [2, 3]. In this context, energy start-ups operating at the intersection of green technologies and digital innovation play a critical role in enabling decentralised energy systems, advancing storage solutions, and facilitating real-time energy optimisation. However, these firms face significant uncertainty related to regulation, financing conditions, and market access, making policy frameworks a decisive factor for their development.

At the same time, governments increasingly rely on regulatory instruments to steer the energy transition, with growing attention to both the intensity and composition of policy measures. According to the Organisation for Economic Co-operation and Development, environmental policy stringency has strengthened considerably across countries, reflecting more ambitious decarbonisation targets and climate commitments [4]. These policies include emissions trading systems, carbon pricing mechanisms, renewable support schemes, and regulatory standards. While stricter policies are generally expected to stimulate innovation by creating incentives and reducing uncertainty, recent evidence suggests that their effects are heterogeneous across instruments and time horizons. The IEA emphasises that market-based mechanisms such as auctions and price signals tend to accelerate investment and innovation. In contrast, regulatory tightening may initially impose adjustment costs before generating long-term benefits [2]. This underscores the importance of understanding not only the overall level of policy stringency but also the specific channels through which different policy instruments influence entrepreneurial dynamics [5, 6].

Furthermore, the growing digitalisation of the energy sector introduces an additional layer of complexity in the sustainability transition [7]. Reports from the European Commission and International Renewable Energy Agency highlight that digital technologies, such as artificial

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intelligence, smart grids, and data-driven energy management systems, are becoming critical enablers of renewable integration and energy system resilience [1, 3]. Digitalisation enhances the efficiency, flexibility, and scalability of energy systems, thereby creating new opportunities for entrepreneurial activity in the energy sector. However, despite the increasing importance of both green and digital innovation, there remains limited empirical evidence on how energy policy stringency affects these two dimensions simultaneously, particularly in a dynamic and cross-country context. Addressing this gap is essential for designing effective policy mixes that support not only environmental objectives but also innovation, investment, and long-term economic sustainability.

Literature review. The relationship between environmental policy stringency and innovation has long been central to the literature on sustainable development, with early contributions demonstrating that stricter environmental regulation can stimulate technological change and improve environmental performance through innovation incentives [8]. The source [9] examines how open science and open access policies serve as drivers of innovation in various European countries. More recent studies extend this perspective by showing that policy stringency is not only associated with environmental outcomes but also interacts with financial development and green growth [10, 11]. At the same time, regulatory pressure is increasingly recognised as a catalyst for broader sustainability dynamics and economic transformation [12, 13]. At the same time, the effectiveness of such policies depends on their design and implementation, as different instruments, such as carbon taxes and subsidies, generate heterogeneous effects across sectors and countries [14, 15]. Furthermore, regulatory standards and policy mixes can shape these effects in distinct ways, influencing both environmental and economic outcomes [16]. This growing body of research highlights the importance of moving beyond aggregate measures of policy stringency to examine the differentiated impact of specific policy tools within the broader energy transition.

In parallel to this strand, a substantial body of literature has explored the determinants of start-up formation and performance in sustainable and digital contexts. Entrepreneurial ecosystems, institutional conditions, and macroeconomic environments are identified as key drivers of start-up activity, with factors such as human capital, financial development, and regulatory quality shaping firm entry and survival [17, 18]. In addition, collaboration between business and academia further strengthens innovation capacity and supports entrepreneurial development [19, 20]. In the context of renewable energy and digital innovation, access to finance and investment conditions are particularly critical, as start-ups often face high uncertainty and capital intensity [21, 22]. Empirical evidence further suggests that policy frameworks can influence venture capital decisions and investment flows, especially when environmental policy signals reduce uncertainty and create new market opportunities [23, 24]. At the firm level, entrepreneurial orientation, leadership, and organisational capabilities, such as ambidexterity and innovation capacity, are shown to enhance resilience and performance under changing economic and regulatory conditions [25, 26]. In addition, green entrepreneurial orientation and leadership practices further support sustainable performance and long-term competitiveness [27, 28]. These findings indicate that both external policy environments and internal organisational factors shape start-up dynamics.

The literature also emphasises the increasing role of digitalisation and technological transformation in shaping modern entrepreneurial ecosystems. The integration of artificial intelligence, digital platforms, and data-driven technologies into start-up activities enhances innovation potential and business performance, particularly in energy-related sectors [29, 30]. Digitalisation is further linked to the development of entrepreneurial ecosystems and innovation networks, where collaboration between business and academia facilitates knowledge transfer and the growth of start-ups [31, 32]. In addition, public support mechanisms strengthen these linkages and enhance innovation outcomes [33]. The emergence of smart cities and digital infrastructure also shapes start-up ecosystems, though evidence suggests the relationship between technological advancement and entrepreneurial activity may not always be linear [34]. In the energy sector, digital transformation supports new business models, such as servitisation and platform-based solutions, enabling start-ups to participate more actively in energy markets [35]. In addition, the development of circular and secure industrial systems further reinforces the role of innovation ecosystems in sustainable transformation [36, 37]. These developments underscore the growing convergence between green and digital innovation in the context of the energy transition.

Another important strand of research focuses specifically on renewable energy entrepreneurship and the role of policy and infrastructure in shaping start-up ecosystems. Empirical studies indicate that reliable energy infrastructure, regulatory frameworks, and market conditions significantly influence the development of renewable energy start-ups, highlighting the importance of institutional support and policy consistency [38, 39]. At the macro level, energy conditions and sustainability-oriented policies are found to affect entrepreneurial capacity and innovation potential across countries. Furthermore, the interaction between policy stringency and broader economic factors, such as financial development and supply chain innovation, is crucial in shaping energy transition outcomes. Evidence also suggests that behavioural and incentive-based approaches, including financial incentives and green promotion mechanisms, can further stimulate sustainable business practices and entrepreneurial engagement [40]. However, regulatory complexity and administrative barriers may hinder start-up development if not properly addressed.

Finally, the literature highlights the importance of knowledge management, leadership, and institutional coordination in supporting sustainable innovation and entrepreneurship [41]. Effective knowledge transfer and governance frameworks are essential for fostering innovation ecosystems and enabling start-ups to scale [42, 43]. At the same time, public–private partnerships play a critical role in strengthening coordination and supporting the growth of entrepreneurial activities [44]. At the same time, entrepreneurs face psychological and organisational challenges, including stress, uncertainty,

and resource constraints, which influence their decision-making and performance [45]. Strategic capabilities and resource-based determinants, including relational capital and innovation capacity, are therefore critical for achieving sustainable performance [46, 47]. In addition, sector-specific transformations, such as decarbonisation strategies and changes in transport and logistics systems, illustrate how policy instruments can reshape market structures and create new opportunities for innovation [48].

The existing literature demonstrates that environmental policy stringency, entrepreneurial ecosystems, and digital transformation are deeply interconnected in shaping sustainable innovation outcomes. However, there remains a clear gap in understanding how different policy instruments simultaneously influence green and digital energy start-ups and how these effects evolve over time. Addressing this gap is essential to designing effective, balanced policy frameworks that support the development of sustainable, innovation-driven energy systems.

This study aims to determine the impact of energy policy stringency and its individual instruments on the development and financing of green and digital energy start-ups, as well as to substantiate practical recommendations for designing policy mechanisms that strengthen their investment attractiveness and scaling potential.

Research objective, methodology and data. This study investigates the impact of energy policy stringency on the development of green and digital energy start-ups using a panel data approach. The empirical analysis is based on a cross-country dataset covering 47 countries over the period 2000–2023, resulting in 1,128 country–year observations. The panel structure allows for the identification of both cross-sectional and temporal variation in entrepreneurial activity and policy environments.

An important feature of the dataset is its country coverage, determined by the joint availability of information on both energy policy stringency and energy start-up activity. Specifically, the sample includes the following 47 countries: Australia, Austria, Bulgaria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, Canada, Chile, Colombia, Costa Rica, Israel, Japan, Korea, Mexico, New Zealand, Argentina, China, India, Indonesia, Peru, Saudi Arabia, and South Africa. The inclusion of countries is therefore not arbitrary. However, it is strictly defined by the existence of consistent and overlapping data on the Energy Policy Stringency Index (EPSI) and its sub-indices (sub-policies), as well as on start-up counts and funding indicators. This ensures comparability across observations but also implies that the sample is biased towards countries with more developed statistical systems and policy reporting frameworks.

The dependent variables capture both the extent of entrepreneurial activity and the availability of financial resources in the energy innovation ecosystem. Specifically, six indicators are used: the number of energy and green start-ups, the number of energy and digital start-ups, early-stage funding and later-stage funding for green start-ups, and early-stage and later-stage funding for digital start-ups. These data are obtained from the International Energy Agency Energy Start-up Data Explorer, which provides harmonised cross-country information on energy-related entrepreneurial activity and investment flows.

The key explanatory variable is the Energy Policy Stringency Index (EPSI), along with its 12 sub-indices that capture specific policy instruments, such as emissions trading systems, carbon taxes, fossil fuel subsidies, feed-in tariffs, renewable energy auctions, and regulatory standards. These data are sourced from the Organisation for Economic Co-operation and Development Data Explorer, which provides consistent, internationally comparable indicators of environmental policy stringency. Including both the aggregate index and its components enables a detailed decomposition of policy effects across different regulatory instruments.

Given the highly skewed and zero-inflated nature of the dependent variables, particularly funding indicators, logarithmic transformations are applied to all outcome variables using the transformation $\ln(1 + x)$. This transformation reduces skewness and kurtosis, improves the distributional properties, and enhances the reliability of statistical inference. The transformed variables are therefore used in all econometric estimations.

The baseline empirical specification employs a two-way fixed-effects (TWFE) model, which controls for unobserved country-specific heterogeneity and common time shocks. The general model can be expressed as

$$Y_{it} = \beta X_{it} + \alpha_i + \lambda_t + \varepsilon_{it}, \quad (1)$$

where Y_{it} denotes the logarithm of start-up activity or funding in the country i and year t; X_{it} represents the policy variable (EPSI or its sub-indices); α_i captures country fixed effects; and λ_t denotes year fixed effects. This specification accounts for time-invariant structural differences across countries and global shocks affecting all units simultaneously.

To address potential issues of heteroskedasticity, serial correlation, and cross-sectional dependence, the models are estimated with Driscoll–Kraay standard errors, which are robust in panel settings with a relatively large time dimension. This approach is particularly appropriate given the global nature of energy markets and the diffusion of policy.

In addition to the baseline models, two extensions are implemented to capture the complexity of policy effects. First, the EPSI is decomposed into its individual sub-indices to examine the heterogeneous impact of different policy instruments. Second, dynamic specifications with one-period and two-period lags of the policy variables are estimated to account for delayed responses in entrepreneurial activity and investment decisions. The lagged model can be written as

$$Y_{it} = \beta_1 X_{i,t-1} + \beta_2 X_{i,t-2} + \alpha_i + \lambda_t + \varepsilon_{it}. \quad (2)$$

These dynamic models allow for the identification of short- and medium-term policy effects and provide insights into the temporal transmission mechanisms of regulatory changes.

All estimations are conducted in the R statistical environment using the *fixest* package, which efficiently implements high-dimensional fixed-effects models. The empirical strategy thus combines robust panel estima-

tion techniques with detailed policy decomposition and dynamic analysis, ensuring a comprehensive assessment of how energy policy stringency influences both the creation and financing of green and digital energy start-ups.

Results. The indicators of entrepreneurial activity reveal substantial heterogeneity across countries and over time (Table 1). On average, the number of energy and green start-ups amounts to 14.13, while energy and digital start-ups average 7.24. However, the medians are considerably lower (4 and 2, respectively), indicating a strong right-skewed distribution. This is further confirmed by high skewness (2.59 and 2.71) and kurtosis values (7.73 and 8.47), suggesting that a relatively small number of countries account for a disproportionately large share of start-up activity. A similar pattern is observed for funding variables. Although the mean early-stage funding for green start-ups exceeds USD 48 million, and later-stage funding averages over USD 33 million, the median is zero across all funding indicators. This reflects a highly uneven distribution, where many country–year observations report no investment activity, while a few exhibit extremely large funding volumes. The extremely high skewness (ranging from 9.89 to 24.09) and kurtosis (up to 686.12) further confirm the presence of outliers and heavy tails, justifying the use of logarithmic transformations in subsequent estimations.

Regarding policy variables, the Energy Policy Stringency Index (EPSI) has a mean and median of 2.98, indicating a relatively balanced distribution around moderate levels of regulatory stringency. The low skewness (0.07) and negative kurtosis (–1.19) suggest an approximately symmetric and relatively flat distribution. Among the sub-indices, instruments such as ETS for electricity (mean 3.39) and air emission standards (mean 4.23) exhibit relatively high average levels and low dispersion, indicating widespread adoption across countries. In contrast, policies such as carbon taxes (mean 0.56), fossil fuel excise taxes (mean 0.29), and renewable energy auctions (mean 0.35) exhibit low mean values and pronounced positive skewness, suggesting that these instruments are implemented in only a limited number of countries or years. Similarly, the prevalence of feed-in tariffs, renewable certificates, and coal phase-out measures is characterised by zero medians, suggesting sporadic or uneven adoption.

The descriptive statistics (Table 1) highlight three important features of the dataset. First, entrepreneurial and funding variables are highly skewed and zero-inflated, with important implications for model selection and supporting the use of count models and log-transformations. Second, policy stringency varies significantly across instruments, reflecting heterogeneous regulatory approaches across countries. Third, the relatively balanced distribution of the aggregate EPSI suggests that it captures broader policy environments more consistently than individual sub-indices. These patterns provide a strong empirical foundation for further econometric analysis of the relationship between policy stringency and the development of green and digital energy start-ups.

The post-transformation descriptive statistics indicate that the logarithmic transformation significantly improves the statistical properties of the dependent variables, making them more suitable for regression analysis. The reduced skewness and kurtosis improve the reliability of parameter estimates and inference, while preserving the underlying economic variation in start-up activity and funding. Consequently, the transformed variables are used in subsequent econometric models to ensure robust, interpretable results.

The baseline results from the two-way fixed-effects models with Driscoll–Kraay standard errors are presented in Table 2. The findings provide consistent evidence that stricter energy policy environments are associated with higher levels of entrepreneurial activity and investment in both green and digital energy sectors.

The estimates indicate a positive and statistically significant relationship between the Energy Policy Stringency Index (EPSI) and start-up activity. Specifically, a

Table 1

Descriptive statistics of variables

Variable	N	Mean	SD	Min	Median	Max	Skewness	Kurtosis
Energy and green start-ups (Number)	1,128	14.13	22.64	0	4	139	2.59	7.73
Energy and digital start-ups (Number)	1,128	7.24	11.55	0	2	78	2.71	8.47
Early-stage funding (green) (1M USD)	1,128	48.08	382.59	0	0	6.89	13.29	193.85
Later-stage funding (green) (1M USD)	1,128	33.28	268.74	0	0	4.19	12.65	170.01
Early-stage funding (digital) (1M USD)	1,128	16.22	71.89	0	0	1.32	9.89	131.72
Later-stage funding (digital) (USD)	1,128	12.47	113.55	0	0	3.38	24.09	686.12
Energy Policy Stringency Index	1,128	2.98	1.72	0.03	2.98	6.96	0.07	-1.19
ETS – Electricity	1,128	3.39	3.46	0	3.50	10	0.24	-1.59
Carbon Tax – Electricity	1,128	0.56	1.89	0	0	10	3.59	12.18
Fossil Fuel Subsidies – Electricity	1,128	4.30	4.49	0	2	10	0.23	-1.77
Fossil fuels excise taxes – Electricity	1,128	0.29	1.20	0	0	8.5	4.69	22.40
Feed-In-Tariffs	1,128	1.74	2.46	0	0	9.5	1.09	-0.14
Renewable energy auctions	1,128	0.35	1.11	0	0	6	3.33	10.44
Renewable energy certificates	1,128	1.08	2.61	0	0	10	2.35	4.17
Coal phase-out policies	1,128	1.28	2.21	0	0	8	1.40	0.54
Planning for renewables expansion	1,128	2.23	3.12	0	0	9	1.10	-0.30
Air emission standards	1,128	4.23	3.32	0	5	10	-0.07	-1.54
Cross-sectoral policies	1,128	2.22	1.91	0	1.83	8.3	0.80	-0.01
International policies	1,128	2.46	1.91	0.19	2.04	8.73	1.35	1.27

Table 2

Baseline TWFE estimates: Energy policy stringency and start-ups

Variables	Green start-ups	(2) Digital start-ups	(3) Early green funding	(4) Later green funding	(5) Early digital funding	(6) Later digital funding
Energy Policy Stringency Index	0.085* (0.041)	0.112* (0.047)	3.084*** (0.592)	2.629*** (0.517)	2.684*** (0.423)	1.879** (0.524)
Observations	1,128	1,128	1,128	1,128	1,128	1,128
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.875	0.846	0.626	0.484	0.616	0.438
Within R^2	0.005	0.009	0.058	0.043	0.045	0.025

Notes: Driscoll–Kraay standard errors in parentheses. Significance codes: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

one-unit increase in EPSI is associated with an approximate 8.5 % increase in green energy start-ups ($\beta = 0.085$, $p < 0.05$) and an even stronger 11.2 % increase in digital energy start-ups ($\beta = 0.112$, $p < 0.05$). These results suggest that more stringent regulatory environments stimulate entrepreneurial entry, with a particularly pronounced effect in digitally oriented segments of the energy sector. However, the relatively low within-R^2 values (0.005 and 0.009) indicate that, while policy stringency has a statistically significant effect, it explains only a small portion of the within-country variation in start-up creation, suggesting that other factors, such as market conditions, innovation ecosystems, and financial development, also play important roles.

The effect of policy stringency is substantially stronger for funding variables. The results show that EPSI has a large and highly significant positive impact on both early- and later-stage funding for green energy start-ups. A one-unit increase in EPSI is associated with an approximate 308 % increase in early-stage green funding ($\beta = 3.084$, $p < 0.001$) and a 263 % increase in later-stage green funding ($\beta = 2.629$, $p < 0.001$). Similar patterns are observed for digital energy start-ups, where EPSI increases early-stage funding by approximately 268 % ($\beta = 2.684$, $p < 0.001$) and later-stage funding by 188 % ($\beta = 1.879$, $p < 0.01$). These results highlight that policy stringency plays a particularly important role in shaping investment flows rather than merely influencing the number of start-ups. In economic terms, stricter policies appear to reduce uncertainty, create market opportunities, and improve expected returns, thereby attracting both venture capital and later-stage investment.

Across funding stages, the effect of EPSI is consistently stronger in early-stage investments than in later-stage funding, especially in the green energy segment. This suggests that policy signals are particularly important at the initial stages of venture development, where uncertainty is highest and regulatory frameworks can significantly influence investor expectations. The slightly weaker, though still significant, effects for later-stage funding indicate that once firms are established, investment decisions may depend more on firm-specific performance and market scalability rather than solely on policy conditions.

The results strongly support the hypothesis that stricter energy policies foster the development of green and digital energy start-ups, primarily through their effect on financial flows. While the impact on start-up counts is positive but modest, the effect on funding is substantial, indicating that policy stringency acts more as a catalyst for scaling and financing rather than purely for firm entry.

The results of the sub-index decomposition models are reported in Table 3. Overall, the findings reveal substantial heterogeneity in the effects of individual policy instruments, indicating that not all components of energy policy stringency contribute equally to the development of green and digital energy start-ups and their financing.

For start-up creation, only a limited subset of policy instruments appears to exert a statistically significant influence. In the case of green start-ups, feed-in tariffs ($\beta = 0.027$, $p < 0.001$) and renewable energy certificates ($\beta = 0.028$, $p < 0.05$) are positively associated with entrepreneurial activity, suggesting that market-based support mechanisms effectively stimulate entry into green energy sectors. Interestingly, fossil fuel subsidies exhibit a positive and highly significant effect ($\beta = 0.034$, $p < 0.001$), which may reflect transitional dynamics in which subsidised fossil energy systems coexist with, or indirectly support, emerging energy ventures. In contrast, cross-sectoral policies are negatively associated with green start-ups ($\beta = -0.055$, $p < 0.05$), indicating that broader regulatory frameworks may impose additional complexity or compliance burdens that deter firm entry. Similar patterns are observed for digital start-ups, where fossil fuel subsidies again show a strong positive effect ($\beta = 0.043$, $p < 0.001$). At the same time, cross-sectoral policies exert a negative and statistically significant influence ($\beta = -0.053$, $p < 0.01$). Other instruments, including ETS and carbon taxes, do not demonstrate statistically significant effects on start-up counts, suggesting that price-based mechanisms may not directly translate into increased firm entry in the short run.

The effects of policy instruments are considerably more pronounced and differentiated when examined in terms of funding outcomes. For early-stage green funding, several instruments emerge as significant drivers, including renewable energy auctions ($\beta = 0.388$, $p < 0.05$), renewable certificates ($\beta = 0.340$, $p < 0.01$), and air emission standards ($\beta = 0.269$, $p < 0.05$). Fossil fuel subsidies also retain a strong positive effect ($\beta = 0.496$, $p < 0.001$), while fossil fuel excise taxes and feed-in tariffs show marginal significance. This indicates that both market-based incentives and regulatory standards play a role in shaping early-stage investment decisions. For later-stage green funding, the effects become even more substantial and widespread. Renewable cer-

Table 3

TWFE estimates with EPSI sub-indices

Variables	Green start-ups	Digital start-ups	(3) Early green funding	(4) Later green funding	(5) Early digital funding	(6) Later digital funding
ETS – Electricity	–0.006	–0.004	0.032	0.070	–0.017	0.176*
Carbon Tax – Electricity	–0.016	–0.008	0.063	–0.289**	0.318	–0.121
Fossil Fuel Subsidies	0.034***	0.043***	0.496***	0.128	0.401***	0.105
Fossil fuel excise taxes	0.048	0.057	0.774	1.158***	0.392	0.619
Feed-In-Tariffs	0.027***	0.013	0.186.	0.160	0.020	0.188*
Renewable auctions	0.002	0.003	0.388*	0.470	0.030	0.395*
Renewable certificates	0.028*	–0.016	0.340**	0.560***	0.345**	0.691***
Coal phase-out	0.008	0.010	0.111	0.217*	–0.101	0.307***
Renewable planning	–0.023	–0.002	0.147	0.439**	0.242**	0.209*
Air emission standards	0.004	0.019	0.269*	0.018	0.295*	0.008
Cross-sectoral policies	–0.055*	–0.053**	–0.266	0.053	–0.836*	–0.229
International policies	0.007	0.001	0.452	0.769**	0.737*	0.307
Observations	1,128	1,128	1,128	1,128	1,128	1,128
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.879	0.850	0.634	0.517	0.623	0.471

Notes: Driscoll–Kraay standard errors. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

tificates ($\beta = 0.560$, $p < 0.001$), fossil fuel excise taxes ($\beta = 1.158$, $p < 0.001$), and planning for renewables expansion ($\beta = 0.439$, $p < 0.01$) emerge as key positive determinants. Additionally, coal phase-out policies and international policy frameworks are positively associated with later-stage funding, suggesting that long-term regulatory commitments and policy credibility are particularly important for scaling investments.

In the digital energy segment, the results further emphasise the importance of targeted policy instruments. Early-stage digital funding is positively influenced by renewable certificates ($\beta = 0.345$, $p < 0.01$), planning for renewables expansion ($\beta = 0.242$, $p < 0.01$), and air emission standards ($\beta = 0.295$, $p < 0.05$). At the same time, fossil fuel subsidies remain significant ($\beta = 0.401$, $p < 0.001$). Cross-sectoral policies, however, exhibit a strong negative effect ($\beta = –0.836$, $p < 0.05$), reinforcing the notion that complex regulatory environments may hinder early-stage investment in digital energy ventures. For later-stage digital funding, the range of significant policy drivers is broader, including ETS ($\beta = 0.176$, $p < 0.05$), feed-in tariffs ($\beta = 0.188$, $p < 0.05$), renewable auctions ($\beta = 0.395$, $p < 0.05$), renewable certificates ($\beta = 0.691$, $p < 0.001$), and coal phase-out policies ($\beta = 0.307$, $p < 0.001$). These results indicate that both market-based mechanisms and structural transition policies are crucial for attracting large-scale investment in digital energy technologies.

The decomposition analysis demonstrates that the aggregate effect of policy stringency masks substantial variation across individual instruments. Market-based support schemes and long-term transition policies appear to be the most effective in stimulating both entrepreneurial activity and investment. In contrast, broad cross-sectoral regulations may have unintended negative effects. Moreover, policy impacts are consistently stronger for funding than for start-up counts, reinforcing the conclusion that regulatory environments primarily influence the scale and financing of ventures rather than their initial entry.

The results of the lagged specifications are reported in Tables 3 and 4, providing additional insight into the temporal dynamics of the relationship between energy policy stringency and start-up development. Overall, the findings indicate that the effects of regulatory stringency are not immediate for firm entry but become more pronounced for financing, particularly with a time lag.

The one-year lag results (Table 4) suggest that the impact of policy stringency on start-up creation is relatively weak and statistically limited. For green start-ups, the coefficient is positive but not statistically significant ($\beta = 0.058$, $p > 0.1$), suggesting that stricter policies do not immediately lead to increased firm entry. For digital start-ups, the effect is slightly stronger and marginally significant at the 10 % level ($\beta = 0.093$, $p < 0.1$), suggesting that digital ventures may respond more quickly to regulatory signals than purely green start-ups. However, the within-R^2 values remain very low, confirming that policy stringency explains only a small fraction of the short-term variation in start-up creation.

In contrast, the effects on funding are strong, positive, and statistically significant across all specifications. A one-year lag of EPSI is associated with substantial increases in both early- and later-stage funding for green and digital start-ups. In particular, early-stage green funding increases by approximately 263 % ($\beta = 2.632$, $p < 0.01$), while later-stage green funding rises by 268 % ($\beta = 2.682$, $p < 0.001$). Similarly, early-stage digital funding increases by 239 % ($\beta = 2.394$, $p < 0.001$), and later-stage digital funding by 171 % ($\beta = 1.711$, $p < 0.05$). These results indicate that policy stringency exerts a strong and relatively rapid influence on investment decisions, supporting the view that regulatory environments shape expectations and reduce uncertainty for investors.

The two-year lag results (Table 5) further reinforce these conclusions while highlighting a clearer temporal structure. The effects on start-up counts become even weaker and statistically insignificant, suggesting that policy stringency does not substantially drive firm entry even over a longer horizon. In contrast, the positive ef-

Table 4

Lagged TWFE estimates (1-year lag of EPSI)

Variables	(1) Green start-ups	(2) Digital start-ups	(3) Early green funding	(4) Later green funding	(5) Early digital funding	(6) Later digital funding
EPSI (t−1)	0.058 (0.036)	0.093 (0.046)	2.632** (0.707)	2.682*** (0.506)	2.394*** (0.438)	1.711* (0.632)
Observations	1,081	1,081	1,081	1,081	1,081	1,081
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.878	0.845	0.622	0.493	0.612	0.444
Within R^2	0.002	0.006	0.042	0.044	0.035	0.020

Notes: Driscoll–Kraay standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5

Lagged TWFE estimates (2-year lag of EPSI)

Variables	(1) Green start-ups	(2) Digital start-ups	(3) Early green funding	(4) Later green funding	(5) Early digital funding	(6) Later digital funding
EPSI (t−2)	0.027 (0.036)	0.058 (0.050)	2.255** (0.733)	2.641*** (0.535)	2.471*** (0.408)	1.751** (0.594)
Observations	1,034	1,034	1,034	1,034	1,034	1,034
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.879	0.849	0.620	0.502	0.612	0.455
Within R^2	0.001	0.003	0.031	0.043	0.037	0.021

Notes: Driscoll–Kraay standard errors in parentheses. Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

fects on funding remain robust and statistically significant across all specifications. Early-stage green funding increases by approximately 225 % ($\beta = 2.255$, $p < 0.01$), and later-stage green funding by 264 % ($\beta = 2.641$, $p < 0.001$). Similarly, early-stage digital funding increases by 247 % ($\beta = 2.471$, $p < 0.001$), while later-stage digital funding rises by 175 % ($\beta = 1.751$, $p < 0.01$). The persistence of these effects over time suggests that policy stringency has a durable impact on capital allocation within the energy innovation ecosystem.

The lagged models provide strong evidence that the primary channel through which energy policy stringency influences the development of green and digital energy sectors is financial rather than entrepreneurial entry. While the number of start-ups responds only weakly to policy changes, investment flows react strongly and persistently, both in the short and medium term. This supports the interpretation that stricter policies primarily act by improving market expectations, enhancing investment attractiveness, and facilitating the scaling of existing ventures rather than by immediately increasing the number of new firms.

The results for the dynamic sub-index specifications, which include the one- and two-period lags of the EPSI components simultaneously, are reported in Table 6. These models provide a more detailed picture of how specific policy instruments affect start-up activity and funding over time. Overall, the findings suggest that the effects of policy sub-indices are highly heterogeneous across instruments, outcomes, and time horizons. In particular, the influence of regulatory stringency is much more visible for funding variables than for start-up counts, consistent with the baseline and aggregate lag models.

For the creation of green start-ups, only a limited number of lagged policy instruments are statistically significant. The one-period lag of fossil fuel subsidies is positively associated with green start-ups ($\beta = 0.031$, $p < 0.01$). At the same time, the one-period lag of renewable energy auctions is also positively and significantly associated ($\beta = 0.030$, $p < 0.01$). This suggests that some policy measures may stimulate entrepreneurial entry with a short delay rather than immediately. At the same time, the lag structure of coal phase-out policies is more complex: the one-period lag is positive ($\beta = 0.034$, $p < 0.01$), whereas the two-period lag is negative ($\beta = -0.047$, $p < 0.01$), indicating that such transition measures may initially encourage market entry but may later be associated with consolidation or rising barriers to entry. For digital start-ups, the pattern is similarly selective. The one-period lag of fossil fuel subsidies has a positive effect ($\beta = 0.039$, $p < 0.05$). In contrast, the one-period lag of coal phase-out policies ($\beta = 0.024$, $p < 0.05$) and renewables planning ($\beta = 0.024$, $p < 0.05$) also support digital entrepreneurial activity. However, the two-period lag of renewables planning becomes negative ($\beta = -0.032$, $p < 0.05$), implying that policy-induced opportunities for digital ventures may be strongest in the earlier phase following implementation. The two-period lag of air emission standards is positive and significant ($\beta = 0.045$, $p < 0.05$), suggesting a somewhat slower transmission channel from stricter standards to digital energy entrepreneurship. Despite these significant coefficients, the within-R^2 values remain modest, indicating that broader factors beyond regulation alone influence start-up creation.

The funding models show much stronger and more persistent dynamic effects. For early green funding, only the two-period lag in air emission standards is positive and statistically significant ($\beta = 0.321$, $p < 0.05$), suggesting that investors may respond to stricter environmental regulation with a longer adjustment period. This implies

that the financing response in early-stage green ventures is less immediate when sub-indices are considered jointly. By contrast, later green funding appears more sensitive to specific policy instruments. The one-period lag of carbon taxes is negative and significant ($\beta = -0.292$, $p < 0.05$), suggesting that carbon taxation imposes short-run adjustment costs on later-stage green firms or temporarily weakens investor confidence. At the same time, the one-period lag of feed-in tariffs ($\beta = 0.310$, $p < 0.01$) and renewable energy auctions ($\beta = 0.618$, $p < 0.05$) is strongly positive, showing that direct support schemes and market-creation mechanisms stimulate later-stage scaling. The one-period lag of international policies is positive at the 10 % level ($\beta = 0.598$, $p < 0.1$), suggesting that international commitments may also strengthen investor expectations, although less robustly than domestic support mechanisms.

For the digital funding variables, the lag structure is particularly informative. In the case of early digital funding, the two-period lag of fossil fuel subsidies is positive ($\beta = 0.429$, $p < 0.05$), while the lag pattern for fossil fuel excise taxes is sharply non-linear: the one-period lag is negative ($\beta = -2.173$, $p < 0.05$), but the two-period lag is positive ($\beta = 2.306$, $p < 0.01$). This may indicate that excise-tax tightening initially discourages early digital investment, but becomes supportive once markets adjust. The one-period lag of international policies is also positive ($\beta = 0.793$, $p < 0.05$), pointing to the importance of global policy coordination and signalling effects in digital-energy financing. At the same time, the one-period lag of cross-sectoral policies is negative at the 10 % level ($\beta = -1.094$, $p < 0.1$), again suggesting that broad and complex policy frameworks may create short-run uncertainty for early-stage investors. For later digital funding, the two-period lag of fossil fuel subsidies is positive and significant ($\beta = 0.311$, $p < 0.01$). In contrast, the one-period lag of renewable certificates ($\beta = 0.657$, $p < 0.01$) and international policies ($\beta = 0.759$, $p < 0.01$) also exerts a positive effect. The one-period lag of coal phase-out policies is positive at the 10 % level ($\beta = 0.207$, $p < 0.1$). These results indicate that later-stage digital investment responds especially strongly to targeted market instruments and strategic transition commitments.

The dynamic decomposition models show that the impact of energy policy stringency is neither uniform nor immediate. Instead, different policy instruments affect different segments of the start-up ecosystem through distinct temporal channels. Support-oriented instruments such as feed-in tariffs, auctions, and certificates appear to be particularly important for later-stage funding. At the same time, transition-oriented and planning-related policies matter more selectively for start-up entry. The results also confirm that the most robust policy effects remain concentrated in financing outcomes rather than the number of start-ups, which supports the broader conclusion that energy policy stringency primarily shapes the scale, maturity, and investment attractiveness of energy ventures rather than simply their entry. The empirical findings provide strong support for the argument that environmental policy stringency acts primarily as a catalyst for investment rather than for firm creation, which is broadly consistent with the theoretical and empirical literature on innovation and sustainability transitions. While the positive but relatively modest effect of the aggregate EPSI on start-up counts (approximately 8.5 % for green and 11.2 % for digital start-ups) confirms that stricter policies can stimulate entrepreneurial entry, the low within-country explanatory power suggests that policy alone is not the dominant driver of start-up formation. This aligns with prior research emphasising the importance of entrepreneurial ecosystems, institutional quality, and human capital in shaping firm entry dynamics [17, 18]. At the same time, the results reinforce the Porter-type argument that regulatory pressure can stimulate innovation, but only as part of a broader system of complementary factors [8]. Thus, the findings suggest that energy policy stringency plays a supportive rather than a decisive role in the emergence of new firms, operating through indirect channels linked to market conditions and ecosystem development.

In contrast, the very strong and statistically significant effects of EPSI on funding outcomes provide clear evidence that policy stringency is a key determinant of financial flows within energy innovation ecosystems. The magnitude of the estimated effects, exceeding 300 % for early-stage green funding and remaining above 180 % for later-stage digital funding, indicates that regulatory environments substantially shape investor expectations and capital allocation decisions. This finding is highly consistent with recent studies showing that environmental policy pressure stimulates green finance and venture capital investment by reducing uncertainty and signalling long-term market opportunities [23, 11]. Moreover, the stronger effects observed for early-stage funding support the argument that policy signals are particularly important under high uncertainty, where institutional credibility and regulatory commitment influence risk perceptions. These results therefore extend the literature by demonstrating that policy stringency affects not only innovation outcomes but also the financial architecture underpinning sustainable entrepreneurship, thereby confirming its role as a transmission mechanism between regulation and market-based investment dynamics.

The decomposition and dynamic analyses further reveal that the impact of policy stringency is highly heterogeneous across instruments and time horizons, which strongly corroborates recent research emphasising the importance of policy design and composition. Market-based instruments such as feed-in tariffs, renewable auctions, and certificates consistently exhibit the strongest positive effects, particularly on later-stage funding, confirming that policies directly creating market demand and revenue certainty are most effective in scaling innovation. This aligns with evidence that targeted policy instruments and incentive-based mechanisms are more efficient at promoting eco-innovation and sustainable investment than broad regulatory frameworks [14, 15]. At the same time, the mixed or even negative short-term effects of carbon taxes and cross-sectoral policies highlight transitional costs and regulatory complexity, supporting the argument that poorly designed or overly broad regulations may hinder entrepreneurial activity [49]. The lagged results additionally demonstrate that policy effects materialise primarily through delayed financial responses rather than immediate firm entry, which aligns with the literature on investment dynamics and policy uncertainty. The findings contribute to the existing body of knowledge by showing that energy poli-

Table 6

Dynamic TWFE estimates with one-period and two-period lags of EPSI sub-indices

Variables	(1) Green start-ups	(2) Digital start-ups	(3) Early green funding	(4) Later green funding	(5) Early digital funding	(6) Later digital funding
ETS (t−1)	–0.005 (0.010)	–0.005 (0.009)	–0.070 (0.211)	0.075 (0.106)	–0.060 (0.115)	0.035 (0.111)
ETS (t−2)	–0.009 (0.012)	–0.006 (0.008)	0.104 (0.131)	0.025 (0.099)	0.029 (0.095)	0.015 (0.103)
Carbon tax (t−1)	–0.040 (0.025)	–0.028 (0.028)	–0.083 (0.188)	–0.292* (0.129)	–0.082 (0.336)	–0.112 (0.065)
Carbon tax (t−2)	0.026 (0.022)	0.027 (0.027)	0.070 (0.263)	–0.044 (0.249)	0.483 (0.346)	–0.031 (0.143)
Fossil fuel subsidies (t−1)	0.031** (0.010)	0.039* (0.016)	0.275 (0.172)	–0.033 (0.101)	0.062 (0.101)	–0.195 (0.098)
Fossil fuel subsidies (t−2)	–0.002 (0.010)	–0.003 (0.015)	0.325 (0.213)	0.170. (0.091)	0.429* (0.169)	0.311** (0.104)
Fossil excise taxes (t−1)	0.046 (0.030)	0.008 (0.052)	0.990 (0.649)	0.167 (0.485)	–2.173* (0.801)	0.530 (0.498)
Fossil excise taxes (t−2)	–0.042 (0.038)	0.023 (0.070)	–0.509 (0.580)	0.925 (0.591)	2.306** (0.777)	0.137 (0.463)
Feed-in tariffs (t−1)	0.015 (0.010)	0.002 (0.011)	0.038 (0.138)	0.310** (0.088)	–0.128 (0.135)	0.152 (0.094)
Feed-in tariffs (t−2)	0.002 (0.011)	0.005 (0.012)	0.108 (0.124)	–0.099 (0.151)	0.161 (0.134)	–0.022 (0.101)
Renewable auctions (t−1)	0.030** (0.008)	0.018 (0.012)	0.024 (0.213)	0.618* (0.247)	–0.077 (0.164)	0.101 (0.172)
Renewable auctions (t−2)	–0.030 (0.019)	–0.013 (0.024)	0.196 (0.163)	0.146 (0.157)	–0.111 (0.133)	0.103 (0.383)
Renewable certificates (t−1)	0.026 (0.030)	–0.052 (0.029)	0.273 (0.346)	0.306 (0.299)	0.070 (0.189)	0.657** (0.229)
Renewable certificates (t−2)	–0.009 (0.036)	0.026 (0.026)	–0.049 (0.368)	0.282 (0.249)	0.222 (0.127)	0.103 (0.226)
Coal phase-out (t−1)	0.034** (0.012)	0.024* (0.010)	0.005 (0.257)	0.274 (0.262)	–0.109 (0.184)	0.207 (0.103)
Coal phase-out (t−2)	–0.047** (0.013)	–0.032. (0.018)	–0.032 (0.255)	–0.084 (0.367)	–0.169 (0.168)	0.034 (0.199)
Renewables planning (t−1)	–0.005 (0.012)	0.024* (0.009)	0.141 (0.186)	0.312 (0.276)	–0.194 (0.175)	–0.194 (0.214)
Renewables planning (t−2)	–0.016. (0.009)	–0.032* (0.014)	–0.147 (0.235)	–0.004 (0.285)	0.408 (0.232)	0.279 (0.178)
Air standards (t−1)	0.008 (0.010)	–0.022 (0.022)	–0.021 (0.164)	–0.068 (0.193)	0.089 (0.150)	–0.121 (0.148)
Air standards (t−2)	0.012 (0.010)	0.045* (0.016)	0.321* (0.124)	0.020 (0.160)	0.313 (0.200)	0.110 (0.137)
Cross-sectoral policies (t−1)	–0.021 (0.057)	0.011 (0.028)	0.258 (0.364)	0.464 (0.359)	–1.094 (0.577)	0.215 (0.359)
Cross-sectoral policies (t−2)	–0.041 (0.061)	–0.057 (0.039)	–0.513 (0.408)	–0.579 (0.484)	0.002 (0.480)	–0.534 (0.451)
International policies (t−1)	0.016 (0.034)	0.021 (0.025)	0.749 (0.484)	0.598. (0.321)	0.793* (0.358)	0.759** (0.251)
International policies (t−2)	–0.002 (0.041)	–0.004 (0.033)	–0.491 (0.427)	0.576 (0.453)	–0.132 (0.832)	0.119 (0.537)
Observations	1,034	1,034	1,034	1,034	1,034	1,034
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.882	0.852	0.627	0.528	0.627	0.478
Within R^2	0.045	0.047	0.071	0.114	0.098	0.084

Notes: Driscoll–Kraay standard errors in parentheses. Significance codes:. $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

cy stringency operates through differentiated and time-dependent channels, reinforcing the need for balanced, well-targeted policy mixes to support green and digital energy start-up ecosystems effectively.

Despite providing novel cross-country evidence on the relationship between energy policy stringency and the development and financing of green and digital energy start-ups, this study has several limitations. First, the analysis relies on aggregated country-level data, which may obscure important heterogeneity across regions, sectors, and firm-level characteristics, particularly in rapidly evolving energy innovation ecosystems. Second, although the dataset is relatively broad, it is constrained by data availability from the IEA and the OECD, limiting the sample to countries with consistent reporting and potentially affecting the generalisability of the findings, especially for developing economies. Third, while using two-way fixed-effects models with Driscoll–Kraay standard errors improves robustness, the results capture associations rather than fully causal relationships, as unobserved institutional, financial, or technological factors may still influence both policy design and entrepreneurial outcomes. Fourth, the inclusion of multiple sub-indices and lag structures raises concerns about multicollinearity and parameter instability. Future research could address these limitations by incorporating firm-level or regional data, expanding the country coverage to include emerging economies, and applying causal identification strategies such as difference-in-differences designs or instrumental variable approaches. Additionally, further studies could explore non-linear effects, interaction terms with institutional quality or financial development, and sector-specific dynamics within the broader energy transition, thereby providing a more nuanced understanding of how policy frameworks shape sustainable innovation ecosystems.

Conclusion. This study set out to determine the impact of energy policy stringency and its individual instruments on the development and financing of green and digital energy start-ups, as well as to identify practical policy mechanisms capable of strengthening their investment attractiveness and scaling potential. By reframing the research objective in terms of the sustainability transition, the analysis aimed to uncover not only whether stricter regulation matters, but also how and when different policy tools translate into entrepreneurial activity and investment outcomes. The empirical analysis is based on a cross-country panel of 47 countries covering the period 2000–2023. Data on start-up activity and funding were obtained from the IEA, while information on the Energy Policy Stringency Index and its sub-components was sourced from OECD. The study employs two-way fixed-effects models controlling for country and year heterogeneity, with Driscoll–Kraay standard errors to account for cross-sectional dependence and serial correlation. In addition to baseline specifications using the aggregate index, the analysis incorporates disaggregated sub-indices and dynamic models with one- and two-period lags to capture delayed policy effects. The results demonstrate that energy policy stringency exerts a positive, statistically significant effect on entrepreneurial activity, although the magnitude is modest: a one-unit increase in the index is associated with a 0.085 increase in green start-ups and a 0.112 increase in digital start-ups, in logarithmic terms. The impact is substantially stronger on financing outcomes, where the same increase in policy stringency leads to a 3.084 rise in early-stage green funding, a 2.629 rise in later-stage green funding, a 2.684 rise in early-stage digital funding, and a 1.879 rise in later-stage digital funding, all statistically significant at conventional levels. Dynamic models indicate that these effects are persistent over time, particularly for funding variables, with one- and two-period lags remaining significant for most financing indicators, while effects on start-up counts are weaker and often insignificant. The decomposition by policy instruments reveals that market-based and support mechanisms, such as feed-in tariffs, renewable auctions, and certificates, consistently exhibit positive and significant effects, especially on later-stage financing. In contrast, regulatory instruments, such as carbon taxes, display mixed or even negative short-term impacts. Furthermore, the heterogeneity across policy tools highlights that not all dimensions of policy stringency are equally effective, with some instruments stimulating early entry and others primarily supporting scaling and investment. These findings have several important policy implications. First, policymakers should recognise that increasing overall policy stringency is not sufficient in itself; the composition of policy instruments is crucial for fostering a vibrant energy start-up ecosystem. In particular, support-based mechanisms that directly create market opportunities, such as feed-in tariffs and competitive auctions, should be prioritised to facilitate the scaling of start-ups and attract investment. Second, the presence of dynamic effects implies that policy interventions require time to materialise in entrepreneurial and financial outcomes; therefore, stable and predictable policy frameworks are essential to sustain investor confidence and avoid short-term volatility. Third, the mixed evidence on instruments such as carbon taxation suggests that complementary measures may be necessary to mitigate transitional costs and ensure that regulatory pressure does not hinder early-stage innovation. Fourth, the strong responsiveness of funding relative to start-up creation indicates that policy stringency primarily influences the depth and maturity of the innovation ecosystem rather than merely increasing the number of entrants; thus, policies should be designed to support both entry and scale-up phases. Finally, international coordination and cross-sectoral alignment of policies can further enhance the effectiveness of national measures by reducing uncertainty and reinforcing long-term expectations, thereby accelerating the sustainability transition through innovation and entrepreneurship.

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Жорсткість енергетичної політики й «зелені» стартапи у цифровій енергетиці

М. Ситницький[*1,2], *Д. Курінський*[3,4], *Я. Ужик*[5], *С. Подосинніков*[6]

1 – Університет Західної Вірджинії, м. Моргантаун, Сполучені Штати Америки
2 – Університет ВІЗІЯ, м. Варшава, Республіка Польща
3 – Сумський національний аграрний університет, м. Суми, Україна
4 – Селкат Холдинг, м. Сінгапур, Республіка Сінгапур
5 – Братиславський університет економіки та бізнесу, м. Братислава, Словацька Республіка
6 – Сумський державний університет, м. Суми, Україна
* Автор-кореспондент e-mail: maksym.sitnicki@mail.wvu.edu

Мета. Дослідження має на меті визначити вплив жорсткості енергетичної політики та її окремих інструментів на розвиток і фінансування «зелених» і цифрових енергетичних стартапів.

Методика. Дослідження базується на аналізі панельних даних 47 країн за 2000–2023 роки, що охоплює 1 128 спостережень «країна-рік». Емпірична база поєднує дані Міжнародного енергетичного агентства й Індексу жорсткості енергетичної політики ОЕСР. Для оцінювання використані двосторонні моделі з фіксованими ефектами та стандартними похибками Дрісколла–Крея. Аналіз охоплює агреговані й дезагреговані показники EPSI, а також динамічні специфікації з одно- та дворічними лагами. Логарифмічні перетворення застосовані для зменшення асиметрії й нульової інфляції змінних стартапів і фінансування.

Результати. Встановлено, що жорсткіше середовище енергетичної політики позитивно впливає на підприємницьку активність й інвестиції в секторах «зеленої» і цифрової енергетики. Зростання EPSI на одну одиницю пов'язане зі збільшенням кількості «зелених» стартапів на 8,5 %, а цифрових стартапів – на 11,2 %. Вплив на фінансування є сильнішим: раннє «зелене» фінансування зростає на 308 %, пізнє «зелене» фінансування — на 263 %, тоді як раннє й пізнє цифрове фінансування збільшуються відповідно на 268 і 188 %. Декомпозиційний аналіз виявив значну неоднорідність ефектів між інструментами політики. Найсильніший позитивний вплив, особливо на пізнє фінансування, мають «зелені» тарифи, аукціони відновлюваної енергетики та сертифікати відновлюваної енергетики. Динамічні оцінки підтвердили стійкість цих ефектів у часі.

Наукова новизна. Дослідження надає міжкраїнні емпіричні докази впливу агрегованих та окремих інструментів енергетичної політики на «зелені» й цифрові енергетичні стартапи. Показано, що жорсткість політики переважно впливає на інвестування й масштабування, а не лише на появу нових стартапів.

Практична значимість. Отримані результати можуть бути використані урядами, регуляторами й інноваційними агенціями для формування збалансованої політики енергетичного переходу, що підтримує інвестиції, масштабування та стале підприємництво.

Ключові слова: *жорсткість політики, енергетичні стартапи, енергетичний перехід, фінансування стартапів, панельний аналіз*