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Combining Policies for Renewable Energy

Is the Whole Less than the Sum of Its Parts?

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Abstract

Since the energy crisis in the 1970s and later the growing concern for climate change in the 1990s, policymakers at all levels of government and around the world have been enthusiastically supporting a wide range of incentive mechanisms for electricity from renewable energy sources (RES-E). Motivations range from energy security to environmental preservation to green jobs and innovation, and measures comprise an array of subsidies to mandates to emissions trading. But do these policies work together or at cross-purposes? To evaluate RES-E policies, one must understand how specific policy mechanisms interact with each other and under what conditions multiple policy levers are necessary. In this article, we review the recent environmental economics literature on the effectiveness of RES-E policies and the interactions between them, with a focus on the increasing use of tradable quotas for both emissions reduction and RES-E expansion.

Key Words: environment, technology, externality, policy, climate change, renewable energy

JEL Classification Numbers: Q21, Q28, Q48, O38

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Carolyn Fischer and Louis Preonas*

1. Introduction

Since the energy crisis in the 1970s and later the growing concern for climate change in the 1990s, policymakers at all levels of government and around the world have been enthusiastically supporting a wide range of incentive mechanisms for electricity from renewable energy sources (RES-E). They express a variety of motivations for promoting RES-E, from energy security to environmental preservation to green jobs and innovation. They also bring a variety of policy measures to the table, from an array of subsidies to mandates to emissions trading.

While there may be broad political consensus on the popularity of renewable energy and scientific consensus on the important role it will need to play in a carbon-constrained world, less attention has been paid to how well the supporting policies work together—or whether they may work at cross-purposes. In particular, the shift toward market-based tradable quota systems for expanding RES-E market shares and reducing emissions of greenhouse gases (GHGs) and other air pollutants has important implications for the roles of additional policy provisions. With tradable quotas, certain policy outcomes (like total emissions or shares of renewable generation) tend to be decoupled from additional efforts, while the incentive levels generated by tradable quotas are linked to all other policy measures. As a result, the net effect of those overlapping measures is much less transparent.

In this article, we review the recent environmental economics literature on the effectiveness of RES-E policies and the interactions between them. We begin with a survey of the variety of policies used in practice and the rationales behind them. We consider studies comparing single types of policies and then explore studies of overlapping policies, many of which focus on the role of cap-and-trade programs. A simple model of supplies and demand in the electricity sector helps elucidate many of these findings and illustrate the effects of a variety

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of different policy combinations. In addition to understanding how specific policy mechanisms interact, one must also consider the situations in which multiple policy levers are necessary. We survey the literature on the role of technology market failures and other externalities related to electricity generation. We conclude with lessons learned and directions for future research.

2. Policies and Rationales for Promoting Generation from Renewable Sources

2.1 Common Rationales

An overwhelming scientific consensus now supports the reduction of greenhouse gas emissions as a necessary measure to combat climate change. According to the Energy Information Agency (EIA), 40 percent of carbon dioxide (CO_2) emissions in the United States come from fossil fuel combustion in the electricity sector.[1] The 2007 Intergovernmental Panel on Climate Change (IPCC) report agrees that any climate change mitigation plan must rely on limiting the production of fossil fuel electricity.[2] The IPCC's forecasts predict that such a shift away from fossil fuels will likely lead to a corresponding shift towards renewable sources.[3] At the 2004 International Conference for Renewable Energies,[4] delegates resolved to increase the global share of RES-E in order to reduce the threat of climate change (Renewables 2004). The conference report cites additional benefits of increased RES-E usage, including "enhanced security of energy supply," potential economic stimulation and job creation, and "protection of the environment at all levels" (5). The report urges policymakers to pursue renewable energy adoption "not as an objective per se," but rather as a means of realizing the above benefits, along with the primary goal of fossil fuel reduction (5).

The European Union 20/20/20 Directive represents the world's most visible, farthest-reaching agreement to promote renewable energy (EU 2009a). Although the multinational directive requires member states to enact their own national RES-E policies (toward the targeted

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[1] Calculated using the Annual Energy Outlook 2009 reference case, the percentage of total emissions attributed to electricity generation from 2007–2009 (EIA 2009). Projections available at http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_18.xls.

[2] See Sections B and C of IPCC 2007.

[3] IPCC (2007). Also see Figure 3.23 on p. 203 of Fisher et al. (2007). Other factors enabling a reduction in fossil fuel energy include improved energy-efficiency measures and carbon capture and storage (CCS).

[4] June 2004 in Bonn, Germany. The conference, comprising 154 participating nations, was sponsored by the United Nations as a follow-up to the 2002 World Summit on Sustainable Development.

20 percent increase in RES-E share by the year 2020), the European Parliament provides several rationales for renewable energy support. Specifically, it justifies the RES-E target as: "promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, especially in rural and isolated areas…, [increasing] export prospects, social cohesion and employment opportunities…[for small] independent energy producers" (EU 2009b, 16). Nevertheless, the RES-E directive remains primarily an "important part of the package of measures needed to reduce greenhouse gas emissions and comply with the Kyoto Protocol" (EU 2009b, 16). Recent legislation in both chambers of the U.S. Congress has sought to create a similar "package" of federal policies to reduce emissions and stimulate renewables production. The House and Senate bills share the same goal: "to create clean energy jobs, achieve energy independence, reduce global warming pollution and transition to a clean energy economy,"[5] points underlined further in President Obama's recent 2010 State of the Union Address. Even the titles of these two bills ("American Clean Energy and Security Act," henceforth ACESA, and "Clean Energy Jobs and American Power Act," respectively) underline the same major themes of the EU Directive—emissions reduction, energy security, and employment opportunities. U.S. state renewables policies often contain additional justifications for RES-E support, generally reflecting local/regional priorities. Hence, renewable energy legislation aims at increasing the rural tax base in Texas; at conserving local water resources by reducing water-related electricity demand in California; and at encouraging private investment and improved air quality in Michigan.[6]

In a rare reality check of what actually motivates RES-E policies, Lyon and Yin (forthcoming) compare these stated justifications with the political and economic factors that drive U.S. states to adopt renewable portfolio standards (RPS). They find that air quality and employment benefits, while frequently cited in renewables legislation, do not serve as significant predictors of RPS policies. In fact, states with high unemployment are actually *slower* to enact RPS policies. The authors determine that the best predictors of state-level RPS include the presence of well-organized RES-E interests, a relatively low reliance on natural gas, and a Democratic state legislature. They conclude that the federal legislative "gridlock" has

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[5] See US Congress (2009a and 2009b). Both H.R. 2454 and S. 1733 begin with nearly identical language. H.R. 2454 is quoted above.

[6] See, respectively, State Energy Conservation Office (2009), California State Legislature (2006), and State of Michigan (2008). Assembly Bill No. 1969 was the first in a series of bills contributing to the current feed-in tariff system in California. See California Public Utilities Commission (2010).

contributed to decentralized environmental policymaking, creating challenges in policy coordination and integration between states.

As we see in the next section, much of the RES-E policy innovation has occurred at the level of the states in the United States and the member states in the European Union. However, as emissions policies develop at the regional and federal levels, in addition to federal RES-E goals, it becomes ever more important to understand how overlapping policies and jurisdictions interact.

2.2 Common Policies

Support for RES-E generation can come from policies designed to directly increase RES-E production (i.e. subsidies for wind power), as well as policies aimed at reducing carbon emissions, conventional air pollutants, and fossil energy dependency. The latter group of policies indirectly promotes RES-E production as a substitute for fossil fuel energy production.

A significant and growing category of these policies are cap-and-trade programs, which set a ceiling on the emissions of covered entities, issue allowances, and allow trading to generate a market price for emissions. The seminal example of such a policy is the U.S. Acid Rain Program, which capped the sulfur dioxide emissions of power plants. Trading has since been expanded to other pollutants, including nitrogen oxide and proposed programs for mercury and CO_2. The Regional Greenhouse Gas Initiative (RGGI) is active across ten U.S. states. The European Union Emissions Trading System (EU ETS) is the largest existing GHG trading program, governing emissions across 30 European nations,[7] and covering large emitters, of which 72 percent are combustion installations. Elsewhere, the New Zealand Emissions Trading Scheme plans to cover fossil fuel emissions across all sectors, as would proposed programs in the United States and Australia.

Emissions pricing can also be implemented through tax policy. The Scandinavian countries and the Netherlands have used CO_2 taxes since 1990, and the Canadian province of British Columbia recently enacted its own. Other regulations can penalize higher emitting sources; for example, four U.S. states have enacted Emissions Performance Standards regulating the emissions intensity of new fossil fuel power plants. While California's policy acts as a de

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[7] All 27 EU Member States, plus Norway, Iceland, and Liechtenstein (EUbusiness 2007).

facto ban on new coal generation, Washington's standard allows fossil fuel suppliers to purchase greenhouse gas reduction credits from other polluters.[8]

Many energy tax policies also discourage fossil energy use, although they may not discriminate according to emissions intensity; some European countries have energy taxes from which renewable sources are exempt, for example. Another common practice is to pay for subsidies to renewables by taxing conventional electricity suppliers.

Policies that directly promote RES-E production use market-based incentives and quantity-based mandates to increase the share of electricity from renewable sources. Renewable portfolio standards require a certain percentage of total electricity production to come from RES-E. To meet the RPS quota, non-renewable energy producers must purchase renewable energy certificates (also known as tradable green certificates, henceforth TGCs; certificates of origin) from RES-E producers. Thirty-five U.S. states (plus the District of Columbia) currently operate a diverse array of RPS policies, with distinct quotas, incentive structures, certificate markets, and enforcement mechanisms. Some European countries, including Sweden, Belgium, and the United Kingdom, have enacted green certificate schemes to reach their respective 2020 RES-E targets.

The majority of European countries have chosen to adopt feed-in tariffs (FiTs) as a primary RES-E support policy. Like RPS, FiTs combine market-based mechanisms with mandates: renewable energy installations receive long-term contracts that guarantee access to the electricity grid at an elevated price. These contracts generally differentiate among renewable sources, offering higher incentives for more expensive technologies (e.g. solar photovoltaic) and for national energy priorities (e.g. onshore wind power in Denmark). Most programs only allow smaller RES-E installations to qualify for FiT contracts, although each country's policy is unique. Outside of Europe, FiTs have been enacted in Australia, Canada, and a few U.S. states, as well as in many developing nations.

Production subsidies represent another common RES-E support mechanism. The United States offers several federal and state subsidies, such as a corporate tax credit per kilowatt-hour of electricity produced from select renewable sources. Similar production subsidies exist in Europe (often referred to as "tenders"), although most have been superseded by either green certificates or FiTs. Both Europe and the United States offer various RES-E investment

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[8] See The California Energy Commissions (2008) and Stoel Rives (2007).

subsidies, which help to incentivize new installations and capital improvement. These subsidies also take the form of tax credits, as well as deductions, exemptions, and government grants.

Finally, R&D support represents an important component of most RES-E policy portfolios. The United States, Canada, and European nations offer a variety of grants, loans, and subsidies for RES-E research projects to help correct technological spillovers and encourage future cost reductions. Table 1 compares the RES-E policy portfolios of select countries.[9]

Table 1: Current Policies Promoting Renewable Energy in the Electricity Sector

Country	Emissions cap-and-trade system	Carbon tax	Non-renewable generation tax	Emissions performance standard	RPS/ TGCs	Feed-in tariffs	RES production subsidies	Investment/ R&D incentives
Canada		✓[10]	✓		✓	✓	✓	✓
Denmark	✓	✓	✓			✓		✓
Germany	✓					✓		✓
Japan	✓				✓			✓
Netherlands	✓		✓		✓	✓[11]		✓
New Zealand	✓							✓
Norway	✓	✓	✓			✓		✓
Spain	✓					✓		✓
UK	✓		✓		✓	✓[12]		✓
U.S. Federal	proposed				proposed		✓	✓
U.S. States	✓			✓	✓	✓	✓	✓

While we focus on this suite of market-based incentives, we acknowledge that a multitude of other policy interventions play important roles in renewable energy promotion, such as those related to regulatory reform, grid enhancement, net metering, contractor licensing, and the like (see, e.g., Brown and Busche 2008). In addition, in a number of regions, green-energy purchasing programs allow electricity consumers (or state governments) to purchase RES-E voluntarily, typically at a price premium.[13] Furthermore, most countries and states have energy-

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[9] Table 1 was primarily generated using four databases: DSIRE (2010), IEA (2009a, 2009b, 2009c). Additional references included REN21 (2009) and Wartmann et al. (2009).

[10] In British Columbia.

[11] The Dutch scheme is considered a "modified feed-in tariff" by the International Energy Agency, often acting as more of a premium. See http://www.iea.org/textbase/pm/?mode=re&id=4031&action=detail.

[12] The United Kingdom plans to implement its feed-in tariffs by mid 2010, but Scarpa and Willis (2009) note that some utilities have voluntarily offered the feed-in tariff rates as early as May 2009.

[13] See Bird and Lokey (2007, 5–7) for examples of voluntary green power programs in the United States.

efficiency programs that influence electricity demand patterns, and some even allow "white certificates" for energy-efficiency improvements to be used in compliance with renewable energy obligations. We do not address these policies specifically but hope that insights from this review of overlapping policies can shed light on interactions with a broad range of other interventions.

3. Comparing Policies

3.1 Theoretical Insights

Several studies compare the cost-effectiveness of individual renewable energy policies for achieving environmental and renewable energy goals. When the primary goal is reducing emissions, single RES-E policies (whether price- or quantity-based) are always less cost-effective than a cap-and-trade or carbon pricing policy (Palmer and Burtraw 2005; Fischer and Newell 2008).

When the primary goal is expanding renewable energy in general, studies indicate that renewable quotas (TGCs or RPS) are relatively less expensive than price-based policies (e.g. technology-specific FiTs). FiTs typically offer higher subsidy rates for more costly technologies, while TGCs encourage competition amongst RES-E technologies. Böhringer and Rosendahl (forthcoming) explain that FiTs can only achieve cost parity with TGCs by offering uniform rates across all RES-E technologies (thereby eliminating special provisions for solar and other expensive technologies).

On the other hand, Unger and Ahlgren (2005) note that most TGC markets enable cheaper renewables (e.g. wind) to dominate expensive ones (e.g. solar).[14] Thus, while TGCs may be favored on a short-term cost perspective, a quota system alone is likely to be insufficient for ensuring long-term innovation and technological development. Abrell and Weigt (2008) point to higher learning rates for less developed (i.e. more expensive) renewables technologies as a

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[14] Langniss and Wiser (2003) identified this as a practical reality of the Texas RPS. Although the RPS ostensibly covers all renewable energy sources, wind energy is by far the most cost-effective. Therefore, "solar generation as well as traditional forms of biomass energy are too costly in Texas to compete with wind power at this time" (530). Some states actively try to correct this feature of their RPS policies, by either providing additional subsidies for solar generation or counting each unit of solar energy at a higher rate (i.e., 1 unit of solar energy produced would trade on the market for the equivalent of 3 units of any other renewable technology).

possible justification for choosing differentiated FiTs over the cheaper alternative. Indeed, the empirical literature seems to find greater policy effectiveness among FiTs.

3.2 Empirical Evidence of the Relative Effectiveness of Individual Policies

A limited number of empirical studies exist on the effectiveness of RES-E policies for promoting renewable generation. However, it is often difficult to disentangle the effects of different policy types.

The 2008 IEA report *Deploying Renewables: Principles for Effective Policies* investigates the effectiveness of global renewables policies by comparing actual RES-E deployment with national policy types and remuneration levels (IEA 2008). The study derives a "quantitative policy effectiveness indicator" for 35 different countries, dividing each country's average increase in renewable energy by its remaining RES-E potential realizable by 2020.[15] It finds that for onshore wind energy, the most effective policies tend to comprise FiTs with relatively modest remuneration levels. In fact, "four of the five countries with the highest levels of policy effectiveness in deploying wind power from 2000 to 2005 as well as in 2004/5, namely Germany, Spain, Denmark, and Portugal, primarily used feed-in tariff systems to encourage that deployment" (IEA 2008, 105). Italy, Belgium, and the United Kingdom have all implemented TGC programs with high remuneration levels, yet "none of these countries scored high levels of deployment effectiveness." Thus, it concludes that "beyond a minimum remuneration level of about USD 0.07 per kilowatt hour (kWh), higher remuneration levels do not necessarily correlate with greater policy effectiveness" (IEA 2008, 106). This TGC policy-effectiveness gap likely stems from intrinsic TGC design problems, as well as non-economic barriers and investors' concerns about risk.

The IEA report also comments on the unique mix of federal and state wind policies in the United States. While it finds the combination of federal production tax credits (PTCs) and state level policies (both incentives and quota systems) contributed to significant wind power growth in 2005, "neither federal nor state support has been sufficient in isolation" (IEA 2008, 108). The study argues that a lack of stability in the federal PTCs and widely varying state policies have

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[15] The study looks at three groups of countries from 2000–2005: EU members of the Organisation for Economic Co-operation and Development (OECD), non-EU members of OECD, and BRICS (Brazil, Russia, India, China, and South Africa). It measures the policy effectiveness for different renewable technologies averaged over 2000–2005, as well as for just 2004–2005.

contributed to an underutilization of wind resource potential. It also cites “time-consuming siting and permitting procedures,” as well as insufficient time horizons in state TGC markets (IEA 2008, 108).

Mulder (2008) expands the evaluation criteria of the IEA to include three separate measures of wind policy effectiveness: reaching stated wind targets at relatively low cost, realizing full potential for wind power, and encouraging relatively fast growth in wind investment. The author likewise singles out Denmark, Spain, and Germany as having the most successful priced-based wind policies of the original 15-member European Union (evaluated from 1985–2005). Mulder emphasizes how these three nations combined FiTs with capital investment subsidies and production, applying the policies early and consistently. Consistent with the EIA finding, Mulder concludes that remuneration level alone is not sufficient to ensure widespread wind power adoption, as the FiT has never been very high in Germany or Spain.[16] Buen (2006) offers further endorsement of Danish wind policy effectiveness, crediting the long-term predictability of its supply- and demand-side measures (e.g., investment subsidies and FiTs).

Fewer empirical studies evaluate the effectiveness of quantity-based RES-E policies (i.e., RPS and other quota systems). Such policies tend to be more recently enacted and non-technology specific, both factors that reduce the likely availability of robust, relevant datasets suitable for statistical analysis.[17] In light of these challenges, Butler and Neuhoff (2008) find that Germany’s feed-in tariff scheme increases wind energy deployment with a lower resource-adjusted cost to society than the quantity-based UK Renewables Obligation.

Of course, specific design issues can matter as well for policy effectiveness, particularly predictability as well as stringency; for example, Langniss and Wiser (2003) point to contracting terms in the relatively successful Texas RPS that discourage speculative bidding and help ensure long-term predictability in purchase obligations. In their review of renewables policies across all 50 states, Brown and Busche (2008) find significant positive correlation between the existence of state RPS policies and RES-E production, especially wind energy. (However, one may still

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[16] Söderholm and Klaassen (2007) acknowledge that high FiTs “have a negative effect on cost reductions as they induce wind generators to choose high-cost sites and provide fewer incentives for cost cuts” (163). Thus, they underline the importance of coupling FiTs with R&D incentives.

[17] Del Río and Gual (2007) highlight the difficulties of establishing a causal link between a particular RES-E support policy and its empirical performance.

wonder if states with higher wind energy potential are more likely to adopt an RPS). They also review a suite of best practices, which include a set of market transformation activities (such as siting facilitation and grid preparation) as well as a set of overlapping incentive policies, which are the subject of our review.

While the primary objective of RES-E policies might be to directly increase renewables production, another goal is to harness the learning potential of new technologies. Klaassen et al. (2005) focus specifically on the empirical effects of public R&D support in Denmark, Germany, and the United Kingdom. The study looks at wind energy R&D through the year 2000, comparing Europe’s largest exporter of wind turbines (Denmark), its biggest wind energy producer (Germany), and a prominent underutilizer of wind resources (United Kingdom). Using a two-factor learning curve that incorporates wind investment costs, cumulative capacity, and public R&D expenditures, the authors find similar R&D learning parameters across all three countries. However, only Denmark closely coordinated R&D support with investment subsidies (to promote both innovation *and* diffusion), enabling the development of a reliable small-turbine wind industry. Söderholm and Klaassen (2007) reach a similar conclusion in favor of coupling R&D subsidies with price-based renewables support.

4. The Incidence of Overlapping Policies

A number of studies investigate the effects of renewable energy support policies, many of which focus specifically on their (potential) interactions with other policy measures. While most of the “policy interaction” literature looks at the RES-E policies of EU member states in relation with the multinational EU ETS, a few papers examine the potential overlaps between federal and state policies in the United States.[18] This section summarizes the findings of the “policy interaction” literature as it relates to RES-E policies. Next, it presents a unifying theoretical framework to illustrate these results, organized by policy combinations, and to deepen understanding of how multiple kinds of policies interact. It also compares these findings with existing theoretical analysis of the isolated effects of single RES-E policies to underline the complex nature of policy overlaps.[19]

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[18] See Morris (2009), McGuiness and Ellerman (2008), and Paltsev et al. (2009). All three reach similar conclusions regarding the effects of the proposed federal cap-and-trade legislation on U.S. state RPS policies.

[19] Palmer and Burtraw (2005), Finon and Perez (2007), and Fischer (2009) all focus on the effects of single RES-E policies.

4.1 Studies of the Countervailing Effects of Overlapping Policies

There exists a strong consensus that isolated policies designed to reduce CO_2 emissions will indirectly encourage RES-E deployment, and isolated RES-E support policies will indirectly contribute to CO_2 emissions reduction.[20] However, several studies question whether renewables policies actually contribute to CO_2 reduction goals when overlapping with an emissions trading system (ETS, also known as cap and trade). Both Morris (2009) and Pethig and Wittlich (2009) point out that under a binding, efficient emissions trading scheme, zero incremental emissions reduction will be realized from a supplementary renewables quota system.[21] Fossil fuel emitters collectively emit the maximum amount allowed by the CO_2 cap, regardless of RES-E incentives or quotas.[22]

As a consequence, nearly all theoretical studies on policy interactions assert that supplementary RES-E support policies increase the compliance costs already incurred under an emissions trading regime. Morris (2009) calculates that in the presence of a U.S. federal cap-and-trade system, overlapping state RPS policies substantially increase costs to society. She argues that by picking the winning technologies, RPS deprives firms of the flexibility necessary to pursue the lowest-cost methods of emissions reduction. Other studies on U.S. state RPS policies reflect similar skepticism that renewables support could efficiently coexist with cap-and-trade (McGuinness and Ellerman 2008; Paltsev et al. 2009), and several studies also find that TGC quotas substantially increase the social costs of the EU ETS (Böhringer and Rosendahl 2010; Abrell and Weigt 2008;Unger and Ahlgren 2005).

Böhringer and Rosendahl (2009 and forthcoming) find that a binding green quota system reduces the profitability of fossil fuels, thereby reducing the aggregate output of fossil fuel producers. In the presence of a binding ETS quota, a second-order effect of reduced fossil fuel profitability is the reduction of the emissions permit price. The authors argue that this has an asymmetric effect favoring the dirtiest fossil fuel technologies. Thus, while overall fossil fuel production falls as a result of combined ETS and TGC quotas, the dirtiest producers actually

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[20] See De Jonghe et al. (2009).

[21] See also Sijm (2005).

[22] One important caveat is that both the EU ETS and the proposed U.S. cap-and-trade system divide total emissions into covered and non-covered sectors. An RES-E policy that provided incentives for non-covered fossil fuel emitters to convert to renewables would encourage further emissions reduction. (Yet technically, this would no longer qualify as a policy overlap with ETS.) This paper is concerned with the electricity sector, which is covered by the EU ETS.

increase output to keep total CO_2 emissions at the binding ETS ceiling. Böhringer and Rosendahl (2009) use a partial equilibrium model of the German electricity sector to bolster their theoretical intuition. The numerical analysis predicts that under a binding ETS policy, lignite coal production[23] steadily increases as the RES-E percentage requirement increases. They warn that this result could undermine justification for renewable support, as “the excess cost of imposing a green quota can be quite substantial.”

A majority of the literature also agrees that renewable support policies contribute to increased share of RES-E deployment, with or without an overlapping policy for CO_2 emissions reduction. However, in one of the earliest papers on the interactions between TGCs and CO_2 emission permit schemes, Amundsen and Mortensen (2003) show that an increase in the percentage requirement for TGCs could reduce the total capacity for renewable energy. Through a simple static equilibrium model of the Danish electricity market, the authors demonstrate that an increase in TGC percentage could decrease total energy consumption, causing a decrease in the total long-run capacity of green electricity. They also find that both harsher CO_2 emissions constraints (under autarky) and a higher import wholesale price for electricity (under external trade) will lead to reduced long-run capacity for renewable electricity.

4.2 A Unifying Theoretical Framework

Fischer (2009) employs a simple yet general model of energy supplies and demand to demonstrate how the relative slopes of these curves determine the price incidence of portfolio standards, not unlike the approach of Böhringer and Rosendahl (forthcoming), who focus on the combination of RPS with cap-and-trade programs. This model can be easily expanded to explore the incidence of multiple policies for renewable generation in a broader variety of combinations.

Consider four different types of generation: baseload technologies x, natural gas g, other fossil fuels f, and renewable energy r. Baseload generation is characterized as fixed and fully utilized generation capacity, such as nuclear energy and (often) large-scale hydropower; notably, these generation sources are also typically exempt from renewable mandates and from emissions regulation, being non-emitting of air pollutants and GHGs. Renewable energy sources include wind, solar, biomass, geothermal, and so on; new, small-scale hydropower may also be included. The fossil fuel sources other than natural gas are primarily coal and occasionally oil. Natural gas-

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[23] Böhringer and Rosendahl (2009) label lignite (soft coal) as the “dirtiest technology,” based on its high CO_2 emissions per kWh electricity produced.

fired generation has an emissions rate of μ_g, while that from other fossil fuels has a higher emissions rate of $\mu_f > \mu_g$.

Whereas the baseload supply curves are fixed and perfectly inelastic (i.e., $dx = 0$), the non-baseload types of generation are assumed to have inverse supply curves [$S_g(g)$, $S_f(f)$, and $S_r(r)$ (where $S_i' \geq 0$ for all i)] that are weakly upward sloping. One can think of these supply curves as marginal cost curves and assume that these technologies receive competitively determined prices, so that their marginal costs are equal to the price received. More generally, the supply curves merely represent the price demanded by producers for an additional unit of generation at the amount supplied. Given that many electricity markets remain regulated, this latter characterization may be more appealing.

Policies to reduce emissions and promote renewables cause the prices received by suppliers to diverge according to the energy source. Let P be the retail (consumer) price of electricity. Let consumer (direct) demand be a downward-sloping function of this price $D(P)$, where $D' < 0$.[24]

As Fischer and Newell (2008) show, all the major market-based policies for renewable energy and climate mitigation, including RPS and tradable performance standards, can be expressed as a combination of taxes and subsidies. We consider three: a price on carbon τ, a tax on fossil energy sources ϕ, and a production subsidy for renewables σ.

The market-clearing conditions are simply that the quantities supplied equal the quantities demanded at the prevailing market prices:

$$\begin{aligned} S_g(g) &= P - \phi - \tau\mu_g \\ S_f(f) &= P - \phi - \tau\mu_f \\ S_r(r) &= P + \sigma \\ D(P) &= g + f + r + x \end{aligned} \tag{1}$$

Next, one can evaluate the effects of different renewable energy policies on consumer prices. Totally differentiating the market-clearing equations, we derive a system of equations governing the responses to the different policy options:

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[24] Fischer (2009) used indirect demand, so our equations will have the inverse of those slopes.

$$dP = \left(dg + df + dr\right) / D' , \tag{2}$$

$$dg = \left(dP - d\phi - \mu_g d\tau\right) / S_g' , \tag{3}$$

$$df = \left(dP - d\phi - \mu_f d\tau\right) / S_f' , \tag{4}$$

$$dr = \left(dP + d\sigma\right) / S_r' , \tag{5}$$

Substituting (3)–(5) into (2) and solving for dP, we derive the electricity price impacts as a function of the various policy changes. The resulting price changes can be expressed as a weighted average of the net tax changes for fossil and renewable energy sources:

$$dP = \omega^F \left(d\phi + \bar{\mu} d\tau\right) - \omega^R d\sigma , \tag{6}$$

where $\bar{\mu} = \left(S_g' \mu_f + S_f' \mu_g\right) / \left(S_g' + S_f'\right)$ is an average emissions rate for fossil-fueled generation, in which the slopes of the supply curves weight the individual emissions rates. Let $\chi = \left(S_r' S_g' + S_r' S_f' + S_g' S_f' - S_r' S_g' S_f' D'\right)$. Then the weights in (6) are $\omega^F = S_r' \left(S_g' + S_f'\right) / \chi$ and $\omega^R = S_g' S_f' / \chi$. Note that $0 < \omega^F < 1, \quad 0 < \omega^R < 1$, and $\omega^F + \omega^R < 1$.

From (6), we see that the retail price of electricity is increasing in the fossil-fueled output tax and the emissions tax, and it is decreasing as renewable energy increases (which lowers necessary fossil-fueled supply). The net effect of changes in multiple policy variables on the price of electricity depends on the relative slopes of all of the supply curves, as well as that of electricity demand. The price influence of policy changes targeting fossil fuels increases with steeper renewable energy supply and flatter fossil energy supply because the flexibility to switch toward renewables is relatively more limited in these cases. The opposite is true for the price influence of renewable sector impacts: they are stronger when the renewable energy supply curve is flatter or the fossil energy supply curves are steeper (Fischer 2009).

Substituting (6) back into (3)–(5), we solve for the impacts on electricity supplies:

$$df = \left(-(1-\omega^F) d\phi - \left(\mu_f - \omega^F \bar{\mu}\right) d\tau - \omega^R d\sigma\right) / S_f' \tag{7}$$

$$dg = \left(-(1-\omega^F) d\phi - \left(\mu_g - \omega^F \bar{\mu}\right) d\tau - \omega^R d\sigma\right) / S_g' . \tag{8}$$

$$dr = \left(\omega^F \left(d\phi + \bar{\mu} d\tau\right) + (1-\omega^R) d\sigma\right) / S_r' . \tag{9}$$

This last equation reveals that second-period renewable output is increasing in all the policy levers. The preceding expressions reveal that both fossil-fueled generation sources decline as the fossil output tax increases and as renewable generation expands. The effect of the emissions tax is twofold: a direct increase in costs that reduces generation in proportion to each source's emissions rate and an indirect effect that increases generation as a result of price increases due to cost increases in the other fossil source. Since coal-fired generation is relatively inelastically supplied compared to natural gas, and since it has a higher emissions intensity, we know that the net effect of a carbon price increase is to penalize coal: $\mu_f > \omega^F \overline{\mu}$. However, for natural gas, which emits CO_2 at about half the intensity of coal, the net effect of a carbon price increase can be positive or negative; since $\omega^F < 1$, it is not clear whether $\mu_g < \omega^F \overline{\mu}$.

At this point, it is useful to distinguish between fixed-price policies and endogenous price policies, as in Fischer and Newell (2008). **Fixed-price policies** are those in which the price variable is chosen directly, as with taxes on emissions, fossil energy taxes, tax credits and subsidies for renewable generation. The cumulative effects of these policies are largely additive, in that a change in one price does not affect the prevailing price of the other policies.[25]

Endogenous price policies are those in which markets set the effective taxes or subsidies through the values placed on tradable credits; examples of such policies include renewable portfolio standards, emissions performance standards, or an emissions cap for the electricity sector. The value of those credits reflects the shadow cost of complying with the regulatory constraint. When markets respond to changes in one policy, the cost of meeting other regulatory obligations changes as well. For example, by expanding renewable generation, other policies can make it cheaper to meet an RPS or an emissions cap.

4.2.1 Overlapping with an Emissions Cap

What are the effects of overlapping other policies with an emissions cap? We consider the effects of a carbon tax, fossil energy tax, and renewable subsidy in interaction with an endogenous emissions price.

Let the change in total emissions pricing be $d\tau = dp_m + dt_m$, where p_m is the price of emissions allowances and t_m is an emissions tax.

When a cap fixes emissions in the electricity sector, then $\mu_g dg + \mu_f df = 0$. Substituting the expressions for *dg* and *df* and solving for p_m,[26] we get

$$dp_m = -dt_m - \mathrm{T}\left((1-\omega^F)d\phi + \omega^R d\sigma\right) \tag{10}$$

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[25] See also De Jonghe et al. (2009) for a discussion of the additive effects of fixed-price policies.

[26] We use Mathematica to solve these systems algebraically.

where $\mathrm{T} = (S_g{}'\mu_f + S_f{}'\mu_g) / \left(S_g{}'\mu_f (\mu_f - \omega^F \bar{\mu}) + S_f{}'\mu_g (\mu_g - \omega^F \bar{\mu}) \right) > 0$.

Thus, the price of emissions allowances declines one-for-one with the imposition of an emissions tax. Essentially, the cap determines the equilibrium marginal abatement cost; if the emissions tax is lower than that marginal cost of compliance, the allowance price will make up the difference.

The allowance price also changes in proportion to increases in a fossil tax or renewable subsidy; however, the magnitude of the effect depends on the relative supply slopes and emissions intensities of the fossil-fueled sources.

Substituting and simplifying, we can express dg and df in terms of $d\tau$, and we find that natural gas-fired generation increases with the net change in the emissions price from overlapping policies, while fossil generation decreases:

$$dg = \frac{\mu_f (\mu_f - \mu_g)}{S_g \mu_f + S_f \mu_g} d\tau; \quad df = -\frac{\mu_g (\mu_f - \mu_g)}{S_g \mu_f + S_f \mu_g} d\tau \tag{11}$$

Thus, policies that raise the emissions price discourage coal-fired generation, while policies that lower the emissions price allow coal-fired generation to displace gas-fired electricity. Importantly, *when emissions are capped, none of the overlapping policies can simultaneously disadvantage both kinds of fossil generation*. In fact, both the fossil energy tax and renewables subsidies (and thereby implicitly an RPS or FiT), by decreasing the allowance price, advantage the dirtier generation sources. Since the cap fixes emissions, these additional policies merely allow shifting of emissions and production among the emitting sources. This result is a reformulation of the analysis by Böhringer and Rosendahl (forthcoming), who show that a renewable portfolio standard overlapping an emissions cap benefits the dirtiest emitters.

In total, the change in fossil generation follows the change in the emissions price that results from overlapping policies:

$$dg + df = \frac{(\mu_f - \mu_g)^2}{S_g \mu_f + S_f \mu_g} d\tau \tag{12}$$

Therefore, since renewable subsidies and additional taxes on fossil energy (including from the imposition of an RPS) decrease the emissions price, they also result in lower fossil generation. Since the dirtier coal-fired generation benefits from the price decrease, to maintain the same level of emissions, it must be that natural gas generation is decreased more than coal-fired generation is increased.

A carbon tax has no effect on either generation source, since the net emissions price does not change. Also note that if both fossil energy sources had the same emissions intensity, overlapping policies would have no effect at all on fossil generation, as they would be completely offset by the emissions allowance price change.

There are some exceptions to these results. One is if the carbon tax is raised to a level above the allowance price, so that the cap no longer becomes binding. Then, it behaves as a fixed-price policy (see De Jonghe et al. 2009, described later).

Another exception is when tradable emissions permits are implemented in a multi-sector (or international) context. In this case, the electricity sector in a single jurisdiction may not be the main driver of prices, so the emerging carbon price can be fixed on markets external to the electricity market. However, since the electricity sector represents a disproportionate share of emissions and mitigation opportunities, even in a comprehensive cap-and-trade system, significant renewable energy policies will affect the carbon market equilibrium.

Renewables do generally benefit from the overlapping policies but to a lesser extent than with only fixed-price policies, due to the corresponding fall in the emissions price. The exceptions are the carbon tax, which has no additional effect, and the fossil energy tax in the special case where those sources had identical emissions intensity.

4.2.2 Overlapping with a Renewable Energy Portfolio Standard

Under a portfolio standard, the fossil-fueled producer must purchase or otherwise ensure a share of at least A green certificates for every unit of nonrenewable energy generated. With a binding renewable market share mandate, the renewable energy sector receives a subsidy per unit output equal to the price of a green certificate, p_R. The effective tax per unit of fossil-fueled output under this policy is then Ap_R. Thus, the full tax on fossil energy and subsidy to renewable energy have an endogenous component, as the market will determine the green certificate price:

$$d\phi = dt_F + Adp_R \tag{13}$$

$$d\sigma = dp_R + ds \tag{14}$$

Furthermore, to the equilibrium conditions (2)–(5) we add the constraint

$$dr = A(dg + df) \tag{15}$$

From (15) and (5), we see that the renewable credit price is decreasing with the production subsidy and the retail electricity price—both of which expand renewable generation on their own—and increasing with policies that expand generation from fossil sources:

$$dp_R = AS_r'(dg + df) - dP - ds \tag{16}$$

Solving the system, we get

$$\begin{aligned} dp_R = &-\left(A(S_f' + S_g')S_r'(1-\omega^F) + S_f'S_g'\omega^F \right) dt / \xi \\ &-\left(S_f'S_g'\omega^F\bar{\mu} + AS_r'\left(S_g'(\mu_f - \omega^F\bar{\mu}) + S_f'(\mu_g - \omega^F\bar{\mu}) \right) \right) d\tau / \xi \\ &-\left(A(S_f' + S_g')S_r'\omega^R + S_f'S_g'(1-\omega^R) \right) ds / \xi \end{aligned} \tag{17}$$

where $\xi = A(S_f' + S_g')S_r'\left(A(1-\omega^F) + \omega^R \right) + S_f'S_g'\left(1 + A\omega^F - \omega^R \right)$.

In a fixed-price world, all of the overlapping policies would normally give preference to renewable energy at the expense of nonrenewable sources; however, now they cause the price of green certificates to fall. The net effect on renewable generation is

$$dr = \left((1-\omega^F - \omega^R)\left(Ads - dt_F \right) - A\bar{\mu}\left(1 - \omega^R + \omega^F + A/\hat{\mathrm{T}} \right) d\tau \right) \frac{\left(S_g' + S_f' \right)}{\xi} \tag{18}$$

where $\hat{\mathrm{T}} = \left(S_g'\mu_f + S_f'\mu_g \right) / \left(S_g'(\mu_f - \omega^F\bar{\mu}) + S_f'(\mu_g - \omega^F\bar{\mu}) \right)$.

Note that, because of the market share mandate, renewable generation is linked to fossil energy generation, as seen in (15). Therefore, additional taxation of fossil energy lowers generation from those sources, but it also reduces renewable generation by relaxing the portfolio constraint. An increase in the emissions price has a similar effect; again, although normally carbon pricing would make renewables more competitive, in this case, since fossil generation contracts, so do renewables when the portfolio constraint is binding. This feature underlies the results of Amundsen and Mortensen (2003).

The flip side of this effect is that additional subsidies to renewables will drive up emissions. By lowering the cost of RES-E generation, subsidies reduce the implicit tax on nonrenewable sources, lowering electricity prices and allowing fossil energy (and thereby emissions) to expand.

4.2.3 Cap and RPS and Additional Policies

Much of the existing literature has focused on the interaction of emission caps and RPS with each other. However, from the above analyses, we can also consider how the combination of an emissions cap and an RPS interact with other policies. For instance, a carbon tax should have no effect on the system, as long as it is applied with the same scope as the emissions cap, since the allowance price will absorb it.[27] An additional tax on fossil fuels causes total fossil generation to contract, but the effect of the tax is mitigated by the adjustment of the emissions price and the green credit price. Still, the net negative effect means that renewable energy will contract along with fossil sources, due to the RPS. Coal will still benefit relative to natural gas-fired generation.

An additional subsidy to renewables expands those sources, but less than would occur without the self-adjusting policies. Fossil sources then face three effects: downward pressure on the retail electricity price as total supply expands, downward pressure on the green credit price, and upward pressure on the emissions price. With a binding RPS, total fossil generation must expand with the additional renewables, meaning the savings in terms of lower green credit costs must outweigh the fall in electricity prices; thus, to continue to meet the emissions cap, there must be a shift away from coal to natural gas.

4.3 Other Issues in Overlapping Policies

4.3.1 Relative Policy Stringency

A consistent theme throughout the policy interaction literature is how the stringency of individual policies determines their effectiveness in overlaps. De Jonghe et al. (2009) find that when ETS and TGCs overlap, a strong ETS requirement can render the renewables quota nonbinding; likewise a high TGC percentage requirement can also render ETS nonbinding. When either quota policy becomes nonbinding, the allowance or certificate price falls to zero, as illustrated below in Figure 1 (taken from De Jonghe et al. 2009). According to these simulation

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[27] With respect to scope, Böhringer, Koschel, and Moslener (2008) find that in the context of (multilateral) EU ETS, (unilateral) national emissions taxes are “environmentally ineffective and increase overall compliance cost of the EU ETS” (16).

results,[28] only a narrow band of CO_2 and RES-E percentage requirements will allow both policies to have binding effects (represented by the sloped surface on both panels).

The study notes that unlike their effect on renewable quotas, strict ETS requirements will never render price-based RES-E policies ineffective in promoting renewables On the other hand, the incidence for taxpayers is quite different for reaching a renewables target in conjunction with an emissions target. Society still incurs the costs of the renewables subsidies, even in cases when a strong ETS requirement provides sufficient incentive to realize the renewables target. By contrast, a non-binding (or lightly binding) renewables quota leads to certificate prices of zero (or very low levels) and minimal social costs. If a renewables quota overlaps with a relatively stringent ETS policy, the certificate price can adjust to reflect a reduced need for renewables support (thereby reducing total costs to society). Böhringer et al. (2009) suggests that the EU ETS itself provides substantial indirect support for RES-E adoption in Europe, such that only mild RES-E policies are needed to reach the EU 20/20/20 renewables goals.

Figure 1. The sloped surfaces represent the only quota combinations where both ETS and TGCs are binding.

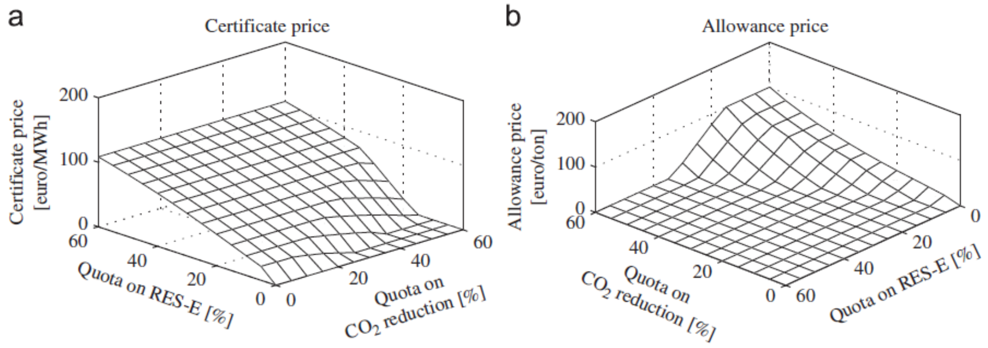

Fig. 11. (a) Certificate price and (b) allowance price for combinations of TGC and CO_2 allowances. Note that the *X*-axis has a reversed direction in panel (b).

Source: De Jonghe et al. (2009)

Credit fungibility can further link the systems and leverage one policy for achieving the other's goals. For example, prior to the EU ETS, the United Kingdom allowed overcompliance with their renewables obligation or energy-efficiency requirements to earn CO_2 credits. Sorrell (2003) points out many of the practical complications that can arise from these arrangements. In

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[28] De Jonghe et al. (2009) use a three-regional model representing France, Germany, and the Benelux countries (i.e., Belgium, the Netherlands and Luxemburg).

addition, the emissions cap is relaxed to the extent that TGCs are exchanged for CO_2 credits. Fischer and Newell (2007) argue that if additional support for renewable energy is desired—beyond that incentivized by the prevailing CO_2 price and RES-E target—the RPS could simply be tightened or other direct renewable support policies brought to bear.

4.3.2 Overlapping Policies and Electricity Prices

There is much disagreement in the literature as to the effect of RES-E policies on the consumer electricity price. Palmer and Burtraw (2005) find that RPS policies ranging from 5–20 percent would raise the U.S. electricity price, whereas renewable energy production tax credits lower electricity price at the expense of tax payers. However, other studies have estimated that RPS policies would lower retail prices (surveyed in Wiser and Bolinger 2007 and Fischer 2009). Fischer (2009) explains that RPS policies can indeed raise or lower the consumer electricity price because they combine a price-increasing tax on fossil generation with a price-decreasing subsidy to renewables, and the result depends on the relative elasticity of the RES-E supply curves (compared to the nonrenewable energy supply curves) and the stringency of the RPS target. The analysis argues that if the RES-E supply curves are sufficiently elastic and the RPS targets relatively low, an RPS serves more as a subsidy for RES-E producers than as an energy tax on fossil fuel producers. Therefore, "models are more likely to predict that RPSs will produce lower consumer electricity prices when they embed rigidities in natural gas supply, assume that large portions of nonrenewable generation are fixed, parameterize relatively flat marginal costs for renewables, or target modest increases" (97).

Although Fischer (2009) does not address RPS in combination with a cap-and-trade system, the above finding helps to explain why many theoretical models combining emissions trading and renewables quotas disagree about consumer energy prices. Unger and Ahlgren (2005) predict that TGCs in Nordic countries could reduce consumer prices when combined with a strong ETS policy. The model assumes some rigidity in the supply of fossil fuel energy and finds that consumer prices are only likely to fall for TGC targets under 25 percent.[29] However, the model also predicts that wholesale electricity prices and CO_2 permit prices are likely to decrease steadily as the TGC target increases beyond 25 percent.

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[29] See also Abrell and Weigt (2008), Rathmann (2007), and Jensen and Skytte (2003). All three papers predict that RES-E support policies in combination with strict ETS might lower consumer prices in certain scenarios, consistent with Fischer (2009).

Traber and Kemfert (2009) explore the combined effects of the EU ETS and FiTs on consumer prices, recognizing the oligopolistic character of the German electricity market, as well as trade and production capacity constraints. They show clearly the two competing effects of FiTs on the price of electricity. Whereas the substitution effect of switching to renewables from fossil fuel energy tends to increase prices, the effect of FiTs on reducing the CO_2 permit price tends to lead to a corresponding decrease in consumer prices. They determine that the net effect of the presence of FiTs slightly increases consumer electricity prices in Germany, while reducing prices for producers.

4.3.3 Overlapping Views on Renewables

Many studies offer contrasting outlooks on the desirability of overlapping RES-E policies, ranging from skepticism (Morris 2009) to realism (Böhringer et al. 2009) to optimism (Unger and Ahlgren 2005). These views tend to reflect different answers to a fundamental question: how much intrinsic value exists (if any) in stimulating renewable energy adoption, beyond CO_2 emission reduction? In fact, Böhringer et al. (2009) refer to the additional costs of renewables policies as a price tag attached to the value of other objectives. Pethig and Wittlich (2009) determine that if a country targets only emissions reduction, it should only use one policy instrument, such as a carbon tax or ETS. However, they favor mixed policies for countries pursuing both emissions and renewables targets, provided that both policy instruments are binding. The next section explores several justifications for mixed policies, in which RES-E support overlaps with emissions reduction mechanisms.

5. Rationales for Overlapping Policies

Most studies on renewable energy policies agree that a CO_2 tax or quota reduces emissions more cost-effectively than either price- or quantity-based RES-E mechanisms. Widespread agreement also exists throughout the interaction literature that supplementary renewable policies increase the total cost of emissions reduction under an ETS regime. These results are unsurprising, given the well-known principle in economics that a single market failure is best addressed with one instrument, while multiple market failures require multiple instruments (Tinbergen 1952). In an aptly titled *IRERE* article, “Instrument Mixes for Environmental Policy: How Many Stones Should Be Used to Kill a Bird?” Braathen (2007) reviews the common practice of using multiple policy instruments for environmental purposes from household waste management to energy efficiency and derives some principles for determining appropriate environmental policy mixes. For renewable energy policies, then, the analogous question is how many "birds" are there to "kill"?[30]

Policymakers commonly justify overlapping renewables support by invoking the renewable energy targets they wish to meet (e.g., 20 percent renewable share by 2020 of electricity in ACESA and of final energy use in the European Union), and most studies favor RES-E support policies as a means of enforcing such targets.[31] This line of justification then begs the question, "Why renewables targets?" Most of the policy interaction literature either treats renewables targets as given (likely reflecting the political reality, especially given the EU 20/20/20 mandates) or cites the need for a more convincing rationale in favor of RES-E support policies.

Sijm (2005)[32] finds three potential rationales for supplementary policies: to improve the design of ETS, to correct market failures that reduce the static/dynamic efficiency of ETS, and to meet other policy objectives besides CO_2 efficiency. Examples of this first category would include RES-E support for sectors not covered by the CO_2 emissions reduction program.

Whereas Sijm's first rationale applies only to instances of inadequate ETS policy design, market failures represent what many consider an essential reality of emissions trading. One group of ETS market failures relate to the *static* efficiency of the energy and/or emissions markets. For instance, "many households fail to invest in highly cost-effective energy/CO_2 saving opportunities because they face high transaction costs, respond poorly to price incentives, are only partly rational, or lack access to capital or adequate information" (Sijm 2005, 84). In the event of any such market failures, or if the price effects of ETS are not passed through to end-users, Sijm (2005) sees potential justification for supplementary policies. Goulder and Parry (2008) agree that market failures can justify additional policy instruments, and they specifically cite consumers' systematic undervaluing of energy-efficiency improvements. Indeed, more often these arguments apply to energy-efficiency investments, but Scarpa and Willis (2009) find some similar evidence for the willingness to pay among households in the United Kingdom for micro-generation installations that include solar photovoltaic, solar thermal, and wind technologies. They find that while most households significantly value RES-E improvements, this value is not

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[30] No pun intended for the wind turbine industry.

[31] Section 2.1 outlines some of the rationales used.

[32] Sijm (2005) predates EU ETS implementation, and his argument that supplementary policies provide no incremental CO_2 reductions aligns nicely with Böhringer and Rosendahl (2009).

sufficient to cover the high capital costs of micro-generation. Technology-based market failures, which relate to the *dynamic* efficiency of ETS, offer another argument for supplementary policies. These arguments have been made for a wide variety of technologies related to climate mitigation (see, e.g., Goulder and Mathai 2000), but also specifically in the area of electricity generation from renewable sources. In the world of efficient markets, a carbon price or quota will indirectly subsidize costlier renewables production, along with long-term R&D investments that maximize future cost reductions. However, R&D investments in renewable energy have a high degree of uncertainty and intangibility, not to mention limited appropriability, large economies of scale, and long time horizons (Sorrell and Sijm 2003; Goulder and Parry 2008). Each factor can cause the private sector to underinvest in renewable energy R&D, thereby limiting technological progress and future cost savings. Sorrell and Sijm (2003) identify learning-by-doing—in which costs decrease over time with cumulative production—as an additional positive externality that compounds the technology market failure. Typically, the more expensive renewable technologies yield the highest returns on R&D investment and learning-by-doing. Yet their higher costs act as a barrier to adoption, which limits learning-by-doing and, by extension, future cost reductions. Hence, an argument can be made for supplementary policies that encourage both R&D and renewables adoption.

5.1 Technological Spillovers and Overlapping Policies

Fischer and Newell (2008) find that supplementary renewables policies can substantially reduce the compliance costs of an emissions constraint by correcting knowledge-based market failures. Knowledge spillovers affect the appropriability of R&D investments, as well as innovations developed via learning-by-doing. They propose three overlapping policy instruments—emissions price, renewables R&D subsidies, and renewables production subsidies—to correct three externalities, respectively—CO_2 emissions, R&D spillovers, and learning spillovers. Using a simple stylized model with parameter values keyed to the U.S. electricity sector, Fischer and Newell calculate that the optimal subsidies (50 percent for R&D and 4 percent of electricity price for learning) lead to a 36 percent reduction of the emissions price necessary to achieve 4.8 percent CO_2 abatement. This reduction in compliance costs more than offsets the cost of the subsidies themselves, with the R&D incentives responsible for the vast majority of savings. However, the optimal learning subsidy is quite small in comparison to typical renewables subsidy rates, making it difficult to rationalize learning-based production subsidies for relatively mature renewables (i.e., wind).[33]

Consistent with Böhringer and Rosendahl (2009), Fischer and Newell (2008) determine that the supplementary policies contribute very little incremental emissions reduction. The emissions price remains relatively more important as an incentive to use renewable technology efficiently than the process of technological change itself (whether through learning-by-doing or R&D). As in the previous literature that abstracted from technological spillovers, they find that an emissions price is still the best single policy to reduce CO_2 emissions. Nevertheless, knowledge-based subsidies can help to mitigate the welfare-reducing effects of an emissions price.[34]

Otto, Löschel, and Reilly (2008) likewise explore the use of supplementary renewables policies to correct ETS market failures. Unlike Fischer and Newell (2008), their study addresses only the R&D spillover effect; hence it proposes simply supplementing ETS with R&D support. The authors present a case for differentiated R&D subsidies because knowledge-based market failures affect individual technologies differently. For example, underdeveloped technologies benefit the most from R&D investment but also suffer the highest knowledge spillover rates. Under an optimal differentiated R&D policy, they predict significant welfare gains when compared to ETS alone. Yet they find that completely correcting the market failure necessitates a negative subsidy on R&D investment in the fossil fuel sector. “Essentially, it means creating disincentives for R&D in CO_2 intensive sectors causing them to wither away and creating large subsidies for non-CO_2 intensive sectors, accelerating their growth” (2868). The authors acknowledge that such extreme policy would likely be unrealistic.

On the other hand, learning-by-doing spillovers can serve as practical justification for RES-E production incentives. Rivers and Jaccard (2006) examine different renewables policy options and find that market-based incentives can mitigate learning spillovers more cost-effectively than regulatory (command-and-control) instruments. However, the authors recognize that political considerations beyond economic efficiency—including effectiveness, political acceptability, and administrative simplicity—can push governments towards regulatory

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[33] However, this learning subsidy is similar in size to the optimal R&D subsidy, if both are expressed as a percentage of revenue.

[34] Goulder and Mathai (2000) provide one of the earlier theoretical studies on overlapping CO_2 prices with R&D subsidies.

instruments. For this reason, they conclude that an RPS policy can serve as a useful hybrid, combining cheaper, market-based incentives with a firm regulatory standard.

Elsewhere, van Benthem, Gillingham, and Sweeney (2008) find that learning spillovers provide sufficient justification for California's solar subsidies, while the environmental externality rationale falls short. Further studies address the technology and learning market failures by analyzing the flow of knowledge across international borders, both from R&D-investing to free-riding EU member states (Pettersson and Söderholm 2009), as well as from developed to developing nations (Bosetti et al. 2008). These studies reinforce the case for a three-policy portfolio that addresses both R&D and learning spillover effects.

Fischer (2008) cautions that the value of public incentives for green technology development and deployment depends not only on the degree of spillovers but also the extent to which the emissions externality is priced. If little market incentive is present to take up the technologies, the investments will not live up to their potential. She indicates that strong public support for innovation in abatement technologies is only justified if at least a moderate emissions policy is in place and spillover effects are significant. In the RES-E context, deployment incentives tend to raise the return to R&D investments and the benefits to dealing with knowledge externalities. A further rationale for innovation policy exists if lower-cost abatement opportunities allow future climate policy to become more stringent. Summarizing these ideas, she concludes, "While mitigation policy must be the engine for reaching environmental goals; technology policy can help that engine run faster and more efficiently, but it only helps if the engine is running" (Fischer 2008, 500).

5.2 Technological Lock-in

Sorrell and Sijm (2003) identify another potential rationale for supplementary renewables policies, which also relies on technology and learning effects. They explain how increasing returns from learning-by-doing may combine with scale economies, inertia, and infrastructure factors "to *lock in* dominant technologies and to *lock out* viable alternatives" (430). This type of feedback effect could negate the potential development of cheaper, more effective RES-E technologies, forcing the electricity sector on a higher-emissions, higher-cost pathway.[35] Schmidt and Marschinski (2009) model this "pathway objective" as a multiple-equilibrium problem, in

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[35] See del Río González (2007) and Sorrell (2003).

which a technological breakthrough can jumpstart the renewables sector to its high-output equilibrium. They find that strong, early renewables promotion can encourage R&D investment, enabling such a breakthrough and helping to prevent lock-in on a suboptimal pathway. Market power represents another potential obstacle to renewables diffusion, as competitive firms may face coordination problems leading to low output. In the event of a technological breakthrough, a single firm is likely to own monopoly rights to the innovation, restricting its access by charging a licensing fee. Schmidt and Marschinski (2009) suggest that renewables investment subsidies could overcome such market imperfections.

5.3 Other Rationales

One frequently cited justification for overlapping policies is a concern for the security of the energy supply. The logic follows that by promoting a diverse mix of policies to increase the share of renewable energy, governments can help to insulate themselves from volatilities in the global fossil fuel markets. While this argument may ring true in many policy circles (specifically in small, fossil fuel-importing nations and OPEC-dependent nations), Sorrell (2003) finds that it "has rarely been subject to serious scrutiny."[36]

Some studies allude (however skeptically) to the potential economic benefits of overlapping renewables policies. These include employment boosts (e.g., "green jobs"), new rural income opportunities, and synergy with the goal of lowering consumer electricity prices.[37] Kammen, Kapadia, and Fripp (2004) find that more labor-intensive renewable generation can lead to job creation: "Across a broad range of scenarios, the renewable energy sector generates more jobs than the fossil-fuel based sector per unit of energy delivered (i.e. per average megawatt)" (2). While a politically salient rationale, this aspect captures the attention of very few economists, who prefer to focus instead on economic efficiency. For example, one U.K. study indicates that the cost-effectiveness of this employment creation is relatively low (cited in Sorrell and Sijm 2003). Although some case studies list jobs as a significant factor driving state-level RPS policies (Rabe 2004), Lyon and Yin (forthcoming) find that states with higher unemployment rates are actually less likely to adopt an RPS, suggesting greater concern for consumer prices in those situations.

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[36] See also Sorrell and Sijm (2003) and del Río González (2007).

[37] See, respectively, Sorrell (2003), Sijm (2005), and Skytte (2006).

Sorrell and Sijm (2003) also note the potential for an "early mover advantage," by which strong, early renewables support could spur the development of viable industries with significant export potential. They find that such a strategy has enabled German firms to capture much of the world's wind energy market. In a theoretical analysis, Greaker and Rosendahl (2008) find that a more stringent environmental policy toward a polluting downstream sector can increase competition among upstream technology suppliers, leading to lower abatement costs. However, an especially stringent environmental policy is not necessarily helpful for developing successful new export sectors based on abatement technology.

One additional rationale is to mitigate other non-CO_2 externalities associated with electricity generation from fossil sources, such as sulfur dioxide, nitrous oxide, and mercury emissions. Sorrell (2003) and Sijm (2005) find these arguments unconvincing in the context of the United Kingdom and European Union more generally, given the existing regulation and pricing of other external costs. Of course, to the extent these pollutants are regulated with emissions caps, many of the same policy interactions occur. Indeed, joint abatement problems raise their own issues (Evans 2007). However, local RES-E policies could still influence the geographic distribution of conventional air pollutants, given the region-wide orientation of the trading regimes. Yet Lyon and Yin (forthcoming) found local air quality not to be a significant predictor of RPS policies in the United States.

Finally, while considering the external costs of fossil energy and external benefits of renewable energy, one must also recognize that renewables are not without their own external costs. For example, remote energy sources and the transmission lines needed to connect them affect landscape quality. Wind turbines have problems with bird strikes, and hydropower interferes with aquatic ecosystems. Solar panel production involves a variety of toxic byproducts, and wind turbines and batteries require rare elements that are almost exclusively mined in China (Rahim 2010). Biomass generation entails emissions of air pollutants. Few studies include this full panoply of external costs and benefits. One exception is Bergmann et al. (2006), who consider the welfare implications of different RES-E investment strategies in Scotland.

6. Choosing Instruments for Renewable Energy: Conclusions and Directions for Research

A variety of rationales motivate the adoptions of policies to support renewable energy sources. Some are politically popular, like addressing climate change, enhancing energy security, promoting green jobs, improving local air quality, and achieving a competitive advantage in related technologically advanced markets. While many economists find these arguments unconvincing, other rationales are compelling, if harder to convey to a popular audience.

In the absence of pricing important pollutants like CO_2 emissions, an environmental rationale can be argued for RES-E support, although such policies are a second-best, indirect means toward emissions reductions. But once emissions from electricity generation are sufficiently priced—or if emissions are capped in a binding manner, regardless of the price—expanded RES-E offers no marginal environmental benefits. Consequently, the justifications for additional renewable energy policies must rely on additional market failures. Among these, the most compelling involve market and regulatory barriers in electricity generation and spillovers from technological innovation and learning.

Particularly in the latter area, a gap remains between the available empirical research and the needs of models used for policy evaluation, which need to represent the manner and magnitudes of these additional market failures. As Pizer and Popp (2008) highlight, "Technological change is at once the most important and least understood feature driving the future cost of climate change mitigation" (2768). They identify as key research priorities quantifying spillovers across industries and regions, disentangling R&D and learning-by-doing effects, and the relative contribution of public versus private R&D.

After identifying the separate market failures that require separate policy instruments, the next question is, what are the appropriate policy combinations to address them? Obviously, some barriers are best addressed directly with regulatory methods (or in some cases deregulation) to create conditions that allow market incentives to work. (Examples include net metering requirements, grid management, regional transmission and competition, and contracting requirements.) Other market failures that imply that private actors have insufficient incentive to invest in renewable technologies can be effectively addressed with market-based incentives. But which ones?

That answer can depend on the market failures and the other policies operating in practice. In an optimal scenario, emissions would be priced according to the marginal damages, R&D would be subsidized according to the spillover rate, and RES-E production would get a modest subsidy to compensate for spillovers from learning-by-doing (Fischer and Newell 2008). However, the actual policy context in the area of renewable energy is much more complex. Just as overlapping jurisdictions and goals exist, so may a lack of political will to sufficiently price externalities with a single policy, when the costs to consumers and taxpayers may be less transparent with multiple instruments. As a result, it is especially important to understand how these policies interact.

Analyses show that in the absence of an emissions cap, subsidies for RES-E do displace fossil energy sources and offer environmental benefits; however, the magnitude of those benefits may be smaller than expected if the marginal generation source displaced is relatively clean compared to the average (e.g., if more natural gas-fired generation is crowded out compared to coal). Furthermore, some benefits may be lost by decreased incentives for conservation, as subsidies lower retail electricity prices. In the presence of an RPS, however, environmental benefits become even less certain. A binding RPS links RES-E to fossil generation, so expansion of one means expansion of the other. Furthermore, any additional subsidies serve to lessen the implicit cost of the RPS, driving down the price of TGCs and making fossil generation more competitive. The consumer price impacts of an RPS are also ambiguous, although the more binding the policy, the more likely it is to drive up retail prices.

A second lesson from the economics literature is that in the presence of a binding emissions cap, additional renewable policies of any kind do not affect emissions. Those additional policies can address other market failures, but their effects on the ETS should be recognized. Policies that expand renewables make it easier to meet the cap, driving down allowance prices to the benefit of the relatively dirty sources and to the detriment of the relatively clean nonrenewable sources. Additional RES-E policies are also more likely to lower consumer prices, again due to the effect on lowering allowance prices. Yet, despite the apparently lower emissions costs, the true costs of meeting the cap are actually higher, at least from a static efficiency perspective; therefore, it is important to verify a dynamic efficiency rationale for RES-E policies.

Third, we need to identify to what extent market failures vary by technologies. If the goal is simply to have a certain share of renewable energy, then an RPS policy necessarily meets that goal in an efficient manner. Still, this theory needs some reconciling with the practical and empirical evidence that feed-in-tariffs tend to be more effective. There is also some evidence that because they are able to price-discriminate, FiTs can achieve a portfolio of RES-E at lower resource costs than TGCs. If an RPS is the most cost-effective mechanism, that result rests on the fact that it tends to promote the most commercially ready technologies. Therefore, if different technologies have different spillover or learning externalities, FiTs and other technologically specific policies can better address these problems, although there is always skepticism about governments' abilities in accurately "picking winners."

Little work has been done on optimal policy choice in the presence of overlapping policies. Evans (2007) considers a joint abatement problem of sulfur dioxide and mercury in electricity generation and finds that the policy choice for one pollutant does depend on the instrument used for the other. Overall, given the damage functions, he finds that emissions taxes are preferred for both. These aspects—including uncertainty in costs and benefits—still need to be addressed in the context of renewable energy.

Another overlapping area we have ignored in this article involves energy-efficiency policies, which are also quite relevant in electricity markets. Indeed, ACESA proposes a Renewable Energy Standard that would also allow for compliance with energy-efficiency improvements. This possibility of both direct and indirect links between RES-E, energy efficiency, and emissions requires greater exploration.

Most studies of renewable energy in the economics literature focus on one (or sometimes two) policy mechanisms. This review signals that proper policy evaluation cannot be conducted in a narrow context; care must be taken to consider the whole of the package. With overlapping policies (particularly inefficient ones), one can no longer point to allowance prices as an accurate reflection of marginal abatement costs. Nor are the benefits of other RES-E policies transparent. Consequently, as more tradable quota mechanisms are adopted, other preexisting policies should be reevaluated to ensure that taxpayers and consumers are still getting their money’s worth of the renewable energy they wish to support.

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