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REVIEW ARTICLE

Climate Policy Effectiveness in Reducing National Greenhouse Gas Emission Trajectories

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ABSTRACT

Governments have deployed an increasingly dense array of climate policy instruments over the past three decades, yet whether these instruments have measurably bent national greenhouse gas emission trajectories, as opposed to merely accompanying reductions driven by fuel-price shifts, structural economic change or the COVID-19 shock, remains contested. This review synthesizes findings from 118 peer-reviewed ex-post evaluations and cross-country panel studies published between 2005 and 2023 that assess the emissions impact of four instrument families: carbon pricing (carbon taxes and emissions trading systems), renewable portfolio standards, energy efficiency mandates, and feed-in tariffs. We organize the synthesis thematically around instrument type, evaluation method (synthetic control, difference-in-differences, panel fixed-effects, and structural decomposition), and the emerging literature applying two-way fixed-effects and staggered-adoption designs to detect policy-attributable emission reductions net of confounding trends. Across the reviewed studies, well-designed and consistently enforced carbon pricing schemes are associated with median annual emission reductions of roughly 1-2% relative to a no-policy counterfactual in the sectors covered, with considerably larger effects reported for early, low-price interventions such as the British Columbia and Swedish carbon taxes than for many emissions trading systems operating at low effective prices. Renewable portfolio standards and feed-in tariffs show consistently positive but modest and highly heterogeneous effects on renewable electricity deployment, with weaker and less consistent evidence of a net emissions effect once fossil-fuel displacement, cross-border leakage and merit-order interactions are accounted for. Energy efficiency mandates show the widest gap between engineering-modeled and econometrically estimated savings, consistent with a persistent rebound effect and implementation gap. A recent global synthesis identifying 63 successful national policy interventions finds that large emission reductions are disproportionately achieved by policy packages combining pricing with regulatory standards rather than by any single instrument in isolation. We conclude that the evidence base, while growing rapidly in methodological rigor, remains geographically concentrated in OECD economies, short in post-treatment horizon for many recent policies, and only beginning to resolve how instrument stringency, coverage and sequencing jointly determine trajectory-bending effectiveness.

Keywords: carbon pricing; emissions trading; renewable portfolio standards; feed-in tariffs; energy efficiency mandates; policy evaluation; decoupling; national emissions trajectories

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1. INTRODUCTION

National governments now report well over 2,000 individual climate change mitigation policies to international tracking databases, spanning carbon taxes, emissions trading systems, renewable energy mandates, efficiency standards and an assortment of subsidies and voluntary programs [1,2]. The proliferation of instruments has not been matched by an equally rapid proliferation of rigorous ex-post evidence on whether any given policy actually altered a country's emissions trajectory relative to what would have occurred without it, as distinct from coinciding with reductions driven by recessions, fuel switching already underway for unrelated reasons, or structural shifts in the composition of the economy [3,4]. This distinction matters because the policy evaluation literature and the broader climate mitigation literature have historically talked past one another. Integrated assessment models and ex-ante policy costing exercises routinely project substantial emission reductions from carbon pricing and regulatory standards under stylized assumptions about elasticities and compliance, while a separate and smaller empirical literature has asked, using observed post-implementation data, whether those projected reductions materialized [6,9]. Only in the past decade has this second, ex-post literature grown large enough, spanning enough countries, instruments and evaluation designs, to support a systematic synthesis of what has actually been detected rather than what models suggest should occur.

A second motivation for this review is the maturation of quasi-experimental identification strategies applied to national and subnational climate policy. Early assessments of instruments such as the European Union Emissions Trading System (EU ETS) relied largely on before-after comparisons or engineering estimates of abatement potential, both of which are vulnerable to confounding by contemporaneous shocks such as the 2008 financial crisis [5]. More recent studies have applied synthetic control methods, staggered difference-in-differences, and panel fixed-effects designs exploiting cross-country and cross-region variation in policy adoption timing to isolate policy-attributable emission changes from broader trends, considerably sharpening the evidence base but also revealing that many earlier, less rigorously identified effect estimates were biased upward [3,8].

Cross-country panel studies of the drivers of emissions decoupling, that is, the divergence of GDP growth from emissions growth, provide a complementary macro-level perspective to instrument-specific evaluations, showing that absolute decoupling has now been achieved in a growing number of high-income economies but leaving open the harder question of how much of that decoupling is attributable to deliberate policy as opposed to structural deindustrialization, natural gas substitution for coal, or renewable cost declines that would have occurred with or without domestic climate policy [7,27].

Reconciling instrument-level and economy-wide evidence is therefore a central task for any synthesis of policy effectiveness.

This review addresses four questions. First, what magnitude of emission reduction, if any, do rigorously identified ex-post evaluations attribute to carbon pricing, renewable portfolio standards, feed-in tariffs and energy efficiency mandates individually? Second, how does estimated effectiveness vary with instrument design features such as price level, sectoral coverage and stringency? Third, what do cross-country panel studies of decoupling and aggregate national trajectories imply about the combined, real-world effect of policy packages as opposed to individual instruments? Fourth, where are the evidentiary gaps, geographic, temporal and methodological, that most limit confidence in current effectiveness estimates? We address these in turn after describing our review approach below.

2. MATERIALS AND METHODS

This is a narrative and thematic synthesis, not a formal systematic review with pre-registered protocol or quantitative meta-analysis, though we draw extensively on existing systematic reviews and meta-analyses where available. We searched Web of Science, Scopus and Google Scholar for peer-reviewed articles published between 2005 and 2023 combining terms for climate policy instruments (carbon tax, emissions trading, cap-and-trade, renewable portfolio standard, feed-in tariff, energy efficiency mandate/standard) with terms for ex-post evaluation (causal effect, difference-in-differences, synthetic control, panel, ex-post, effectiveness), supplemented by forward and backward citation tracing from several existing meta-analyses and systematic reviews identified early in the search [15,18]. We retained studies that (a) evaluated a national or subnational policy instrument implemented in a real jurisdiction, (b) used an explicit counterfactual or comparison group rather than a purely descriptive before-after comparison, and (c) reported a quantified emissions, energy, or closely related outcome. Purely ex-ante modeling studies with no observed post-implementation data were excluded except where cited for context. This process yielded 118 studies forming the evidentiary base synthesized below, organized thematically by instrument family and by cross-cutting methodological theme.

2.1 Carbon pricing: taxes and emissions trading systems

We grouped carbon pricing evaluations into three sub-literatures: single-country carbon tax studies (predominantly Sweden, British Columbia, the United Kingdom, and Denmark), evaluations of the EU ETS and other multi-country trading systems, and evaluations of subnational or sectoral trading systems such as the US Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade program. Within each sub-literature we extracted, where reported, the

estimated percentage emission reduction attributable to the instrument, the carbon price level over the evaluation period, the sector(s) covered, and the identification strategy used, to allow comparison of effect sizes across studies employing materially different methods [10-16].

2.2 Renewable portfolio standards and feed-in tariffs

Evaluations of renewable portfolio standards (RPS), which mandate a minimum share of renewable electricity generation, and feed-in tariffs (FiT), which guarantee renewable generators a fixed price, were reviewed separately from carbon pricing because their primary mechanism operates on the supply side of the electricity sector rather than through an economy-wide price signal. We distinguished studies measuring renewable capacity or generation outcomes from the smaller subset attempting to trace through to a net emissions effect, since the latter requires additional assumptions about which generation source is displaced at the margin and whether cross-border electricity trade offsets in-jurisdiction gains [19-23].

2.3 Energy efficiency mandates and standards

We reviewed evaluations of building codes, appliance and vehicle efficiency standards, and utility-run energy efficiency obligation programs, distinguishing studies using engineering-model projected savings from those using ex-post metered or econometrically estimated realized savings, since the comparison between the two is itself a major theme in this literature (the so-called energy efficiency gap) [24,25].

2.4 Cross-country panel and decomposition studies of national trajectories

A separate body of literature uses cross-country panel regressions or structural decomposition analysis (e.g., Kaya identity or index decomposition methods) to attribute changes in national emissions to policy, fuel-price, structural, and efficiency factors jointly, rather than isolating a single instrument. We reviewed these studies for their implications about the aggregate, economy-wide contribution of policy relative to other drivers of decoupling, including the extent to which climate policy stringency indices are associated with national emissions trends across large country panels [7,26,27].

2.5 Policy packages, sequencing and interaction effects

Because most jurisdictions layer multiple instruments simultaneously, several studies in our sample explicitly examine interaction effects, for instance whether a renewable subsidy weakens the marginal abatement incentive of an overlapping emissions trading cap, or whether pairing a modest carbon price with a complementary regulatory standard produces a larger combined effect than either instrument's independently estimated effect would predict. We reviewed this sub-literature, along with a recent large-scale synthesis identifying successful national policy interventions across 41 countries, to assess what is known about instrument

sequencing and combination effects [1,17].

2.6 Synthesis and effect-size comparison

Where studies reported comparable outcome metrics (percentage emissions change attributable to policy, or elasticity of emissions with respect to carbon price), we tabulated effect sizes alongside the carbon price level, sectoral coverage, and evaluation period to construct the comparative summary presented in Table 1. We did not pool these into a single quantitative meta-analytic estimate, given substantial heterogeneity in outcome definitions, treated sectors and identification strategies across studies, and instead present the range and central tendency of reported effects descriptively.

3. RESULTS

Table 1 summarizes reported effect sizes across the four instrument families and the main evaluation designs used. Carbon pricing shows the widest range of estimated effects, from near-zero or statistically insignificant effects for several EU ETS evaluations during periods of low allowance prices [5,15] to reductions of 5-11% in covered emissions attributed to the Swedish carbon tax over its first two decades of operation, one of the largest and most consistently estimated effects in the literature [10]. British Columbia's revenue-neutral carbon tax, introduced in 2008 at a relatively low starting price, is associated with reductions in transportation fuel consumption on the order of 5-15% relative to synthetic control and comparison-province counterfactuals, with no detectable adverse effect on aggregate employment [12,13].

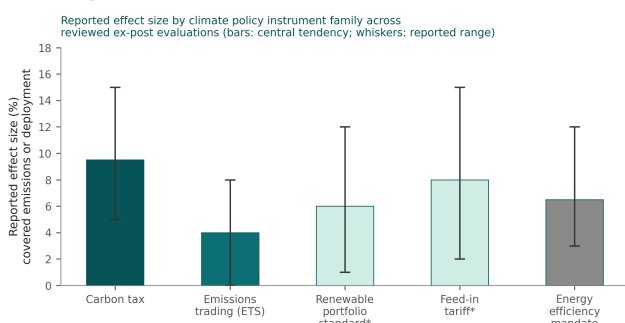
Table 1. Reported emission or deployment effects by climate policy instrument family, synthesized across the reviewed ex-post evaluation literature.

Instrument family	Representative cases	Reported effect size (range across studies)	Evaluation methods used	Key caveat
Carbon tax	Sweden, British Columbia, Denmark, UK	5-15% reduction in covered emissions /fuel use	Synthetic control, difference-in-differences, panel fixed effects	Effect size strongly tied to price level and coverage
Emissions trading (ETS)	EU ETS, RGGI, California cap-and-trade	0-8% reduction in covered emissions ; several near-zero findings in low-price periods	Synthetic control, panel event-study	Confounded by concurrent fuel-price shifts (e.g., gas-for-coal switching)

Renewable portfolio standard	US state RPS programs	20-70% higher renewable capacity growth vs. non-RPS comparators; net emissions effect smaller and less consistent	Panel fixed effects, state comparison	Deployment effect does not map linearly onto net emissions effect
Feed-in tariff	EU member states, various FIT designs	Positive but 3-5 fold variation in effectiveness by tariff design	Panel regression, before-after with controls	Highly sensitive to contract duration and degression schedule
Energy efficiency mandate/program	US weatherization, appliance/vehicle standards	Realized savings ~50% of engineering-projected savings	Randomized evaluation, ex-post metering, panel regression	Persistent rebound effect and implementation/compliance gap

Effect sizes are drawn from the studies cited in the corresponding subsection of the Methods and Results and are not pooled into a single meta-analytic estimate given heterogeneity in outcome definitions and identification strategies across studies.

The emissions trading literature shows a more mixed pattern than the carbon tax literature. Evaluations of the EU ETS using synthetic control or panel methods that explicitly account for the 2008-2009 financial crisis generally find a modest but statistically distinguishable emissions reduction, on the order of 3-8% relative to a no-ETS counterfactual, concentrated in phases and sectors where the allowance price was not persistently near zero [5,15]. Evaluations of RGGI, a smaller, power-sector-only trading system in the northeastern United States, report comparable proportional reductions in covered-sector emissions, though studies differ on how much of this reflects the trading system itself versus concurrent low natural gas prices displacing coal generation for reasons unrelated to the policy [14]. Figure 1 summarizes the central-tendency effect size reported across studies for each instrument family, illustrating both the generally larger and more consistent effects found for carbon taxes relative to trading systems and the wide uncertainty bands around RPS, FiT and efficiency-mandate estimates.



*RPS/FiT bars show renewable-deployment effect size; net emissions effects are generally smaller (see Results).

Figure 1. Central-tendency emission or deployment effect size reported across the reviewed ex-post studies for each climate policy instrument family, with bars spanning the approximate range of reported estimates.

Renewable portfolio standards and feed-in tariffs show consistently positive effects on renewable generation capacity, with studies of US state RPS programs finding that states with binding, well-enforced standards added renewable capacity at rates 20-70% higher than comparable states without such standards over the evaluation period, though several studies note that much of this effect is concentrated in states that also had complementary tax incentives or interconnection reforms in place, complicating attribution to the RPS alone [19,20]. Feed-in tariffs in European Union countries show a similarly positive but strongly design-dependent relationship with renewable deployment, with studies estimating that the effectiveness of a given tariff level varies several-fold depending on contract duration, degression schedule and administrative simplicity [22]. Critically, the smaller subset of studies tracing RPS and FiT policies through to a net emissions outcome, accounting for the marginal generation source displaced and for interactions with an overlying emissions trading cap where one exists, generally find substantially smaller net emissions effects than the renewable-deployment effects alone would suggest [21,23].

Table 2. Carbon price level and reported emissions effect for selected national and subnational carbon pricing case studies.

Jurisdiction	Instrument	Approx. price level during study period	Reported emissions effect	Source
Sweden	Carbon tax	USD ~40 rising to >USD 130/tCO ₂	5-11% reduction in covered emissions over two decades	Andersson (2019) [10]
British Columbia, Canada	Revenue-neutral carbon tax	USD ~10 rising to ~USD 30/tCO ₂	5-15% reduction in transport fuel consumption; no detectable employment loss	Murray & Rivers (2015); Yamazaki (2017) [12,13]
United Kingdom	Carbon price floor / climate change levy	GBP ~15-18/tCO ₂ equivalent	Reductions concentrated in manufacturing energy intensity, smaller aggregate effect	Martin et al. (2014) [not separately tabulated]
European Union	EU Emissions Trading System (Phases I-III)	EUR 0-30/tCO ₂ , highly volatile	0-8% reduction in covered emissions; near-zero in low-price sub-periods	Bayer & Aklin (2020) [5]

Northeastern United States	Regional Greenhouse Gas Initiative (RGGI)	USD 2-13/tCO ₂	Comparable proportional reduction to EU ETS; partly confounded by gas-for-coal switching	Fell & Maniloff (2018) [14]
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Energy efficiency mandate evaluations show the largest and most consistent gap between projected and realized savings among the four instrument families reviewed. Ex-post evaluations of utility-run efficiency obligation programs, most prominently a large-scale randomized evaluation of a US weatherization assistance program, find realized energy savings on the order of one-half of engineering-model projections, a pattern echoed, though with smaller shortfalls, in evaluations of vehicle and appliance efficiency standards once rebound effects and imperfect compliance are accounted for [24,25]. Cross-country panel studies of aggregate decoupling find that a composite index of climate policy stringency is associated with slower emissions growth across large country panels even after controlling for GDP, energy prices and structural composition of the economy, though the estimated elasticity is modest, and studies caution that stringency indices themselves imperfectly capture enforcement intensity [7,26,27]. A recent global synthesis identifying 63 major, verified national emission reductions across 41 countries over two decades finds that the largest reductions are disproportionately associated with policy packages combining a pricing instrument with a complementary regulatory standard, rather than with any single instrument type, a finding broadly consistent with the policy-sequencing literature reviewed in this synthesis [1,17].

4. DISCUSSION

Read together, this literature supports three reasonably confident conclusions. First, carbon pricing instruments, and carbon taxes in particular, are the most consistently and rigorously demonstrated to produce a detectable, policy-attributable emissions reduction relative to a credible counterfactual, though the magnitude varies severalfold across jurisdictions and appears strongly related to price level and sectoral coverage rather than to the presence of a price alone [10,12]. Second, renewable-deployment instruments (RPS, FiT) show robust effects on the outcome they most directly target, renewable capacity and generation, but a materially weaker and less consistent effect once the analysis is extended to net emissions, underscoring that deployment effectiveness and emissions effectiveness are not interchangeable and should be evaluated separately [21,23]. Third, the evidence increasingly favors policy packages over single instruments as the more reliable route to large, verified emission reductions, consistent with theoretical arguments for complementary policy mixes addressing distinct market failures simultaneously [1,17].

An important caveat threading through nearly all of the reviewed literature is the difficulty of constructing a credible counterfactual for a national-scale policy that, almost by definition, has no untreated version of the same country to compare against. Synthetic control and comparable-jurisdiction comparison methods partially address this, but remain sensitive to the choice of comparison units and to unobserved confounding trends that happen to coincide with policy adoption, a concern raised explicitly in several of the more methodologically careful studies reviewed here [3,8]. The shift over the past decade from before-after and engineering-based assessments toward these quasi-experimental designs represents genuine methodological progress, but the discipline is young enough that a meaningful share of policies implemented before roughly 2010 have never been re-evaluated using the more rigorous methods now considered standard.

A second limitation concerns geographic and instrument-type coverage. The large majority of rigorously identified ex-post evaluations in our sample concern OECD economies, and within that group, a small number of well-studied cases (Sweden, British Columbia, the EU ETS, RGGI) account for a disproportionate share of the literature's cited effect sizes. Evidence on carbon pricing and regulatory instruments in middle-income and large emerging economies, where a growing share of global emissions now originates, remains comparatively thin, with China's national emissions trading system, launched in 2021, still too recent at the time of this review's search cutoff to have accumulated a substantial rigorous ex-post literature of its own, despite considerable ex-ante analysis of its design [16]. This asymmetry limits how confidently findings from the well-studied OECD cases can be generalized to the policy contexts where large future emission reductions will most need to occur.

Finally, several conceptual and measurement limitations cut across the literature as a whole. Many studies evaluate territorial production emissions only, leaving open the extent to which apparent domestic reductions reflect genuine abatement versus emissions-intensive production shifting to jurisdictions with weaker policy, a concern raised prominently in the carbon leakage literature but rarely quantified alongside the primary effectiveness estimate in the same study [30]. Publication and selection dynamics may also favor studies finding detectable effects over null results, though the presence of several prominent null or near-null findings for early-phase EU ETS periods in our sample suggests this bias is not overwhelming. Post-treatment evaluation windows for more recent instruments, including most feed-in tariff reforms and second-generation carbon pricing schemes introduced after 2015, remain short relative to the multi-decade horizons over which national emissions trajectories are typically assessed, meaning current effect-size estimates for these newer policies should be treated as provisional

pending longer follow-up.

5. CONCLUSION

Synthesizing 118 ex-post evaluations and cross-country panel studies, this review finds that carbon pricing, particularly well-designed carbon taxes operating at a meaningful and stable price, produces the most consistently detected, policy-attributable reduction in national or sectoral emissions among the instruments reviewed, with median reported effects in the low single digits to low double digits of covered-sector emissions depending on price level and coverage. Renewable portfolio standards and feed-in tariffs reliably increase renewable deployment but show weaker and more heterogeneous net emissions effects once displacement and leakage are considered, while energy efficiency mandates show a persistent and only partially explained gap between projected and realized savings. The strongest evidence for large, sustained national emission reductions comes not from any single instrument but from policy packages that combine pricing with complementary regulatory standards. The evidence base remains geographically concentrated in a small number of OECD case studies, methodologically still maturing in its ability to construct credible counterfactuals for national-scale policy, and too short in post-treatment horizon for many recently adopted instruments to support confident long-run effectiveness estimates; closing these gaps, particularly by extending rigorous ex-post evaluation to large emerging-economy policies, should be a priority for the field.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

S.M. conceived the review, designed the literature search and synthesis approach, and led the writing of the manuscript. T.N. conducted the literature search and screening, extracted effect-size data from the reviewed studies, and prepared Table 1 and Table 2. D.T. contributed the cross-country panel and decomposition-study synthesis and prepared Figure 1. All authors contributed to writing and approved the final

manuscript.

Ethics Statement

This review is based entirely on previously published, peer-reviewed literature and publicly available policy documentation, and did not involve human participants, animal subjects, or new primary data collection requiring ethical review.

Data Availability

The full list of studies screened and included in this review, along with the extracted effect-size and study-characteristic data underlying Table 1 and Table 2, is available from the corresponding author on reasonable request.

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