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Article

Timing of Corporate Green Investment Under Policy Uncertainty: A Real Options Approach

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Abstract: Changes in carbon pricing, environmental standards, green subsidies and technology policy complicate the timing of corporate green investment. This paper uses real options theory to explain how firms balance the value of retaining investment flexibility against the costs of delay. It provides a conceptual synthesis of published research, illustrated by renewable-energy remuneration reform in Spain and industrial electricity-levy relief in Germany. The analysis distinguishes changes in expected profitability from uncertainty about future returns. Uncertain support for installed assets may discourage investment, whereas a deadline for securing new-project subsidies can encourage earlier commitment. A credible increase in expected compliance costs may also favour earlier abatement when investment reduces those costs; greater volatility around the expected cost path can instead strengthen the incentive to wait. These effects depend on policy design, irreversibility, technological change and implementation lead times. The policy illustrations clarify these mechanisms without establishing their separate causal effects. Predictable review schedules, transparent eligibility rules and credible transition arrangements can reduce avoidable uncertainty while preserving scope for policy adaptation. Effective policy should therefore address both the level of investment incentives and the conditions governing their duration.

Keywords: policy uncertainty; green investment; real options; investment timing; policy credibility

1. Introduction

The transition to a low-carbon economy requires firms to replace emissions-intensive equipment, improve energy efficiency and deploy renewable technologies. Corporate investment decisions therefore influence both the scale and the pace of decarbonisation. Many green projects require substantial initial expenditure, involve assets with limited alternative uses and generate returns over long operating lives. Once capital has been committed, reversing the decision can be costly. These characteristics make the timing of investment sensitive to expectations about future policy and market conditions [1]. A project that appears financially attractive today may still be postponed if waiting allows the firm to obtain valuable information before making an irreversible commitment.

Policy uncertainty arises when firms cannot reliably anticipate the content, timing or durability of future rules. Carbon taxes, emissions trading, environmental standards and renewable-energy support affect different components of project cash flows. Policy sequencing is therefore consequential: governments must strengthen climate incentives while maintaining credible expectations about how instruments will evolve [2]. Uncertainty may concern future carbon-market coverage, allowance allocation, subsidy eligibility or the technology required to meet an environmental standard. It should be distinguished from an announced and credible increase in policy stringency. Firms facing

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these conditions must weigh the information gained by waiting against forgone operating benefits, continued compliance expenditure and the possibility of losing support eligibility. Neither immediate investment nor postponement is invariably optimal.

This paper examines three questions. How does policy uncertainty affect the threshold at which firms undertake irreversible green investment? How do policy credibility, subsidy design, carbon-pricing expectations and technological change alter the relative attractiveness of investing and waiting? Under what conditions can a policy change encourage earlier investment rather than delay it? The analysis concentrates on investment timing while recognising that timing, project scale and the decision to abandon an opportunity are related but distinct outcomes. In particular, a reduction in investment expenditure need not demonstrate that firms are merely waiting; it may also reflect smaller projects or opportunities that are no longer profitable.

The contribution is an integrated interpretation of established real options theory rather than a new formal model. The paper distinguishes expected project profitability, the value of flexibility and the costs incurred during delay, then applies these distinctions to selected policy episodes and published studies. Its approach is a conceptual literature synthesis with illustrative cases, not a systematic review or an independent causal evaluation. The cases contrast policy mechanisms rather than represent a statistically selected sample. This scope permits a structured discussion of investment incentives while avoiding conclusions about the magnitude of effects that the available evidence cannot establish.

Section 2 reviews research on uncertainty, green investment and real options. Section 3 explains the theoretical foundations of investment timing. Section 4 develops the mechanisms and examines the Spanish and German policy illustrations. Section 5 evaluates the relevance and limits of existing evidence and discusses implications for policy design. Section 6 concludes.

2. Literature Review

The relationship between uncertainty and irreversible investment has a long theoretical history. Bernanke explains why firms may postpone irreversible commitments when waiting provides information about future returns [3]. Dixit and Pindyck develop this reasoning into a general framework in which an investment opportunity is an option that can be exercised at a chosen time [1]. Investment may consequently require a return above the conventional break-even level. Firm-level evidence is consistent with this mechanism. Gulen and Ion report a negative relationship between policy uncertainty and capital investment among US listed firms, with stronger effects where investment is more irreversible [4]. This evidence concerns corporate investment broadly, however, and should not automatically be interpreted as a direct estimate of green-investment timing.

Green investment is particularly exposed to policy because regulations and public support influence the revenues, operating costs and competitive position of low-carbon technologies. Meckling and Nahm examine how industrial interests and political competition shape proposed technology bans in the automotive industry, showing that technology policy is embedded in political processes [5]. Fischer and Newell compare environmental and technology instruments for climate mitigation, highlighting the interactions between emissions incentives and support for innovation [6]. These contributions help explain why the composition of a policy package matters. Their implications for timing require an additional distinction between the expected strength of an incentive and the credibility of its continuation. A generous incentive with uncertain duration need not provide the same investment signal as a smaller but dependable commitment.

Real options research already addresses renewable-energy investment timing directly. Popp reviews the roles of environmental policy and innovation incentives in developing and diffusing cleaner technologies [7]. Boomsma, Meade and Fleten analyse investment timing and capacity under alternative renewable-electricity support schemes [8]. Ritzenhofen and Spinler examine regulatory switches between feed-in tariffs and

more market-oriented remuneration, obtaining results that depend on tariff levels and the likelihood of a regime change [9]. Subsidy withdrawal does not have a uniform effect: Boomsma and Linnerud distinguish the effects of withdrawing support for installed projects from terminating eligibility for future projects [10]. Nagy, Hagspiel and Kort likewise show that a higher withdrawal risk for a one-off investment subsidy can accelerate investment while reducing capacity [11]. These studies make policy design, rather than uncertainty alone, central to the timing decision.

Research on Chinese firms offers complementary evidence on environmental regulation and green innovation. Qi, Lin and Cui examine environmental-rights trading and green patenting among listed firms [12]. Li and Xiao distinguish pollution-discharge fees from environmental subsidies and report different innovation incentives, illustrating why instruments cannot be treated as interchangeable [13]. Deng and Hao investigate energy-price uncertainty and environmental policy within a dynamic investment model [14]. Energy-price uncertainty is distinct from uncertainty about environmental regulation. These studies address different outcomes and mechanisms: green patents capture inventive activity, whereas investment models concern capital commitments under specified assumptions. Neither type of evidence alone establishes the timing of equipment installation following an uncertain policy announcement.

The relevant question is therefore how to connect these strands without overstating their common findings. Research on general corporate investment explains why uncertainty can discourage commitment; environmental-policy studies show that incentives differ across instruments; and real options models clarify the conditions governing delay. The present analysis organises these insights around expected returns, flexibility and delay costs. It does not claim that previous research has neglected timing or that the same response applies across technologies and jurisdictions. Instead, it identifies distinctions that are easily obscured when all policy changes are represented by a single uncertainty measure.

3. Theoretical Foundation

3.1. NPV and Real Options

The conventional net present value (NPV) rule compares the discounted value of expected project cash flows with the initial investment cost. A positive NPV indicates that the project creates value relative to the stated baseline, but does not necessarily establish that investing immediately is optimal. Expenditure already incurred is a sunk cost and should be excluded from the current incremental decision; an irreversible outlay that has not yet been made remains relevant. A fixed invest-now NPV calculation does not separately value management's ability to postpone that outlay and learn about future conditions. Real options theory incorporates this flexibility by treating investment as a right rather than an obligation [1]. Exercising that right commits capital and surrenders the opportunity to wait. The appropriate comparison is therefore between the value of immediate investment and the value of keeping the opportunity available.

3.2. Option to Wait and Investment Threshold

McDonald and Siegel show that uncertainty and irreversibility can make the optimal investment trigger higher than the point at which conventional NPV becomes positive [15]. Pindyck reviews the implications of this insight for investment valuation and policy [16]. In benchmark models, a firm invests when the benefit of immediate commitment compensates for the option it gives up. Greater uncertainty can raise the required trigger when the expected payoff path is held constant and the opportunity remains available. Lower recoverability of capital can further increase the importance of preserving flexibility. These predictions depend on the model's assumptions, including the persistence of uncertainty, competitive conditions and the benefits forgone during delay. The investment threshold is consequently a conditional decision rule, not a universal fixed premium above project cost. A positive NPV can coexist with rational postponement, while an approaching deadline can make postponement costly even under uncertainty.

3.3. Uncertainty and Investment Timing

The option value of waiting must be distinguished from the cost of delay. The former is the benefit of retaining flexibility; the latter includes forgone operating returns, continued emissions-related expenditure and lost eligibility for support. Greater volatility in project value can strengthen the first channel, whereas a credible increase in expected compliance costs can strengthen the second when earlier abatement avoids those costs. Löfgren, Millock and Nauges provide empirical evidence on uncertainty and hurdle rates for pollution-abatement investment in Swedish industry [17]. Their study connects uncertainty to firms' investment requirements without implying that every form of uncertainty has an identical effect. Energy-market shocks add another layer: Gillingham and colleagues discuss how the COVID-19 pandemic affected energy use and environmental outcomes [18]. Their analysis provides context for changing demand and investment conditions, rather than a direct test of a real options mechanism. Separating market shocks, policy uncertainty and expected policy stringency is necessary for interpreting observed investment behaviour.

4. Mechanism and Case Study

4.1. Influence Mechanism

Policy conditions influence green-investment timing through expected profitability, the value of flexibility and the costs of delay. A reduction in expected support can lower project value even if the new rule is perfectly certain. Uncertainty about future operating rules may separately make waiting attractive when useful information is expected to arrive before capital is committed. These channels can operate simultaneously, but they should not be conflated. Firms compare the net benefits of investing now with the continuation value of the opportunity [1,15]. If expected returns become insufficient, the relevant outcome may be cancellation rather than postponement. Any interpretation of lower investment must therefore consider whether the opportunity remains viable.

Subsidy design determines the direction of the timing incentive. If support can be reduced after a plant is installed, anticipated revenues may decline and irreversible commitment can become less attractive. If investing before a deadline instead secures support that later entrants cannot obtain, waiting risks losing a valuable entitlement. A prospective withdrawal can consequently accelerate investment, especially when installed projects retain their agreed treatment [10]. A one-off investment subsidy can also affect timing and capacity differently: threatened withdrawal may encourage earlier entry with a smaller project [11]. Regulatory uncertainty is therefore not synonymous with a stronger incentive to wait. The exposure of existing assets, the eligibility rule and the enforceability of commitments determine which mechanism is relevant.

Policy credibility affects these mechanisms by shaping expectations about future rules. Transparent eligibility conditions, scheduled reviews and dependable transition arrangements can reduce uncertainty about operating returns. This may reduce the option premium required for investment; it does not mean that credibility lowers the cost of waiting and thereby accelerates investment. Carbon pricing requires a similar distinction. A higher expected carbon-price path can increase the value of avoided emissions, whereas greater volatility around that path can preserve the value of flexibility. Experience with carbon markets highlights the importance of institutional design and credible incentives [19]. Earlier investment becomes more attractive only if the project reduces sufficient compliance exposure and can be implemented in time. Predictability cannot compensate for a project that remains financially unviable.

Technological change further modifies the investment threshold. Expected improvements in equipment cost or performance may favour waiting, while long construction periods, operating savings and compliance deadlines may favour earlier commitment. The effects of support design and technology therefore need to be considered jointly [8,7]. Figure 1 separates the principal policy channels, and Table 1 summarises their conditional implications. These relationships are conceptual: no

numerical investment threshold or effect size is estimated. Their purpose is to explain why similar policy announcements can produce different responses across projects with different sunk-capital exposure, operating profiles and implementation requirements.

Table 1. Policy Conditions and Conditional Investment-Timing Responses.

Policy condition	Economic channel	Timing implication and condition
Uncertain post-investment support	Lower expected revenues and potentially more valuable flexibility	Delay or cancellation; distinguish uncertainty from reduced profitability.
Expiry of new-project eligibility	Support is lost if commitment occurs too late	Earlier investment if entry secures protected support.
Higher expected carbon costs	Greater benefits from avoided emissions	Earlier abatement if the project reduces sufficient compliance exposure.
Greater volatility at the same expected cost path	More valuable flexibility in benchmark models	Possible delay; depends on deferral rights and forgone benefits.
Expected technological improvement	Cheaper or more effective equipment later	Possible delay, offset by interim costs and implementation lead times.
Credible policy commitments	Less uncertainty about rules and future returns	Lower option premium; profitability is still necessary.

Note. Conceptual synthesis based on [1], [8], [10] and [11]. Responses are conditional, not universally signed effects.

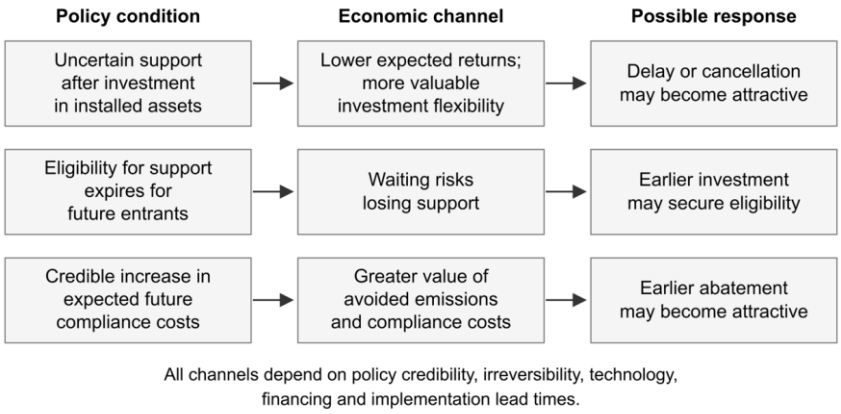


Figure 1. Conceptual Channels Linking Policy Conditions to Green Investment Timing.

Note. Author's synthesis of the real options literature. Arrows indicate conditional mechanisms rather than estimated causal effects.

4.2. Case Study

4.2.1. Spain and Renewable Energy Remuneration Reform

Spain illustrates the distinction between support for future entrants and remuneration of installed assets. Its earlier renewable-energy expansion occurred under policy arrangements that shaped expectations about operating revenues. Comparative research on European onshore wind shows that the design of support instruments matters for deployment [20]. In January 2012, Royal Decree-Law 1/2012 suspended remuneration pre-allocation and removed incentives for specified new installations that had not obtained the required registration, while initially preserving the treatment of operating and already registered projects [21]. Royal Decree-Law 9/2013 subsequently changed the

remuneration framework, including the treatment of existing installations [22]. These were distinct interventions with different implications for prospective and committed investment. Research on Spain's policy reversal places these changes within a wider institutional and market context [23]. They should not be reduced to a single subsidy cut occurring around 2013.

A real options interpretation is that uncertainty about further changes to remuneration can make irreversible commitment less attractive. Wind projects require specialised assets and substantial expenditure before operating revenues are earned; uncertainty affecting those revenues therefore matters [8]. At the same time, reduced expected remuneration can weaken investment even without an increase in uncertainty. The Spanish policy record does not isolate these two effects, and changes in financing, electricity prices, technology costs and permitting may also influence project decisions. The episode consequently illustrates exposure to policy revision rather than proving that a higher option value alone caused investment stagnation. Nor does subsequent investment activity imply that the original tariff arrangements were restored. The analytically relevant distinction is between the profitability of a project under revised rules and the additional value of waiting for those rules to become clearer.

4.2.2. German Industrial Levy Relief and Environmental Conditions

Germany demonstrates why industrial electricity-levy relief must be distinguished from carbon-pricing obligations. The EEG surcharge was reduced to zero on 1 July 2022 and subsequently abolished [24]. In December 2023, the European Commission approved amendments extending reductions in combined-heat-and-power and offshore levies through 2033, subject to revised eligibility rules [25]. This sequence does not support a general claim that all electricity-price relief progressively disappears as the EU Emissions Trading System tightens.

The relevant incentive is conditional access to relief. Section 30 of the Energy Financing Act requires qualifying firms to satisfy statutory management-system requirements and satisfy specified energy-efficiency, renewable-electricity or production-decarbonisation conditions [26]. Where investment is necessary to satisfy an applicable condition, postponement can jeopardise future relief and increase delay costs. This is an institutional mechanism, not evidence that particular firms have already retrofitted earlier. Verde's review concerns EU emissions trading, competitiveness and carbon leakage; it does not identify the timing effect of German levy conditions [27]. Establishing that effect would require firm-level investment dates, eligibility information and a credible comparison group. The German illustration therefore complements the Spanish case by showing how the design of support conditions can create incentives that differ from uncertain operating remuneration.

5. Existing Empirical Evidence and Discussion

This paper presents no original empirical estimates. Published findings are used to assess the plausibility and boundaries of the proposed mechanisms. Baker, Bloom and Davis develop a widely used index of economic policy uncertainty [28]. Gulen and Ion connect policy uncertainty to lower corporate investment, with stronger responses among firms facing greater irreversibility [4]. This pattern is consistent with an option-to-wait explanation, but can also reflect changes in expected profitability, financing constraints or risk premia. Moreover, a broad uncertainty index does not identify uncertainty about a specific climate instrument. Empirical evaluation of green-investment timing would need to distinguish policy announcements from implementation and observe whether firms postpone, resize or abandon projects. Aggregate expenditure alone cannot fully resolve these alternatives.

Evidence on green investment also differs in its method and outcome. Boomsma, Meade and Fleten and Ritzenhofen and Spinler use real options models to analyse support schemes and regulatory regimes [8,9]. Their findings are conditional model implications rather than estimates of firms' realised responses to carbon-price volatility. Löfgren and

colleagues estimate hurdle rates for pollution-abatement investment [17], providing a closer empirical connection to investment requirements. Green-patent studies address another margin: Calel and Dechezleprêtre identify an effect of the European carbon market on low-carbon technological innovation [29], while research on Chinese firms examines responses to environmental-rights trading and heterogeneous regulatory instruments [12,13]. Patenting can precede, accompany or fail to produce physical investment. Table 2 compares these evidence types and the conclusions each can support.

Table 2. Selected Studies and the Limits of Inference about Investment Timing.

Study and design	Relevant evidence or implication	Limit for the present argument
Gulen and Ion [4] Firm-level investment analysis	Policy uncertainty is associated with lower investment; irreversibility matters.	General capital expenditure does not isolate green-project delay.
Löfgren et al. [17] Retrospective investment analysis	Uncertainty is related to estimated hurdle rates for pollution-abatement investment.	Estimated hurdle rates do not identify policy-specific commissioning effects.
Boomsma et al. [8]; Ritzenhofen and Spinler [9] Real options models	Support schemes and regime-switch assumptions alter timing incentives.	Conditional model results are not realised causal effects.
Boomsma and Linnerud [10]; Nagy et al. [11] Real options models	Withdrawal rules can produce different timing and capacity responses.	Results depend on eligibility rules and treatment of installed projects.
Calel and Dechezleprêtre [29]; Qi et al. [12] Policy and patent studies	Environmental policy can induce low-carbon or green innovation.	Patents do not directly measure physical investment timing.
Hepburn et al. [30] Expert survey	Recovery-policy options differ in perceived economic and climate benefits.	Does not estimate corporate waiting values or investment triggers.

Note. Selected evidence is compared by research design; findings are not pooled into a common effect estimate.

Policy credibility remains relevant, but the evidence should be described at the level actually examined. Hepburn and colleagues assess fiscal recovery options through an expert survey, including their economic and climate implications [30]. Their study supports discussion of green policy priorities; it does not estimate firms' waiting values or demonstrate a causal effect of uncertain stimulus plans on project delays. Likewise, policy-sequencing research offers a rationale for building durable climate incentives without establishing that predictability always produces immediate investment [2]. Credible commitments can reduce avoidable uncertainty, yet their effects depend on expected profitability and exposure to the instrument. A future subsidy deadline may stimulate investment through the threat of lost eligibility, whereas uncertainty about payments to installed projects may discourage commitment. These mechanisms require different policy responses.

Investment timing has implications beyond the amount of capital ultimately deployed. Delay may prolong emissions-intensive production and defer energy savings, but earlier commitment is not automatically socially optimal. Waiting can permit the adoption of more effective technology; subsidy withdrawal risk can encourage earlier investment with smaller capacity [11]. Policy design should balance these considerations through credible long-term objectives, scheduled reviews and transparent treatment of existing commitments. Frequent discretionary adjustments may undermine the predictability needed for capital-intensive projects. Future empirical research could

combine project announcements, financing decisions and commissioning dates with policy eligibility records to distinguish anticipation from implementation effects. Such analysis would also need to control for electricity prices, interest rates, technology costs and project approvals before attributing timing changes to policy uncertainty.

6. Conclusion

Real options theory explains why a financially attractive green project may not be undertaken immediately. When investment is substantially irreversible and useful information is expected to arrive, postponement preserves flexibility. The firm compares the net value of immediate investment with the continuation value of waiting, which accounts for forgone benefits and costs incurred during delay. A positive conventional NPV is therefore informative about profitability but may be insufficient to establish optimal timing.

The direction of a policy-induced timing response depends on the exposure created by the instrument. Uncertain remuneration for installed assets may weaken commitment, while an approaching deadline for securing new-project support can encourage earlier investment. A credible rise in expected compliance costs may favour earlier abatement when the investment avoids those costs; greater volatility around the expected path can strengthen waiting incentives. Policy credibility, technological improvement and implementation lead times affect the balance among these channels.

The Spanish and German illustrations show why policy chronology and institutional detail matter. Changes to renewable-energy remuneration and conditions attached to industrial levy relief create different incentives and cannot be interpreted through a single uncertainty mechanism. Transparent eligibility rules, dependable transition arrangements and predictable review schedules can reduce avoidable uncertainty. Their effectiveness also depends on the underlying economic incentive: credibility alone does not make an unprofitable project worthwhile, and accelerated private investment does not necessarily maximise social benefits.

The analysis is limited to a conceptual synthesis and selected policy illustrations. It establishes neither causal investment effects nor numerical decision thresholds. Further research using firm-level or project-level data should distinguish uncertainty from changes in expected policy stringency, and investment timing from innovation, capacity choice and project cancellation. These distinctions would permit a more precise assessment of how policy design influences the pace of corporate decarbonisation.

References

1. A. K. Dixit and R. S. Pindyck, *Investment under Uncertainty*. Princeton, NJ: Princeton Univ. Press, 1994. doi: 10.2307/j.ctt7sncv
2. M. Pahle, D. Burtraw, C. Flachsland, N. Kelsey, E. Biber, J. Meckling, O. Edenhofer, and J. Zysman, "Sequencing to ratchet up climate policy stringency," *Nature Climate Change*, vol. 8, no. 10, pp. 861–867, 2018. doi: 10.1038/s41558-018-0287-6
3. B. S. Bernanke, "Irreversibility, uncertainty, and cyclical investment," *The Quarterly Journal of Economics*, vol. 98, no. 1, pp. 85–106, 1983. doi: 10.2307/1885568
4. H. Gulen and M. Ion, "Policy uncertainty and corporate investment," *The Review of Financial Studies*, vol. 29, no. 3, pp. 523–564, 2016. doi: 10.1093/rfs/hhv050
5. J. Meckling and J. Nahm, "The politics of technology bans: Industrial policy competition and green goals for the auto industry," *Energy Policy*, vol. 126, pp. 470–479, 2019. doi: 10.1016/j.enpol.2018.11.031
6. C. Fischer and R. G. Newell, "Environmental and technology policies for climate mitigation," *Journal of Environmental Economics and Management*, vol. 55, no. 2, pp. 142–162, 2008. doi: 10.1016/j.jeem.2007.11.001
7. D. Popp, "Innovation and climate policy," *Annual Review of Resource Economics*, vol. 2, no. 1, pp. 275–298, 2010. doi: 10.1146/annurev.resource.012809.103929
8. T. K. Boomsma, N. Meade, and S.-E. Fleten, "Renewable energy investments under different support schemes: A real options approach," *European Journal of Operational Research*, vol. 220, no. 1, pp. 225–237, 2012. doi: 10.1016/j.ejor.2012.01.017
9. I. Ritzenhofen and S. Spinler, "Optimal design of feed-in-tariffs to stimulate renewable energy investments under regulatory uncertainty—A real options analysis," *Energy Economics*, vol. 53, pp. 76–89, 2016. doi: 10.1016/j.eneco.2014.12.008
10. T. K. Boomsma and K. Linnerud, "Market and policy risk under different renewable electricity support schemes," *Energy*, vol. 89, pp. 435–448, 2015. doi: 10.1016/j.energy.2015.05.114

11. R. L. G. Nagy, V. Hagspiel, and P. M. Kort, "Green capacity investment under subsidy withdrawal risk," *Energy Economics*, vol. 98, p. 105259, 2021. doi: 10.1016/j.eneco.2021.105259
12. S. Qi, S. Lin, and J. Cui, "Do environmental rights trading schemes induce green innovation? Evidence from listed firms in China," *Economic Research Journal*, vol. 53, no. 12, pp. 129–143, 2018.
13. Q. Li and Z. Xiao, "Heterogeneous environmental regulation tools and green innovation incentives: Evidence from green patents of listed companies," *Economic Research Journal*, vol. 55, no. 9, pp. 192–208, 2020.
14. Z. Deng and Y. Hao, "Energy price uncertainty, environmental policy, and firm investment: A dynamic modeling approach," *Energy Economics*, vol. 130, p. 107306, 2024. doi: 10.1016/j.eneco.2024.107306
15. R. McDonald and D. Siegel, "The value of waiting to invest," *The Quarterly Journal of Economics*, vol. 101, no. 4, pp. 707–727, 1986. doi: 10.2307/1884175
16. R. S. Pindyck, "Irreversibility, uncertainty, and investment," *Journal of Economic Literature*, vol. 29, no. 3, pp. 1110–1148, 1991.
17. Å. Löfgren, K. Millock, and C. Nauges, "The effect of uncertainty on pollution abatement investments: Measuring hurdle rates for Swedish industry," *Resource and Energy Economics*, vol. 30, no. 4, pp. 475–491, 2008. doi: 10.1016/j.reseneeco.2008.09.002
18. K. T. Gillingham, C. R. Knittel, J. Li, M. Ovaere, and M. Reguant, "The short-run and long-run effects of COVID-19 on energy and the environment," *Joule*, vol. 4, no. 7, pp. 1337–1341, 2020. doi: 10.1016/j.joule.2020.06.010
19. R. G. Newell, W. A. Pizer, and D. Raimi, "Carbon markets 15 years after Kyoto: Lessons learned, new challenges," *Journal of Economic Perspectives*, vol. 27, no. 1, pp. 123–146, 2013. doi: 10.1257/jep.27.1.123
20. M. T. García-Álvarez, L. Cabeza-García, and I. Soares, "Analysis of the promotion of onshore wind energy in the EU: Feed-in tariff or renewable portfolio standard?" *Renewable Energy*, vol. 111, pp. 256–264, 2017. doi: 10.1016/j.renene.2017.03.067
21. Jefatura del Estado, "Real Decreto-ley 1/2012, de 27 de enero," *Boletín Oficial del Estado*, no. 24, pp. 8068–8072, Jan. 28, 2012. [Online]. Available: https://www.boe.es/eli/es/rdl/2012/01/27/1
22. Jefatura del Estado, "Real Decreto-ley 9/2013, de 12 de julio," *Boletín Oficial del Estado*, no. 167, Jul. 13, 2013. [Online]. Available: https://www.boe.es/eli/es/rdl/2013/07/12/9
23. D. Gabaldón-Estevan, E. Peñalvo-López, and D. Alfonso Solar, "The Spanish turn against renewable energy development," *Sustainability*, vol. 10, no. 4, p. 1208, 2018. doi: 10.3390/su10041208
24. Bundesnetzagentur, "Ehemalige EEG-Umlagepflichten und Leitfäden zur Eigenversorgung," [Online]. Available: https://www.bundesnetzagentur.de/899824. Accessed: Oct. 10, 2026.
25. European Commission, "EU-Kommission genehmigt Änderungen der deutschen Beihilferegelungen zur Unterstützung stromintensiver Unternehmen," Dec. 19, 2023. [Online]. Available: https://germany.representation.ec.europa.eu/nachrichten-und-veranstaltungen/pressemitteilungen/eu-kommission-genehmigt-anderungen-der-deutschen-beihilferegelungen-zur-unterstutzung-2023-12-19_de
26. Federal Republic of Germany, "Energiefinanzierungsgesetz, § 30: Voraussetzungen der Begrenzung," *Gesetze im Internet*. [Online]. Available: https://www.gesetze-im-internet.de/enfg/__30.html. Accessed: Oct. 10, 2026.
27. S. F. Verde, "The impact of the EU Emissions Trading System on competitiveness and carbon leakage: The econometric evidence," *Journal of Economic Surveys*, vol. 34, no. 2, pp. 320–343, 2020. doi: 10.1111/joes.12356
28. S. R. Baker, N. Bloom, and S. J. Davis, "Measuring economic policy uncertainty," *The Quarterly Journal of Economics*, vol. 131, no. 4, pp. 1593–1636, 2016. doi: 10.1093/qje/qjw024
29. R. Calel and A. Dechezleprêtre, "Environmental policy and directed technological change: Evidence from the European carbon market," *The Review of Economics and Statistics*, vol. 98, no. 1, pp. 173–191, 2016. doi: 10.1162/REST_a_00470
30. C. Hepburn, B. O'Callaghan, N. Stern, J. Stiglitz, and D. Zenghelis, "Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?" *Oxford Review of Economic Policy*, vol. 36, no. Suppl. 1, pp. S359–S381, 2020. doi: 10.1093/oxrep/graa015

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