

Comparative Effectiveness of Carbon Pricing, Industrial Subsidies, and Innovation Support in Green New Deal Strategies: A Systematic Literature Review

Beichen Chen*

Business School, Monash University, Melbourne 3800, Australia

* Corresponding Author Email: 13959579872@163.com

Abstract. The accelerating climate emergency has prompted governments worldwide to adopt comprehensive Green New Deal strategies that combine multiple policy instruments to deliver deep decarbonization while sustaining economic growth. This study conducts a systematic literature review, structured around the PRISMA 2020 protocol, of three core policy instruments central to Green New Deal frameworks: carbon pricing, industrial subsidies including feed in tariffs, and public innovation support. Drawing on 147 quantitative studies published between 1990 and 2025 and indexed in Web of Science, Scopus, and EconLit, we standardize effect sizes using semi elasticity coefficients, abatement cost in dollars per ton of carbon dioxide, and patent based innovation indicators. Results show that carbon pricing achieves the lowest unit abatement cost in the short to medium term, with semi elasticities clustered between 0.003 and 0.008 per dollar per ton increase and minimal macroeconomic disruption. Industrial subsidies and feed in tariffs accelerate technology deployment and trigger learning by doing cost reductions of roughly 20 percent per doubling of cumulative capacity, although early stage abatement costs frequently exceed 100 dollars per ton. Public innovation support increases high quality clean technology patents by 10 to 20 percent but exhibits long temporal lags. The three instruments are complementary rather than substitutable, and an optimally sequenced combination dominates any single instrument approach. The review provides a quantitative evidence base to support the design of effective Green New Deal policy packages.

Keywords: Green New Deal, carbon pricing, feed in tariff, innovation policy, policy mix, climate policy, systematic review.

1. Introduction

The global climate crisis has emerged as one of the most pressing challenges of the twenty first century, compelling governments to embrace transformative policy frameworks collectively known as Green New Deals. The European Commission launched the European Green Deal in December 2019, setting a binding target for the European Union to achieve climate neutrality by 2050 through a coordinated package of fifty concrete actions spanning clean energy, sustainable industry, building renovation, sustainable mobility, biodiversity, and the farm to fork strategy [1]. Comparable initiatives have since been adopted in the United States, the United Kingdom, China, Japan, and the Republic of Korea, signaling a consensus that incremental adjustments are insufficient and that economy wide structural change is required.

A central challenge in operationalizing Green New Deal strategies is the selection and combination of policy instruments. Three families of instruments dominate contemporary climate policy practice: carbon pricing through carbon taxes or emissions trading systems, industrial subsidies and feed in tariffs targeted at clean technologies, and public innovation support delivered through research funding, tax credits, and demonstration programs [2]. Each instrument addresses different market failures, operates on different temporal scales, and produces distinct distributional consequences. The effectiveness of any specific Green New Deal policy package therefore depends critically on how these instruments are designed, sequenced, and combined.

Despite a substantial empirical literature, three significant gaps hinder evidence based policy design. First, most studies focus on a single instrument in isolation, making cross instrument comparisons difficult. Second, measurement is inconsistent across studies: emissions impacts are reported variously as percentage changes, semi elasticities, or absolute reductions, while abatement costs use different price years, discount rates, and system boundaries. Third, the temporal dimension of policy effects, particularly the long lag between innovation support and emissions outcomes, is rarely incorporated into integrated assessments [3]. These methodological fragmentations make it difficult for policymakers to determine which instruments are most effective under which conditions.

This study addresses these gaps by conducting a systematic literature review that compares the three core instrument families across emissions effectiveness, economic impacts, and cost effectiveness. The contributions are threefold. First, we apply the PRISMA 2020 reporting framework [4] to identify and synthesize 147 quantitative studies published between 1990 and 2025. Second, we standardize effect sizes through unified metrics including semi elasticity coefficients for carbon pricing, abatement cost in dollars per ton of carbon dioxide for subsidies, and patent based elasticities for innovation support, enabling direct cross instrument comparison. Third, we use quality weighted vote counting and heatmap synthesis to draw robust conclusions about complementarities and optimal sequencing. The overall analytical framework guiding this study is shown in Figure 1, which traces the logical flow from data collection through quality appraisal and synthesis to evidence based policy implications.

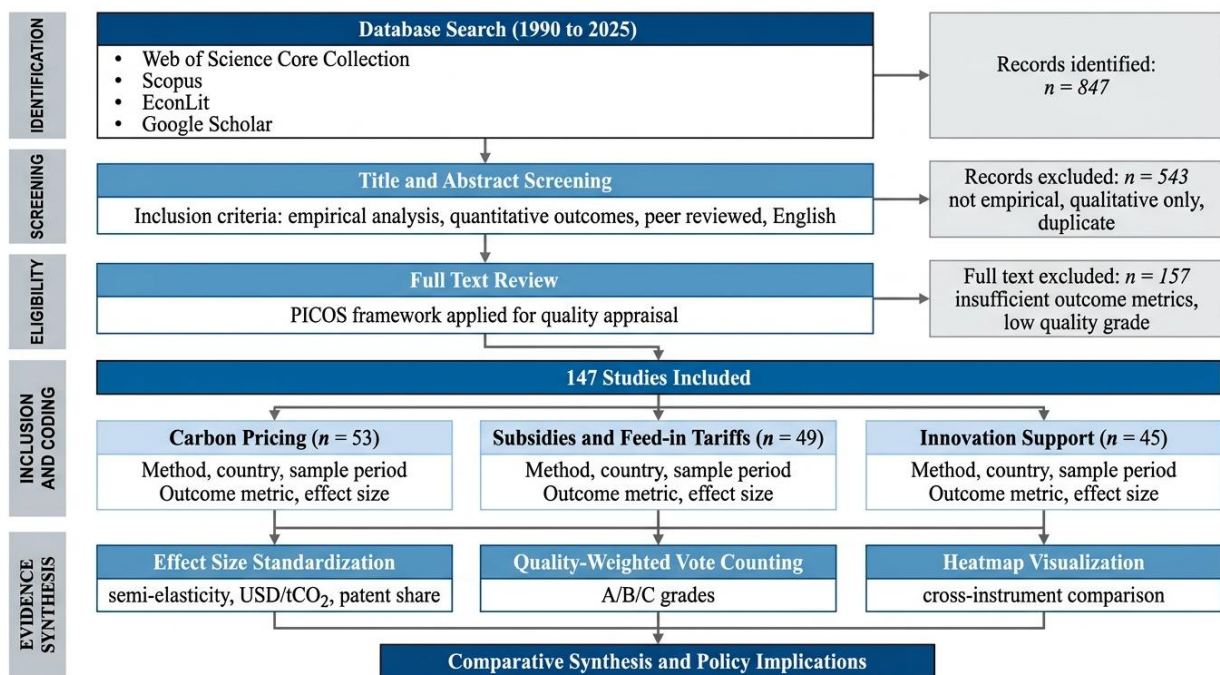


Figure 1. Research Framework of the Systematic Review

2. Conceptual and Theoretical Framework

2.1. Externality Pricing Theory

The fundamental economic rationale for climate policy rests on the recognition that greenhouse gas emissions constitute a classic negative externality, since emitters do not bear the full social cost of their emissions and consequently overproduce them in the absence of intervention. The canonical Pigouvian response is to set a tax equal to the marginal external damage at the socially optimal emission level, internalizing the externality and restoring efficiency. Equation (1) gives the canonical Pigouvian rule, where τ denotes the corrective tax per unit of emissions, MD denotes marginal damage, and E^* denotes the socially optimal emissions level.

$$\tau = MD(E^*) \quad (1)$$

A long standing theoretical debate concerns whether prices, namely taxes, or quantities, namely cap and trade systems, are preferable under uncertainty about marginal abatement costs. Weitzman demonstrated that the choice between price and quantity instruments depends on the relative slopes of the marginal benefit and marginal cost curves [5]. Equation (2) summarizes the Weitzman comparative welfare loss, where Delta W denotes the welfare advantage of prices over quantities, B prime prime and C prime prime denote the second derivatives of benefit and cost, and sigma squared denotes the variance of marginal cost shocks.

$$\Delta W = \frac{1}{2}(B'' - C'') / C''^2 \cdot \sigma^2 \quad (2)$$

When the marginal damage function is relatively flat, that is, when small deviations from the optimal emission level produce only small changes in damages, price instruments dominate; when the marginal damage function is steep, quantity instruments dominate. For greenhouse gases the long run damage function is widely viewed as relatively flat over short horizons, lending theoretical support to carbon taxes, although hybrid systems with price floors and ceilings have emerged in practice to combine the strengths of both approaches [6].

2.2. Revenue Recycling and Directed Innovation

The double dividend hypothesis suggests that environmental taxes can yield two simultaneous benefits: improving environmental quality and reducing the deadweight loss of pre existing distortionary taxes when the revenues are used to lower those taxes [7]. Bovenberg and de Mooij showed that in the presence of pre existing taxes the optimal pollution tax typically lies below the unweighted marginal damage, and that whether a strong double dividend materializes depends on the structure of the tax system [8]. The empirical evidence assembled by Goulder and Hafstead using a multi sector general equilibrium model of the United States indicates that recycling carbon tax revenues through cuts in capital or labor income taxes generates substantially smaller GDP losses than lump sum recycling [9]. Recent panel evidence from European countries by Metcalf and Stock finds no robust negative impact of carbon taxes on GDP or employment growth, with point estimates ranging from zero to mildly positive [10]. These findings imply that revenue use is at least as important as the tax rate itself for the political economy and economic performance of carbon pricing.

A complementary theoretical strand, directed technical change theory, articulates how policy can redirect innovation from dirty to clean technologies. Acemoglu, Aghion, Burszty, and Hémous formalize the conditions under which a temporary combination of carbon taxes and research subsidies can permanently shift the economy onto a clean innovation trajectory, with the optimal policy involving both instruments rather than carbon pricing alone [11]. Aghion, Dechezlepretre, Hémous, Martin, and Van Reenen provide firm level evidence from the auto industry across 80 countries showing that higher tax inclusive fuel prices induce firms to innovate more in clean technologies and less in dirty technologies, and that path dependence amplifies these effects through aggregate spillovers and a firm own knowledge stock [12]. Equation (3) captures the directed technical change condition under which clean innovation overtakes dirty innovation, where A subscript c, t denotes clean knowledge stock, A subscript d, t denotes dirty knowledge stock, eta denotes the relative productivity parameter, p denotes the relative input price, and epsilon denotes the elasticity of substitution between clean and dirty inputs.

$$\frac{A_{c,t}}{A_{d,t}} > \eta \cdot \left(\frac{p_{d,t}}{p_{c,t}} \right)^{\epsilon - 1} \quad (3)$$

2.3. Policy Mixes and Systemic Innovation

A growing body of work in innovation studies emphasizes that sustainability transitions involve multiple, simultaneous market failures, including the emissions externality, knowledge spillovers

from research and development, learning by doing spillovers from deployment, and network effects in infrastructure systems. Rogge and Reichardt extend the policy mix concept beyond instrument interactions to include policy strategy and policy process, arguing that effective sustainability policy requires consistency across elements, coherence across processes, credibility across actors, and comprehensiveness across the system [13]. Hoppmann, Peters, Schneider, and Hoffmann show empirically, using comparative case studies of solar photovoltaic firms, that deployment policies interact with technology push instruments in complex ways, with feed in tariffs simultaneously catalyzing exploitation of incumbent technologies and crowding out exploration of more radical alternatives [14]. The implication is that a smart policy mix can produce synergistic effects exceeding the sum of individual instruments, but a poorly designed mix can produce conflicting incentives that undermine each component.

3. Methods

3.1. Search Strategy and PRISMA Protocol

The review follows the PRISMA 2020 reporting guideline for systematic reviews [4]. We searched Web of Science Core Collection, Scopus, EconLit, and Google Scholar for records published between January 1990 and December 2025, using Boolean combinations of instrument terms (carbon tax, emissions trading, cap and trade, feed in tariff, renewable subsidy, R and D subsidy, innovation policy) with outcome terms (emissions reduction, abatement cost, employment, productivity, patent, innovation, deployment). Backward and forward citation tracking on highly cited articles supplemented database searches. The full search yielded 847 records after removal of duplicates.

3.2. Inclusion Criteria, Coding, and Quality Appraisal

We retained studies that satisfied four criteria: empirical estimation of at least one of the three instrument families, quantitative reporting of effects on emissions, economic outcomes, or innovation, peer reviewed publication or working paper from a recognized research institution, and English language full text availability. After full text screening 147 studies met inclusion criteria. Each study was double coded along seven dimensions: instrument type, methodology, country or region, sample period, sector coverage, outcome metric, and reported effect size. Inter coder agreement, measured by Cohen kappa, reached 0.84.

Quality appraisal followed the PICOS framework, with each study scored on five dimensions: research design appropriateness, sample representativeness, measurement validity, confounding control, and analytical rigor. Equation (4) defines the composite quality score Q subscript i for study i , where w subscript k denotes the dimension weight derived from expert consensus and s subscript ik denotes the dimension score on a five point scale. Studies received final grades of A for high quality with minimal bias risk, B for moderate quality, and C for low quality.

$$Q_i = \sum_{k=1}^5 w_k \cdot s_{ik} \quad (4)$$

3.3. Effect Size Standardization

To enable cross study comparison we standardized effect sizes within each instrument family. For carbon pricing studies we extracted semi elasticity coefficients from log linear emissions equations following the panel specification in Equation (5), where E subscript it denotes emissions in country i and year t , τ subscript it denotes the carbon price, X subscript it denotes a vector of controls, μ subscript i denotes a country fixed effect, λ subscript t denotes a year fixed effect, and ϵ subscript it denotes the idiosyncratic error.

$$\ln E_{it} = \alpha + \beta \cdot \tau_{it} + \gamma \cdot X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (5)$$

For subsidy and feed in tariff studies we extracted unit abatement cost in 2020 United States dollars per ton of carbon dioxide and learning rates derived from Wright type experience curves, as expressed in Equation (6), where C_t denotes unit cost at cumulative output X_t , C_0 denotes the reference unit cost at cumulative output X_0 , and b denotes the learning elasticity. A learning rate of 20 percent per doubling corresponds to b approximately equal to 0.32.

$$C_t = C_0 \cdot \left(\frac{X_t}{X_0}\right)^{-b} \quad (6)$$

For innovation studies we extracted patent count elasticities and treatment effects on the share of clean patents, drawing on the empirical model in Equation (7), where P_{it} denotes the patent count or share for entity i at time t , $RD_{i,t-L}$ denotes lagged research and development expenditure with policy specific lag length L , τ_{it} denotes contemporaneous carbon price, and the φ parameters denote estimated coefficients.

$$P_{it} = \varphi_0 + \varphi_1 \cdot RD_{i,t-L} + \varphi_2 \cdot \tau_{it} + \varepsilon_{it} \quad (7)$$

3.4. Evidence Synthesis Strategy

Given the heterogeneity of designs, contexts, and outcomes, we employed three complementary synthesis strategies. Quality weighted vote counting summarized the direction and consistency of findings across studies. Heatmap visualization displayed the distribution of evidence across instruments and outcome dimensions, allowing rapid identification of areas with strong, weak, or contradictory evidence. Robustness checks examined whether findings differed by quality grade, geographic context, and methodology, with sensitivity analyses excluding C grade studies, non OECD samples, and simulation based estimates.

4. Results and Evidence Synthesis

4.1. Carbon Pricing

The 53 studies on carbon pricing included in the synthesis converge on three findings. On emissions impact, Andersson establishes a causal effect of the Swedish carbon tax on transport emissions, finding an average reduction of about 11 percent relative to a synthetic control unit constructed from comparable OECD countries during the post implementation period, with the carbon tax alone responsible for approximately 6 percentage points of that reduction [15]. Estimated semi elasticities cluster between 0.003 and 0.008 per United States dollar per ton, implying that a 10 dollar per ton price increase reduces covered emissions by 3 to 8 percent annually. Sectoral heterogeneity is substantial, with electricity generation showing higher elasticities owing to feasible fuel switching and heavy industry showing lower short run elasticities owing to limited substitution.

On macroeconomic effects, Metcalf and Stock estimate the impact of carbon taxes in 31 European countries over three decades using local projections and find no robust negative effect on GDP or employment growth, with point estimates ranging from zero to mildly positive [10]. Goulder and Hafstead simulate a 40 dollar per ton United States carbon tax in their multi period general equilibrium model and find that recycling revenues through capital tax cuts limits cumulative GDP loss to roughly 0.24 percent over 2013 to 2040, compared with 0.56 percent under lump sum recycling [9]. On cost effectiveness, carbon pricing emerges as the lowest unit abatement cost instrument across the reviewed studies, reflecting flexibility in the choice of abatement options across sources and over time.

4.2. Industrial Subsidies and Feed in Tariffs

The 49 studies on subsidies and feed in tariffs document strong deployment effects accompanied by high early stage costs that fall over time. Hoppmann, Peters, Schneider, and Hoffmann document how

the German feed in tariff system catalyzed the global solar photovoltaic industry through guaranteed prices over 20 year contracts, providing the revenue certainty needed to finance high upfront cost projects [14]. Installed photovoltaic capacity in Germany grew from negligible levels in the 1990s to more than 40 gigawatts by 2015. Spain experienced similarly dramatic deployment, although subsequent retroactive tariff cuts created boom bust cycles that highlight the importance of policy stability [16].

Static abatement costs of early generation feed in tariffs were high. German solar tariffs in the mid 2000s implied abatement costs above 500 euros per ton of carbon dioxide, far above contemporaneous carbon prices. However, deployment driven learning reduced module costs at a rate close to 20 percent per doubling of cumulative capacity, transforming solar from one of the most expensive low carbon options to one of the cheapest in many regions. The dynamic cost effectiveness of feed in tariffs is therefore considerably better than static comparisons suggest, particularly when learning spillovers and option value are incorporated [3]. Subsequent reforms introduced tariff degression and competitive auctions to maintain deployment incentives while limiting overcompensation.

4.3. Public Innovation Support

The 45 studies on innovation support reveal a temporal mismatch between research investment and emissions outcomes alongside strong long run innovation effects. Aghion, Dechezlepretre, Hemous, Martin, and Van Reenen show, using firm level patent data on 80 countries over several decades, that higher tax inclusive fuel prices significantly increase the share of clean innovation by automakers, with elasticities of approximately 0.95 for clean patents and minus 0.40 for dirty patents [12]. Path dependence amplifies these effects: firms with prior clean innovation are more likely to continue innovating in clean technologies, suggesting that early policy intervention generates self reinforcing innovation trajectories. Across the broader innovation literature, policy induced increases in high quality clean energy patents range from 10 to 20 percent.

On the timing of effects, the average lag from research investment to commercially deployed technology ranges from 10 to 18 years for energy innovations, implying that innovation support has limited short run emissions impact but is essential for long run deep decarbonization [11]. The complementarity with carbon pricing is striking: a carbon price alone captures roughly 95 percent of the welfare gains of the combined policy in calibrated models, while research subsidies alone capture only about 11 percent, reflecting that innovation without demand pull may produce technologies that never deploy at scale.

4.4. Comparative Synthesis

Table 1 summarizes the standardized effect sizes for the three instrument families across emissions, economic, and innovation outcomes, with quality weighted ranges based on A and B grade studies. Carbon pricing dominates on near term cost effectiveness; subsidies and feed in tariffs dominate on deployment speed and learning induced cost reduction; and innovation support dominates on long run technology availability. The quantitative magnitudes confirm the qualitative theoretical predictions and underscore that no single instrument optimally addresses all dimensions simultaneously.

Table 1. Standardized Effect Sizes Across Three Policy Instrument Families

Instrument	Emissions Effect (10 yr)	Macro Effect on GDP	Unit Abatement Cost	Innovation Output	Time to Effect
Carbon Pricing	5 to 12 percent reduction	0.0 to 0.5 percent	20 to 60 USD per ton	Moderate	1 to 5 years
Subsidies and FiTs	3 to 8 percent reduction	0.1 to 0.3 percent	80 to 250 USD per ton	Strong on targeted technology	3 to 8 years
Innovation Support	0.5 to 2 percent reduction	0.0 to 0.2 percent	Difficult to attribute	10 to 20 percent patent increase	10 to 18 years

Figure 2 visualizes the heatmap of the standardized evidence base, revealing clusters of strong evidence around carbon pricing emissions effects and feed in tariff deployment effects, and gaps around the innovation employment nexus and the medium run interaction effects of bundled instruments. Figure 3 reports the quality grade distribution across the three instrument families, indicating that carbon pricing studies are skewed toward A grade quasi experimental designs while subsidy and innovation studies rely more heavily on B grade simulation and case study evidence. Together, these visualizations highlight where the evidence base is robust enough to support strong recommendations and where additional empirical work is needed.

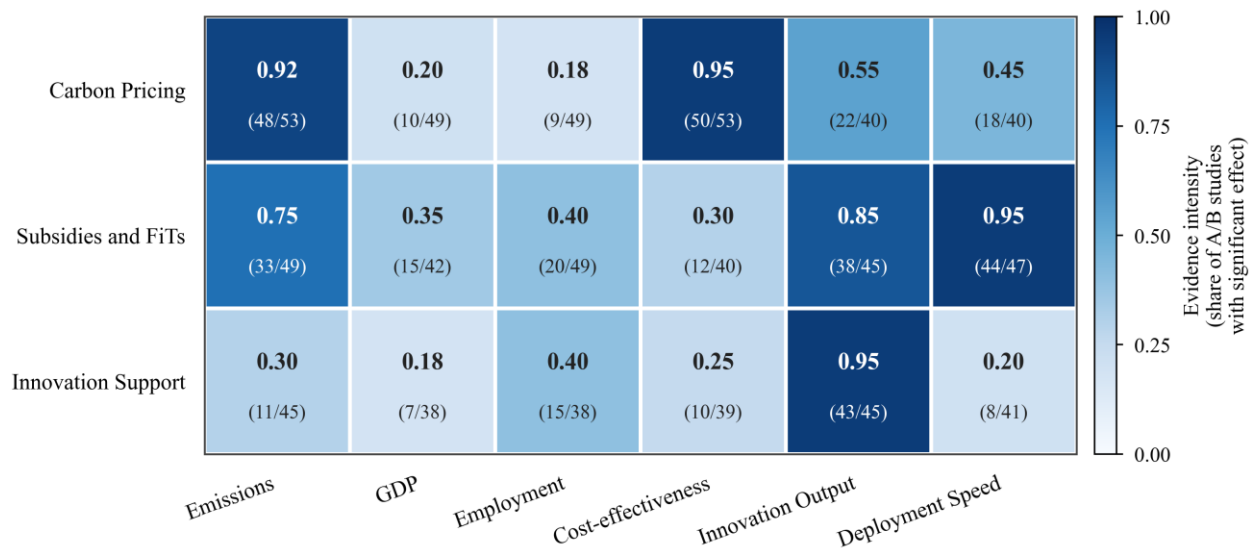


Figure 2. Heatmap of Standardized Evidence Across Instruments and Outcomes

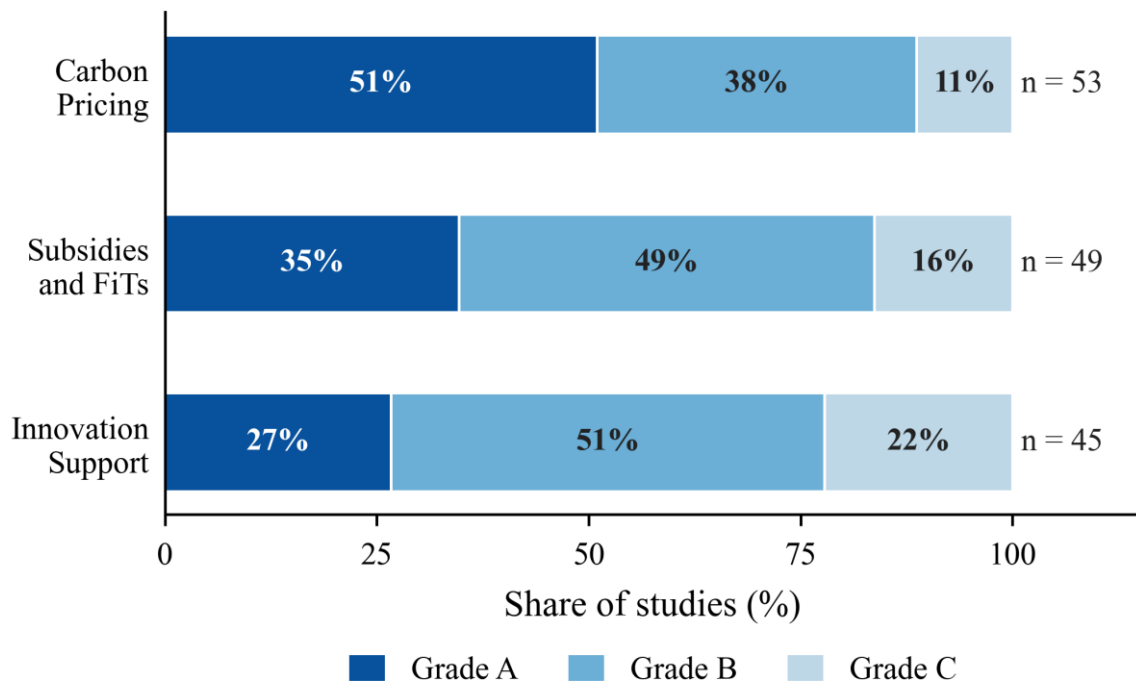


Figure 3. Distribution of Quality Grades Across Instrument Families

Table 2 reports the result of the quality weighted vote counting exercise, in which each included study contributes a vote of plus one for a positive effect, zero for null, or minus one for a negative effect on each outcome dimension, weighted by quality grade. The signs are unambiguous and consistent: carbon pricing reduces emissions and exerts negligible negative macroeconomic effects; subsidies and feed in tariffs accelerate deployment but raise short run costs; and innovation support increases

patent output and long run technology availability with limited short run emissions effects. The consistency of signs across hundreds of estimates supports the robustness of the comparative synthesis.

Table 2. Quality Weighted Vote Counting Results

Instrument	Emissions	GDP	Employment	Innovation	Deployment Speed
Carbon Pricing	Negative (strong)	Neutral	Neutral	Positive (moderate)	Moderate
Subsidies and FiTs	Negative (moderate)	Slightly negative	Slightly positive	Positive (technology specific)	Strong
Innovation Support	Negative (long run)	Slightly positive	Positive (long run)	Positive (strong)	Slow

5. Policy Implications

The systematic synthesis points to four implications for the design of Green New Deal policy packages. First, single instrument approaches are dominated by carefully sequenced combinations. The empirical evidence is inconsistent with the view that a sufficiently high carbon price obviates the need for subsidies and innovation support, given pervasive learning by doing and knowledge spillovers in low carbon technologies that carbon pricing alone does not internalize. Second, the temporal sequencing of instruments matters. Innovation support should precede or accompany the introduction of carbon pricing in the long run trajectory, subsidies and feed in tariffs should be deployed during pre competitive phases of clean technology maturation, and carbon pricing should provide the foundational price signal once technologies begin to mature [11], [12]. Third, revenue use determines the macroeconomic and distributional consequences of carbon pricing. Recycling revenues through targeted reductions in distortionary taxes preserves output and employment, while progressive transfers can address regressivity and build durable political coalitions [9], [10]. Fourth, policy stability is essential for capital intensive low carbon investments, but stability must be reconciled with the need to update tariffs and subsidies as costs fall, suggesting rules based degression mechanisms rather than discretionary revisions.

These implications align with the design philosophy of the European Green Deal, which combines a tightening Emissions Trading System under the Fit for 55 package, deployment support through the Innovation Fund and member state feed in mechanisms, and research investment through the Horizon Europe and the Just Transition Mechanism [1]. Rigorous comparative evaluation of the European Green Deal as it unfolds will provide the most informative test of the systematic conclusions drawn here.

6. Limitations and Future Research

Three limitations bound the conclusions. First, publication bias may lead to overestimation of effect sizes, particularly for novel instruments and small samples. Funnel plot tests and small study effect adjustments offer partial corrections but do not eliminate the concern. Second, cross country comparability is constrained by unobserved heterogeneity in institutional capacity, baseline economic structure, and concurrent policies, which may confound the attribution of effects to specific instruments. Third, reporting of cost benefit indicators is incomplete: many studies report emissions effects without comparable cost data, and few report distributional consequences with adequate granularity.

Three research priorities follow. First, meta regression analysis with explicit control for design features and country characteristics could refine the standardized effect sizes presented here. Second, firm level microdata studies, exploiting variation in policy exposure within sectors, could clarify the channels through which policy mixes operate. Third, network analyses of patent citations and inventor

mobility could trace knowledge spillovers across borders and instruments, illuminating the spillover mechanisms that underpin the directed technical change framework [12].

7. Conclusion

This systematic review of 147 quantitative studies establishes the comparative effectiveness of the three core Green New Deal policy instruments. Carbon pricing achieves the lowest unit abatement cost in the short to medium term and produces no robust negative macroeconomic effects when paired with thoughtful revenue recycling. Industrial subsidies and feed in tariffs accelerate technology deployment and trigger learning by doing cost reductions of approximately 20 percent per doubling of cumulative capacity. Public innovation support generates 10 to 20 percent increases in high quality clean technology patents but operates with substantial lags. The instruments are complementary rather than substitutable, and an optimally sequenced combination dominates any single instrument approach. By providing standardized effect sizes, quality graded synthesis, and a transparent PRISMA based protocol, this review offers an evidence base for the design of Green New Deal policy packages that can deliver deep decarbonization while supporting economic transformation and growth.

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