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Designing Power Markets to Maximize the Effectiveness of Carbon Pricing

Lessons From International Experience

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Introduction

Policymakers in China are currently designing and implementing both carbon markets (which will initially cover only the power sector) and electricity markets. Experience in other global regions counsels that these markets should not be designed in isolation. Understanding the impacts that each has on the other is key to good design — that is, to ensuring that the markets are as economically efficient as possible and the carbon program is achieving its goals at lowest possible cost for both end-use customers and the power sector as a whole.

Designing electricity markets and carbon markets in isolated policy "silos" does not lead to best outcomes, international experience shows. The impact of carbon prices on power system dispatch and wholesale spot market electricity prices is affected by a host of system conditions, operating protocols and investment incentives — all along the continuum between competitive markets and administratively managed ones.

Moreover, the cost-effectiveness of carbon pricing — maximizing carbon reductions while minimizing the cost per ton of reduction actually achieved — is not as straightforward as it may seem. Experience demonstrates that, in the power sector particularly, how a carbon price is administered is critically important.

The purpose of putting a price on carbon (or any pollutant) is to raise the prices of carbon-emitting production in relation to cleaner, non-carbon-emitting production and thereby drive demand and investment for that cleaner production. There are three direct and interrelated channels through which a price on carbon can cause emissions reductions in the electric sector: (1) by changing power sector dispatch (i.e., system operations), (2) by affecting investment (and disinvestment) decisions regarding power plants and other sector resources and (3) by altering demand for energy. In this paper, we examine these interactions and ask how power markets can be adapted to maximize the effectiveness of the carbon price.[1] We identify key design elements that ensure that both work in concert and as intended, and we offer observations and recommendations for policymakers — in particular, those designing the carbon market — in China. Our findings can be summarized this way:

1) Experience in Europe and North America demonstrates that the effectiveness of carbon markets is greatly enhanced by economic (or merit order) dispatch and that one way to achieve economic dispatch is to implement well-designed electricity markets. Under this dispatch principle, power plant operational decisions are based on their relative operating (primarily fuel) costs. The less expensive units will operate first, and as demand in real time increases, the relatively more expensive units will operate next. Carbon pricing can then influence these crucial grid operational decisions by changing the relative price of various units. Policymakers in China are in fact proceeding in this direction by implementing new "spot" electricity markets based on the principle of economic dispatch. Much progress has been made on this issue in China. Building on this progress and achieving full economic dispatch across the country (whether through competitive spot energy markets or administrative means) is critical.

2) Along with economic dispatch, it is important to get other elements of electricity market design right to make the carbon market both effective and efficient. Those elements include:

    a) Resource compensation: How generators and other power sector resources (such as end-use energy efficiency and demand response) are compensated matters. A poorly designed compensation model could perpetuate reliance on inefficient, carbon-emitting resources that are more expensive on a total cost basis than lower-emitting units.

    b) Market monitoring: Independent market monitoring and oversight is necessary to prevent abuses of market power, which typically have the effect of overcompensating fossil-fueled resources, and (more importantly) to help ensure economic dispatch. Market monitoring should ideally include oversight of the carbon market as well as the electricity markets.

    c) Moderating the impacts of carbon prices on electricity consumers: A price on carbon emissions will increase the operational (fuel) costs of fossil fuel-fired power plants and, in competitive electricity markets, will tend to raise the market prices paid to generators. How those increases in costs are treated and who benefits from the higher prices will influence the effectiveness of the carbon market.

3) A powerful lesson in both Europe and the U.S. is that the influence of the carbon price can be greatly enhanced by the manner in which the revenues the price generates are spent. Directing the revenue to investments in low-carbon assets (in particular, end-use efficiency and renewables) can multiply by many times the effect of the carbon price alone.

4) Even in parts of the world that have developed sophisticated electricity and carbon markets,

[1] Here we are only describing how the carbon price can affect behavior in the electric sector — that is, how participants in electricity markets are likely to respond to the price. However, as we discuss in the section "Mitigating the Impacts of Carbon Pricing on Electricity Prices," there are additional steps that policymakers can take when designing carbon emissions trading schemes to both keep the programs' costs down and increase their effectiveness — that is, produce greater emissions reductions than the carbon price alone will cause.

power sector planning remains a critical component of energy and environmental policy. Planning must be integrated with both carbon market design and electricity market design. Carbon markets are best designed when seen as one element of an integrated portfolio of complementary policies all aimed at achieving China's energy, economic and climate goals.

5) Retail price reform will need to move forward across the country as electricity and carbon markets evolve. Retail prices that reflect the true underlying costs, including carbon costs, of electricity production will aid the carbon market's ability to reduce emissions.

Power Sector Dispatch

Electricity is in one very important way a commodity unlike any other. Whereas steel or aluminum, for example, can be produced before it is used and stored in warehouses until delivered to customers, electricity generation must be matched with use of electricity on a moment-by-moment basis — that is, in real time. Electricity grids are managed by system operators (known in China as dispatch organizations), which are responsible for maintaining near-instantaneous balance of overall supply and demand on the grid. Demand fluctuates throughout the day, as do other conditions on the grid, such as the availability of generation and congestion on transmission lines.

Generator dispatch is the process of deciding which generators to use to meet demand and to maintain the stability of the grid, or system security.[2] Those responsible for dispatch must make these decisions on a day-by-day, hour-by-hour and minute-by-minute basis so that electricity demand and supply are always in balance. In recent years, dispatch organizations have begun to face a new challenge of balancing the grid with the presence of growing amounts of renewable sources of generation — wind and solar — that cannot be directly controlled in the manner of a traditional coal- or gas-fired power plant. This challenge is, however, surmountable. Experience around the world shows that doing so has more to do with how, and for what purposes, energy suppliers get paid than it does with purely technical grid matters. The key is *flexibility*, in both supply and demand, and to reward market actors — whether traditional large-scale generators or smaller distributed resources — that can provide it at reasonable cost and at the right place and time.[3] Dispatch organizations are already adept at managing the system, in real time, to deal with changes in demand and supply. Now, more and more, they also need to deal with the variability of generation output, particularly renewables output. Valuing flexibility in dispatch (i.e., system operations) will uncover huge reserves of quickly dispatchable load and generation: resources that can vary their consumption or output to efficiently balance supply and demand in a more variable system.

In North America, Europe and most other places in the world, system operators make dispatch decisions based on the relative economics of the generators available to them. This is called economic or merit order dispatch. It's straightforward: It ranks generators by their operating costs (also referred to as short-run marginal costs or variable costs), which mostly reflect fuel cost and the efficiency with which the generator converts that fuel into electricity.

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[2] In Chinese, the word "diaodu," literally "dispatch," is commonly used to refer to a wide variety of system operations, including day-ahead and real-time operations. We follow that usage here.

[3] We use the terms "supplier" and "resource" somewhat interchangeably with "generator." It's important, however, to keep in mind that this also includes suppliers of nongeneration resources such as demand response and storage.

This information on operating costs may come from estimates conducted by the system operator, from electricity market signals or from some combination of the two. Where there is a carbon price, the cost of emissions is also reflected in the operating cost of each generator (see the section “Effect of Carbon Pricing on Electricity Market Prices”).

According to this ranking of available generators, the system operator makes use of the least costly generators first.[4] As demand goes up, more costly generators are brought on. As demand falls, the more expensive plants are turned off first. The system operator repeats this exercise multiple times each day to deal with fluctuating demand and supply and changing grid conditions. The system operator may not always be able to use the least-cost generator, due to grid congestion or other changes in grid conditions. However, subject to the reliability constraint (see the next section on generator compensation), minimization of total operating costs across generators is a key principle for operation of the grid.

Figure 1 on the next page demonstrates a merit order for a given hour on a hypothetical power system.[5] Renewable energy has zero fuel cost and zero social cost of emissions, so when it is available, it is usually ranked first in the merit order. Coal- and gas-fired generators have varying levels of efficiency and thus different operating costs, and so have different positions in the merit order.

Carbon pricing and economic dispatch interact to support renewable generators and other relatively low-emissions generators. Because carbon costs are part of any generator’s operating costs and because carbon emissions vary across generators, a carbon price reinforces the position of relatively low-emissions resources in the merit order.

An electricity wholesale market can be thought of as a mechanism to incentivize generators and other resources to reveal their true operating costs, which can then be used to ensure economic dispatch.[6] In principle, in a wholesale market the market operator establishes a market price at the level of the operating cost of the marginal resource (as in Figure 1), and all resources earn that market price. In a well-designed, fully competitive wholesale market, a supply resource that bids (or offers) a price per kilowatt-hour higher than its true operating cost will find that it is sometimes not dispatched even when it would be able to cover its costs (and possibly even be profitable) to be dispatched. Conversely, a supply resource that bids a price per kilowatt-hour lower than its true operating cost may find that it loses money if it earns a market price that is lower than that resource’s operating cost. In this way, an ideal electricity market can help reveal information about operating costs and improve the efficiency of dispatch. This kind of outcome is seen in wholesale electricity markets across Europe.

In a well-designed, competitive wholesale market, the interaction of carbon pricing and economic dispatch typically allows relatively low-emissions generators to earn higher revenues.

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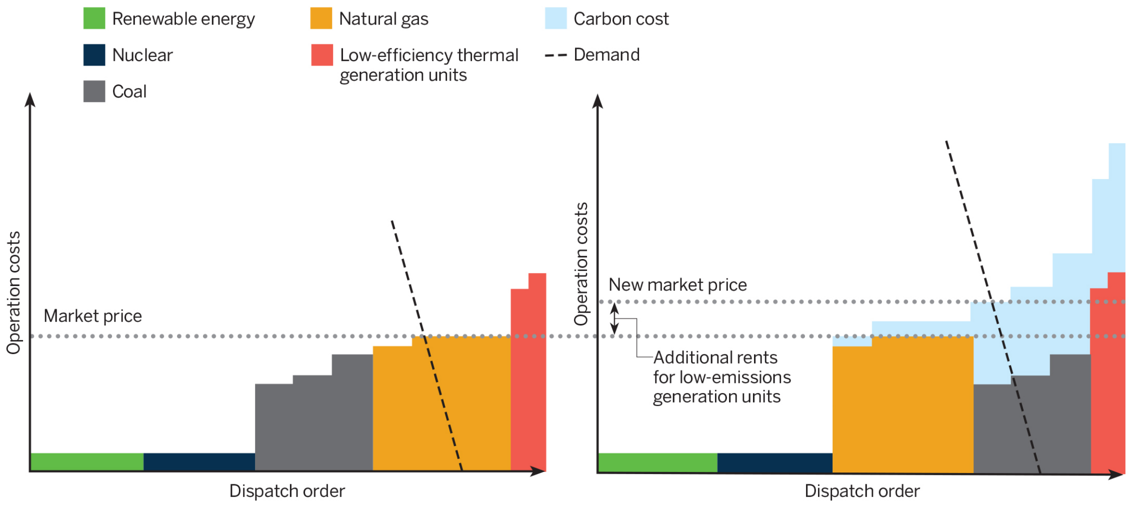
[4] Note that capital costs are not reflected in the dispatch ranking. The logic is that dispatchers are responsible for minimizing the costs of producing electricity from the set of resources that already exist.

[5] Dupuy, M., and Li, A. (2016). *Topics in carbon market design: Power sector dispatch reform and China’s national ETS*, pp. 10-12. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/topics-carbon-market-design-power-sector-dispatch-reform-chinas-national-ets/

[6] Ideally, electricity markets also encourage end users to reveal their true willingness to pay for electricity and the true value of lost load, but for various reasons this has been a somewhat elusive goal around the world. See, for example, Energy Union Choices. (2016, March). *Priorities for the Market Design Initiative: What’s missing? What’s most important?* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/priorities-for-the-market-design-initiative-whats-missing-whats-most-important/. This can be ameliorated with smart pricing policies, which we discuss in the following section.

In principle, this should provide an incentive to invest in more low-emissions generation capacity and to invest in less high-emissions capacity. This is because, in a typical competitive electricity spot market, all generators are paid the market price, and the effect of a carbon price will be to increase revenues for zero-emissions power plants (as in Figure 1). There can, however, be distributional consequences to this; we examine this question in more detail below in the section "Effect of Carbon Pricing on Electricity Market Prices."

Figure 1. Effect of carbon pricing on merit order dispatch and revenue in competitive spot market



Source: Dupuy, M., and Li, A. (2016). *Topics in Carbon Market Design: Power Sector Dispatch Reform and China's National ETS*

The central conclusion is that economic dispatch is a prerequisite for any policy aimed at minimizing the total cost of a carbon pricing regime in the power sector. Although economic dispatch can be accomplished through administrative means, global experience has revealed the power of competitive wholesale markets to impose cost discipline on generators. Well-designed and well-implemented electricity markets can be a good way to establish economic dispatch, while carbon pricing can work to ensure that the costs of carbon externalities are fully considered in economic dispatch. In this way, carbon pricing and electricity markets can work together to improve the operations of the electric system — that is, a market-based approach that internalizes a cost for carbon will minimize total system operational cost by favoring the more efficient, less polluting generators.

China is in the midst of a transition to economic dispatch, and the implementation of electricity markets is an important aspect of this. The spot market pilots are based on the principle of economic dispatch, but much work remains to be done to design and fully implement these markets in the pilot provinces, let alone across the country. Ensuring that economic dispatch is strongly in place is important to ensuring that carbon markets will be able to work effectively.

Generator Compensation

How generators and other resources get paid affects their behavior. How the design of electricity markets affects this compensation and how it can be structured best to complement the aims of a carbon pricing mechanism are important matters for policymakers to address.

Policymakers and market designers in Europe and North America have developed a variety of approaches to generator compensation. One priority of any market approach is to ensure a desired level of reliability and that compensation methods in each market in some way or another reward generators for providing that reliability.[7] However, reliability is just one of a number of important policy goals. Improved local air quality and reductions in greenhouse gas emissions to meet the Paris Agreement are also important goals for many policymakers, to name just two. This means that a power system that makes the greatest use of low- and non-emitting resources — wind and solar, in particular, and energy efficiency and customer demand response — is needed. Accordingly, the compensation mechanisms should incentivize investment in such resources and the retirement of resources that do not support specified policy goals, such as coal-fired generation capacity. Compensation mechanisms should also support integration of the new resources into the grid and promote efficient operation of all available resources.

In the Northeast and mid-Atlantic regions in the U.S., the regional transmission organizations ISO New England and PJM Interconnection operate both energy and capacity markets.[8] The capacity mechanism in these markets promises payments for capacity to be available during system peak hours (primarily in the summer) and makes these payments for a specified number of years. The UK market also supplements its energy market with a capacity mechanism. Although the markets in these places work well in many ways, the use of capacity markets has been problematic and has led to some inefficient investment and retirement decisions by market participants. One aspect of this is that capacity markets — at least as implemented in these places — have tended to overemphasize reliability and reward unnecessarily expensive resources when less expensive and cleaner resources could have done the job just as well. Market designs that treat reliability as their sole aim struggle not only to integrate clean resources into their systems but also to minimize total system costs. This has been a challenge in both the ISO New England and PJM regions, where a combination of state policies and the carbon emissions trading scheme called the Regional Greenhouse Gas Initiative (RGGI) has been driving investment in renewables (see the section on RGGI below). Most recently, federal regulators imposed a new market design element in PJM (likely to be repeated in New England) without regard to state clean energy policies. It creates a price floor for capacity that will effectively increase the cost of lower cost, cleaner renewables in relation to inflexible, primarily coal-fired plants. It also reduces or even nullifies the effect of the RGGI carbon price by reducing the "pain" (the financial disadvantage) that the price imposes on those emitting plants.

In contrast, several northern European markets (Denmark, Germany and the Low Countries), as well as Texas in the U.S., rely only on energy markets; this market approach is called, accordingly, the energy-only model. These markets rely on scarcity pricing to ensure that all

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[7] There are two aspects of reliability that system operators want to meet. One is system security, or operational reliability in real time. The other is resource adequacy, or sufficiency of resources to meet demand over the medium to long term.

[8] The spot markets under development in several provinces in China are roughly analogous to the independent system operator (ISO) and regional transmission organization (RTO) markets that cover about two-thirds of the United States. Because the terms ISO and RTO are nearly synonymous in the U.S., we will use them interchangeably when referring to these U.S. ISO/RTO markets. For more information on ISO/RTO markets, see Hurlbut, D., Zhou, E., Porter, K., and Arent, D. F. (2015). *'Renewables-friendly' grid development strategies: Experience in the United States, potential lessons for China* (NREL/TP-6A20-64940). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy16osti/64940.pdf (and available in Chinese at https://www.nrel.gov/docs/fy16osti/66729.pdf). See also Federal Energy Regulatory Commission. (2015). *Energy primer: A handbook of energy market basics.* https://www.ferc.gov/market-oversight/guide/energy-primer.pdf

generators are adequately compensated. They do this by allowing prices for operating reserves (i.e., energy needed to preserve system security at times of system peak or stress) to rise to very high levels. In the Texas case, prices can rise up to a cap of $9,000 per megawatt-hour.[9] This happens only occasionally and does not substantially affect average annual costs to consumers, but it does deliver a very strong price signal to resources, either on the generation side or on the demand side, that are actually available to meet system needs at times of relative scarcity.

The energy-only market approach, if implemented well, does a good job of rewarding flexibility of both supply and demand, encouraging innovation and more efficient consumption and thereby making it easier to integrate wind and solar resources and balance the system in real time. In Texas, more than 30% of the energy is supplied by non-emitting generation, and the share is steadily increasing.[10]

The question, then, for policymakers and electricity market designers is this: Does our market design promote or inhibit achievement of stated public policy goals? Reliability is a goal, but it is not the only one. A better way to think about this problem might be this: How should we design power markets to achieve our policy objectives at lowest cost and without impairing reliability? Getting the market design right means more than merely ensuring that the system will provide reliable power. It means making sure that it serves other important needs in the country. A carbon market will only be effective — that is, drive investment and operations away from carbon-emitting production — if it is not undermined by other, opposing incentives in the system. The trick here is for market designers to understand how their proposed compensation schemes reward behavior. If the market rules induce increased investment and use of fossil fuel-fired facilities, then the carbon market will fail to achieve its objectives. If, on the other hand, the power market rules complement the carbon market, reductions in harmful emissions will be accelerated.

In China, the power sector reform effort that was launched in 2015 (with Document 9) has been leading to changes in generator compensation. A big part of this is the design and implementation of the spot electricity markets. These markets promise to better align generator compensation with goals to integrate renewable energy, retire relatively carbon-intensive generators and improve the efficiency of power sector dispatch. However, there is still much work to be done to get the compensation details right for generators and other resources.[11] In this regard, we suggest it would be useful to develop more detailed rules to:

- Create a level playing field for all resources, including demand-side and storage resources, to participate (and earn fair compensation) in the spot markets.

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[9] Market designers in Texas have put a lot of effort into ensuring well-designed scarcity pricing. The Texas market features an energy-only market coupled with a real-time, energy-based reliability mechanism (called the Operating Reserves Demand Curve) and ensures that sufficient capacity is available to meet system security needs while providing sufficient revenue to encourage new investment. Surendran, R., Hogan, W. W., Hui, H., and Yu, C-N. (2016, June 27-29). *Scarcity pricing in ERCOT* [Presentation]. FERC Technical Conference. https://www.ferc.gov/CalendarFiles/20160629114652-3-FERC2016_Scarcity Pricing_ERCOT_Resmi Surendran.pdf

[10] John, J. S. (2019, January 19). *Texas grid operator reports fuel mix is now 30% carbon-free.* Greentech Media. https://www.greentechmedia.com/articles/read/a-snapshot-of-texas-growing-appetite-for-wind-and-solar-power

[11] See Dupuy, M. (2019). *Comments on National Energy Administration's "Advancing Electricity Spot Market Implementation."* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/comments-on-national-energy-administrations-advancing-electricity-spot-market-implementation/. See also Regulatory Assistance Project and Natural Resources Defense Council. (2017). *Electricity wholesale markets: US experience and recommendations for China*. https://www.raponline.org/knowledge-center/electricity-wholesale-markets-us-experience-and-recommendations-for-china/

- Make use of scarcity pricing. Removing or loosening price floors and ceilings in spot markets will be necessary to allow the markets to transmit economically accurate price signals to market participants regarding the value of power at different times and, perhaps, places, especially when demand is high and supply is scarce.

Market Regulation and Market Monitoring

Electricity markets can be thought of as tools to help meet important social goals, including economic dispatch, reduced costs, lower emissions and better investment decisions. But electricity markets can do these things only if they are designed and regulated well. In practice, in the United States, Europe and other places around the world, electricity markets are heavily regulated: They are embedded in and wouldn't function without detailed rules, including rules for market regulation and market monitoring.

Electricity markets can be susceptible to insufficient competition, which can undermine economic dispatch and other social goals. U.S. electricity markets historically suffered from a lack of competition, at least at certain times and in certain parts of the country. In the California crisis of the early 2000s, certain owners of generation resources were able to exercise market power, meaning they controlled a great enough share of resources in the market that they were able to undermine economic dispatch for their own gain. This severely disrupted the market and led to widespread blackouts, not to mention unnecessary emissions from the use of relatively inefficient generation units.[12] This crisis helped spur a renewed push to improve market regulation, monitoring and oversight in the U.S., and for this reason we focus on the U.S. experience here. In China, lack of competition may be a particularly pressing problem, given that the power sector features a relatively small number of large state-owned generation companies, some of which dominate large shares of generation ownership in particular provinces or regions.

In the U.S., market regulation and market monitoring include not only day-by-day and hour-by-hour scrutiny of the behavior of market participants but also ongoing efforts to identify changes to market rules that will promote economic efficiency and competition and will support policy goals, including for clean energy. The Federal Energy Regulatory Commission (FERC) takes several steps to ensure market integrity:

- It requires that each ISO/RTO establish an independent market monitoring unit (MMU) with the following responsibilities and functions:[13]
    - Evaluate existing and proposed market rules and market design elements and present recommendations for rule changes to ISO/RTO management, FERC, market participants and other stakeholders. The independent MMUs play this role

[12] The term "market power" is often used interchangeably with "monopoly power." Both refer to a supplier's ability to manipulate prices, which, in competition, is impossible. Two decades ago in California, some suppliers controlled enough of the supply, at certain times and in certain places, that they were able, by withholding small amounts of generation from the market, to drive up the price for energy to more than offset their revenue losses from reduced production. They made more money by producing less output than they would have in a competitive market. That is the very definition of monopoly.

[13] Federal Energy Regulatory Commission, Docket Nos. RM07-19-000 and AD07-7-000, Order 719 on October 17, 2008, pp.169-247. https://www.ferc.gov/whats-new/comm-meet/2008/101608/E-1.pdf

and contribute to the ongoing discussions and rule changes within each ISO/RTO. This is important because market rules need to be constantly reevaluated in light of market performance and evolving circumstances.

- Publish detailed reports on the performance of the ISO/RTO markets on a timely (at least quarterly) basis. In addition to informing discussions about market rule changes, the reports are important sources of information about market conditions for existing and prospective market participants and help to increase the transparency and efficiency of the market.
- Provide inputs to the market power mitigation processes in each ISO/RTO. The independent MMUs typically play a role in the automated processes that constantly screen for noncompetitive bids. This may also include assisting in estimating operational costs (i.e., what in the U.S. is known as the reference level) for specific generators and other resources, which provide a key yardstick for detecting and mitigating market power.

- FERC exposes suspected rule violations on the part of market participants or the ISO/RTO management.
- It requires each ISO/RTO to have detailed rules and procedures for detecting and mitigating (i.e., correcting) market manipulation before it occurs. In these rules, the emphasis is on preventing market manipulation rather than punishing it afterward. In other words, market power mitigation serves to adjust offers from participants who have failed predefined tests (this is called the structural approach) or whose bids fail screens for "conduct and impact." These detailed rules are intended to immediately correct the behavior of market participants that submit, or are in the position to submit, offers (bids) that exploit market power. This process allows the ISO/RTO to immediately require that such offers be mitigated, or lowered to an appropriate level, according to rules that were developed through public processes and to which all participants must adhere. In addition, FERC has authority to investigate and penalize market participants who have exercised market power in the past.
- Crucially for economic dispatch, FERC also requires that ISOs/RTOs collect data to estimate operational costs of generation units. The ISOs/RTOs use these estimates, or reference levels, to judge whether the market is competitive, whether the market is leading to outcomes consistent with economic dispatch and whether any generators are exercising market power. The estimates are also used to correct the bids of market participants — that is, to establish the level to which offers are mitigated. The estimates are based on data about the operational costs of each generating unit (and comparable resources). For example, for a coal-fired generation unit, key data include the cost of coal faced by the unit and the efficiency with which the unit burns coal at different levels of output.

In China, an effective regulatory structure will be important for ensuring that the new spot markets deliver meaningful benefits: reduced operational costs (improved dispatch), better investment decisions and lower emissions. Policymakers in China should consider doing the following:

- Develop and publish a detailed structure and authority for the collection of data on operating costs and the creation of reference levels for each resource that are calculated and updated based on that data.
- Develop and publish detailed rules for market power screening and mitigation procedures. In short, it should be very clear how and when a generator's bid will be mitigated to the reference levels, and these reference levels should be clearly linked to the operating cost of the generator. Having these procedures in place will be particularly important in the initial years of spot market operation, when insufficient competition and market design problems may be severe. For example, presence of a dominant generation owner in any particular province or region may lead to weak competition, but this problem can be alleviated by adjusting the bids of the dominant generator according to well-designed reference levels. That is, economic dispatch can be achieved according to estimated reference levels where bids are subject to distortion by monopoly.
- Establish independent market monitors, with clearly stated authority, responsibility and access to data. Policymakers should consider setting a basic principle that market regulation and market monitoring focus on supporting least-cost dispatch and a level playing field for clean energy resources. The market monitor should publish regular reports on market efficiency and on operational/dispatch outcomes in each province. The reports should also include recommendations for any market rule changes needed to ensure a level playing field, including for distributed energy resources and demand-side resources (including demand response).

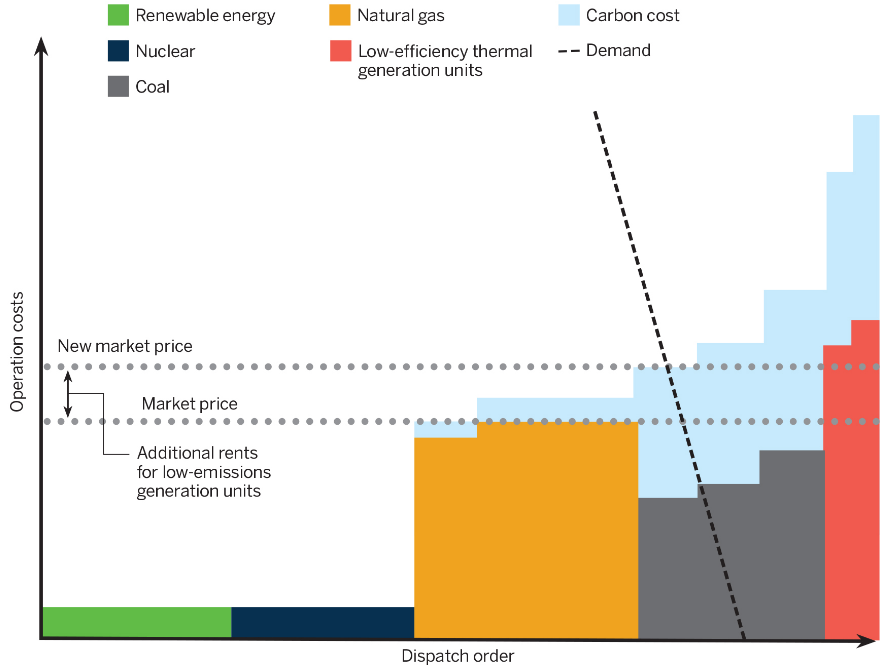
Effect of Carbon Pricing on Electricity Market Prices

A price on carbon emissions in the power sector is manifested by an increase in the variable (operating) costs of thermal (fossil fuel-fired) generators. The increase is easily calculated: It is the product of the price of a ton of carbon dioxide emissions and the number (or fraction) of tons a generator emits per megawatt-hour of output. The amount of emissions that a generator produces is a direct function of the fuel being used and the plant's thermal efficiency: The more efficient it is, the less carbon it emits.

In systems that rely on economic dispatch, the carbon price can alter the order in which plants are dispatched. The more efficient plants and the ones that use less carbon-intensive fuels will operate more than they would have, absent the carbon price. The magnitude of this change in operation hours depends on the level of the carbon price and the relative prices of the different fuels, among other factors. If dispatch is determined by a competitive energy market in which all suppliers receive the single market-clearing price (which is determined by the most expensive bid among all the bids necessary to meet demand in the period), then one sure effect of a carbon price is that non-emitting generation and thermal units that are able to operate at a lower cost than the new market-clearing price will see an increase in their revenues. The energy markets in Europe and North America, as well as in China's spot market pilots, are in fact designed this way. In these markets, generators have a financial incentive to reduce emissions and improve their efficiency. This is a central aim of carbon markets, and it depends on a well-functioning approach to economic dispatch.

Figure 2 provides an expanded view of the right side of Figure 1. It illustrates how a carbon price increases the overall cost of generation in a competitive wholesale energy market where all suppliers of energy needed to meet demand for that particular interval receive the market-clearing price. In Figure 2, the vertical line slanting to the left represents electricity demand at a certain moment in time and shows how demand is slightly responsive to price, as less capacity is required to meet demand at higher prices. The clearing price is the point on the vertical axis where the electricity demand line crosses the supply curve.

Figure 2. Influence of carbon price on generation costs, revenues and dispatch order



Source: Dupuy, M., and Li, A. (2016). *Topics in Carbon Market Design: Power Sector Dispatch Reform and China's National ETS*

In this illustration, the operating cost of a coal plant determines the clearing price. When a carbon price is applied and where the marginal plant is fossil fueled, the clearing price increases and all generators that clear in the market receive additional income (this portion of generator revenue above the generator's operating cost is called inframarginal rent). Whenever a fossil-fueled unit is on the margin (i.e., when it sets the clearing price), any resource receiving market-based prices will receive added revenue from the carbon-influenced clearing price. For low-carbon generation (the wind and nuclear plants in the figure), the added revenue exceeds added costs, and the carbon price delivers increased profits. Even the relatively low-cost fossil-fueled units benefit from this effect, as they also receive the higher clearing price, and the additional revenue will pay back some, all or more than the cost of the carbon allowances, depending on its carbon intensity (i.e., thermal efficiency) relative to the marginal (market price-setting) plant.[14] In Figure 2, the coal plant must pay for its emissions, but it still runs, and the higher clearing price will allow it to recover about half of its carbon charges.

Carbon pricing, in principle, should affect power sector dispatch. However, in practice, European and U.S. experience shows that it takes a high carbon price to significantly affect dispatch and drive down carbon emissions, and policymakers in those places have appeared unwilling or politically unable to set such high carbon prices.[15]

Mitigating the Impacts of Carbon Pricing on Electricity Prices

Power market and carbon market designers in Europe and North America have recognized the impact of carbon prices on electricity prices (what can be called the "problem of inframarginal rents") and have developed ways to cope with it. These take two general forms: (1) investment of revenues from carbon allowance auctions in emissions-reducing measures such as end-use energy efficiency and renewables and (2) "virtual" or "shadow" carbon pricing applied to emissions to alter dispatch while mitigating the impact on market clearing prices.[16]

Investing in Emissions-Reducing Measures: Regional Greenhouse Gas Initiative

RGGI was the first carbon allowance trading program in North America. It was developed during the mid-2000s and launched in 2008. It is a voluntary program among 10 states in the Northeast and mid-Atlantic regions of the U.S. So far, it applies only to greenhouse gas emissions from the power sector.

The designers of RGGI — who worried that the addition of a carbon price to market prices for electricity would result in higher inframarginal rents (often described as windfall profits) for some generators, especially carbon-emitting generators, while not producing meaningful reductions in emissions — made two structural decisions that proved critical to the program's efficacy. The first was allowance allocation through auctions: Emitters of greenhouse gases would have to pay for the ability to do so. The second was the dedication of all or a portion of the auction revenues to investments in greenhouse gas-reducing measures, primarily end-use energy efficiency.

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[14] Cowart, R., Bayer, E., Keay-Bright, S., and Lees, E. (2015). *Carbon caps and efficiency resources: Launching a "virtuous circle" for Europe*, p. 13. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/carbon-caps-and-efficiency-resources-launching-a-virtuous-circle-for-europe/

[15] Caps or other means of keeping allowance prices below specified levels are evidence of this reluctance. The Regional Greenhouse Gas Initiative (discussed in the following section) has a "cost containment reserve" of extra emissions allowances, which will be released to the market if the allowance price exceeds a specified level (U.S. $13 per short ton in 2021). Interestingly, there is a like mechanism to remove allowances from the market if the price falls below a specified floor (U.S. $6 per short ton in 2021). Together, these tools keep allowance prices within acceptable bounds. See Regional Greenhouse Gas Initiative. (n.d.). *Elements of RGGI.* https://www.rggi.org/program-overview-and-design/elements

[16] Other actions, such as the price floors that the United Kingdom has imposed on carbon allowances that its participants in the EU Emissions Trading Scheme must purchase, are not designed to mitigate the economic impacts of the carbon market but rather to ensure a minimum revenue level from the allowance auctions and, at times of low allowance prices, to maintain a stronger incentive to reduce emissions.

The RGGI designers considered several approaches for allocating the allowances that their cap-and-trade program would create. In the end, they settled on auctions because auctioning is the most economically efficient way of doing so and it provides an administratively simple means of securing the revenues for public purposes. Moreover — and this was especially important — the designers recognized that, even if allowances were given to emitters for free, their value would nonetheless be recognized in the wholesale electricity markets, and consumer prices would rise to reflect that value. This is because emitters, once they are in possession of the allowances, have a choice about what to do with them: They can use them to cover their own emissions or they can sell them to other emitters. Either way, they will not forgo that value; they will capture it in their supply bids in the electricity markets.

This was not a theoretical problem at all. The RGGI designers had seen what had transpired in Europe. In the very first compliance period under the European Union Emissions Trading System (ETS), utilities in the UK and Germany included the allowance value in their recoverable expenses, even though allowances had been given to utilities *for free*. That meant that European consumers paid for them (and for the additional inframarginal rents given to lower-emitting generators), despite their governments collecting no revenues for them.[17, 18]

By deciding to auction the carbon allowances, the RGGI designers ensured that the total direct cost of the allowances would be collected from generators and be available for public uses. To this degree, at least, consumers would be "compensated" for part of the increased cost of electricity caused by the carbon price. But the designers went further and determined that the auction proceeds should be dedicated explicitly to carbon-reducing measures and other consumer benefits: energy efficiency, clean energy investments and, in limited circumstances, ratepayer rebates targeted mostly to low-income consumers. The RGGI states currently allocate approximately 60% of the allowance value for support of state efficiency programs and the remainder to other greenhouse gas abatement measures (e.g., renewables), direct bill assistance and program administration.[19] Following the successful RGGI allowance auctions beginning in 2008 and 2009, the European Union and later California incorporated auction mechanisms

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17 With free allocations, "the market price will rise through the opportunity cost pass-through of the marginal supplier, even though the allowances do not represent out-of-pocket costs for generators. This rising market price offers the possibility of windfall profits for recipients of free allowances (higher price received without a corresponding increase in input costs) as was found in the EU ETS before it auctioned allowances." Litz, F., and Murray, B. (2016, March). *Mass-based trading under the Clean Power Plan: Options for allowance allocation* (Working paper NI WP 16-04). Nicholas Institute and Great Plains Institute. https://nicholasinstitute.duke.edu/content/mass-based-trading-under-clean-power-plan-options-allowance-allocation

18 For more on the European experience, see Baldwin, R., Cave, M., and Lodge, M. (2012). *Understanding regulation: Theory, strategy, and practice*, p. 203. Oxford University Press; Sijm, J., Neuhoff, K., and Chen, Y. (2006, May). *CO_2 cost pass through and windfall profits in the power sector*. Electricity Policy Research Group. http://www.eprg.group.cam.ac.uk/wp-content/uploads/2008/11/eprg0617.pdf; and Kill, J., Ozinga, S., Pavett, S., and Wainwright, R. (2010). *Trading carbon: How it works and why it is controversial*, pp. 37-42. FERN. https://www.fern.org/news-resources/trading-carbon-how-it-works-and-why-it-is-controversial-651/

19 Hibbard, P., Okie, A., Tierney, S., and Darling, P. (2015, July). *The economic impacts of the Regional Greenhouse Gas Initiative on nine Northeast and mid-Atlantic states: Review of RGGI's second three-year compliance period (2012-2014)*, Figure 2, p. 30. Analysis Group. https://www.dec.ny.gov/docs/administration_pdf/ag15rggi.pdf

into their allowance distribution systems and dedicated a portion of the revenues for public benefits purposes.[20]

The net economic benefit to the states in the RGGI region during the first three years of the program (compliance period 2009-2011) was $1.6 billion (in 2011 dollars). The states spent virtually all of the auction proceeds, over $900 million, on goods and services, specifically on energy efficiency, renewables and other public benefits programs. The direct and indirect multiplier effects of that spending — of which the largest portion was the reduction in electricity bills caused by the investment in end-use energy efficiency — was far in excess of the decrease in generators' revenues as a consequence of the efficiency spending.[21]

It also lowered the total consumer cost of electricity services enough so that the carbon savings were achieved at a net negative cost to consumers. In other words, the RGGI experience demonstrates that significant carbon reductions in the power sector can be achieved at low net cost to consumers. The two essential elements are (1) auctioning carbon allowances and (2) investing the resulting revenues into low-cost and even negative-cost resources that additionally reduce carbon emissions.

The net benefits of the next two compliance periods (2012-2014 and 2015-2017) were roughly the same: By redirecting the auction revenues, the RGGI states reaped 130% to 160% in economic value. Furthermore, this was accomplished in the third compliance period when the emissions cap was cut by more than half (from approximately 188 million tons per year to 91 million in 2014 and by 2.5% per year thereafter), and as a consequence, the price per ton emitted rose (by an average of $1.67 over the three-year period).[22]

Finally, we note that the short-term effect of the carbon price on electricity prices was offset in the longer run by the downward pressure put on prices by that investment in end-use efficiency. During the 2009-2011 period, for example, the market's inclusion of allowance costs in wholesale prices caused a short-run bump in consumer electricity prices of about 0.7% during the 2009-2011 period. However, consequence of reductions in demand associated with the investment in energy efficiency caused market prices to fall in the longer run.[23] Consumers saved money both because they purchased less electricity and because their reduced demand lowered the price of that electricity.

[20] Santikarn, M., Kardish, C., Ackva, J., and Haug, C. (2019). *The use of auction revenue from emissions trading systems: Delivering environmental, economic, and social benefits.* International Carbon Action Partnership. https://icapcarbonaction.com/en/?option=com_attach&task=download&id=646. See also Littell, D., and Farnsworth, D. (2016, April). *Carbon markets 101: "How-to" considerations for regulatory practitioners*. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/carbon-markets-101-how-to-considerations-for-regulatory-practitioners/

[21] Hibbard, P., Tierney, S., Okie, A., and Darling, P. (2011, November). *The economic impacts of the Regional Greenhouse Gas Initiative on ten Northeast and mid-Atlantic states*, pp. 2-6, 31 and subsequent. Analysis Group. https://www.analysisgroup.com/Insights/publishing/the-economic-impacts-of-the-regional-greenhouse-gas-initiative-on-ten-northeast-and-mid-atlantic-states/

[22] Darling, P., Hibbard, P., and Tierney, S. (2018, April). *The economic impacts of the Regional Greenhouse Gas Initiative on nine Northeast and mid-Atlantic states: Review of RGGI's second three-year compliance period (2015-2017)*, pp. 4-19. Analysis Group. https://www.analysisgroup.com/Insights/publishing/the-economic-impacts-of-the-regional-greenhouse-gas-initiative-on-nine-northeast-and-mid-atlantic-states--review-of-rggis-third-three-year-compliance-period-2015-2017/

[23] Hibbard et al., 2011, pp. 7, 34.

Reflecting Carbon Costs Through Shadow Pricing: New York ISO Proposal

The New York Independent System Operator (NYISO) manages a competitive wholesale market among investor-owned utilities, publicly owned utilities and independent power producers and ensures security of supply across the state. New York's Legislature and governor have adopted very ambitious climate change legislation requiring that, by 2040, all electricity serving New York must come from zero-emissions sources.[24] However, as recently as 2018, 40% of New York's power supply came from fossil-fueled generators.[25] New York has adopted a suite of energy efficiency and decarbonization policies to meet its climate targets.

In support of this package, the NYISO has developed a proposal to reflect the social cost of carbon emissions in the wholesale power market, while moderating its impacts on total system costs and consumer bills.[26] This plan would thus build in some protections against the cost impacts of carbon prices, as they are magnified in "single clearing price" competitive power markets. The proposal has been designed, studied and amended over a two- to three-year period and is now awaiting approval by the state of New York and FERC.[27]

The key elements of the NYISO carbon pricing proposal are as follows:

- Unlike a carbon cap-and-trade program, in which the price of carbon will fluctuate, the NYISO program will use a fixed carbon price. This is intended to deliver quite clear signals to plant owners and investors for a period of years as to what the cost of emissions will be for emitters and what the added value of low-carbon resources will be for renewable and nuclear generators. The NYISO does not intend to determine this value itself but rather to rely on a social cost of carbon per ton of emissions set by the state's energy and environmental agencies.

- This carbon price will be added to each generator's bid price in the competitive wholesale power market administered by the NYISO and will thus affect the merit order dispatch in each market-clearing period (each hour or part-hour across the year).

- However, fossil units do not actually receive all of the benefit of the higher clearing price that will often result. Fossil generators' payments *from* the market settlements pool are reduced to reflect a deduction for the carbon charges related to their emissions. That is, dispatch will be reordered to reflect the effect of the carbon price on bids, and purchasers of power (the load-serving entities, or LSEs) will pay the higher cost of system operation. However, the generators will be required to pay for the emissions they produce (i.e., tons

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[24] Dewey, R. (2020, February 4). Carbon pricing proposal in New York provides path to nation's clean energy future. *The Hill*. https://thehill.com/opinion/energy-environment/481332-carbon-pricing-proposal-in-new-york-provides-path-to-nations-clean

[25] U.S. Energy Information Administration. (2019, August 15). *Profile analysis. New York state profile and energy estimates.* https://www.eia.gov/state/analysis.php?sid=NY

[26] New York Independent System Operator. (2018, December 7). *IPPTF carbon pricing proposal: Prepared for the Integrating Public Policy Task Force*. https://www.nyiso.com/documents/20142/2244202/IPPTF-Carbon-Pricing-Proposal.pdf/60889852-2eaf-6157-796f-0b73333847e8. This was the original proposal. It has since been modified as described herein.

[27] For a thorough review of this proposal see Tierney, S. F., and Hibbard, P. J. (2019, October 3). *Clean energy in New York state: The role and economic impacts of a carbon price in NYISO's wholesale electricity markets.* Analysis Group. https://www.nyiso.com/documents/20142/2244202/Analysis-Group-NYISO-Carbon-Pricing-Final-Summary-for-Policymakers.pdf/75a766a8-623f-c105-ddcf-43dd78cb4bca?t=1570098881971

of carbon emitted times the social cost of carbon), and these monies will be refunded to the load-serving entities to offset in part the higher cost of the reordered dispatch.[28]

- Meanwhile, suppliers of power with zero or low carbon emissions do benefit from higher net revenues because a portion of the inframarginal rent is passed on to them in the settlements process.
- Although a portion of the incremental costs of reordered dispatch is refunded to the load-serving entities, the LSEs will nevertheless receive the price signals that the carbon program creates. New York has for years settled its power markets on a locational basis, with 11 different price zones across the state, reflecting the differences in power availability and the costs of transmission congestion in different places at different times. (One reason is that large wind farms are located in the northern part of the state, far from the major load centers around New York City in the south.) Under the carbon pricing proposal, LSEs would still be exposed to locational prices, but now those prices would reflect carbon-related costs in each zone. For this reason, low-carbon resources located in a high-price zone would be even more valuable than similar resources far from the state's main load centers, giving a powerful signal to investors to keep and build new low-carbon resources in those locations.
- Imports of power into New York will also be included in the carbon pricing plan to avoid giving imports a competitive advantage over in-state generators and to avoid so-called carbon leakage (adding emissions outside the carbon regime).
- The NYISO carbon pricing plan is designed to moderate the consumer costs that would otherwise result from simply flowing a carbon tax into the wholesale market in three ways. First, the settlements process does not return to the highest-emitting units the full value of increased clearing prices resulting from inclusion of carbon prices in their bid prices. Second, the settlements process delivers to LSEs a portion of the inframarginal rents that would otherwise flow to all generators in the settlements process, to be used to lessen the impact of the scheme on retail consumers. And third, it is expected that, by delivering higher prices to zero- and low-emitting generators via the power market, it will be possible to minimize the amount of direct subsidies and price supports that have been offered to renewable generators in other programs and which are reflected in power rates today.

The NYISO carbon pricing proposal is not yet implemented. Nevertheless, it reveals some important lessons about ways to integrate carbon pricing and power market operations. The carbon charge imposes a predictable cost on the highest-emitting fossil generators while restricting their ability to simply recover that cost in higher power prices. Meanwhile, it delivers new revenues to zero- and low-emitting generators to keep existing units, including nuclear generators, in operation and to encourage investors in new renewable generation. By recovering and returning a portion of the inframarginal rents to LSEs, it shows one way to reduce the cost of carbon pricing for retail consumers. And it builds on New York's important policy of delivering both time-varying and location-sensitive power pricing.

Because this program would not directly deliver carbon revenues to energy efficiency programs, it does not take advantage of one of the lowest-cost and widely available resource options to reduce greenhouse gases: end-use energy efficiency. But it would operate alongside a number of

[28] Tierney and Hibbard, 2019, p. 8. It will be managed through the settlements process.

very strong efficiency programs in New York, including those delivered by utilities and by state government and those supported by RGGI revenues, so this omission is not a major problem in context. In the absence of these other efficiency programs, it would be important to recycle a substantial portion of the additional revenue generated in the wholesale market to support low-cost, low-emissions resources, particularly end-use energy efficiency.

California Cap-and-Trade Program

California has a carbon pricing scheme that, like RGGI, features a significant role for allowance auctioning, the revenue from which is used to mitigate cost impacts on consumers of carbon pricing. Unlike the RGGI states, however, California returns most of the allowance revenues to consumers as credits on their bills. This lowers each consumer's overall bill, but because the carbon cost is still reflected in the retail electricity price, it does not fully dampen the incentive that carbon pricing gives each consumer to reduce electricity consumption.

The California cap-and-trade program is part of the Western Climate Initiative, which is the largest carbon market in North America.[29] It is a multisector program that covers electricity generation and imports, large industrial facilities and either fuel suppliers (California) or fuel distribution and importers (Quebec).[30] The California and Quebec programs are linked, and compliance instruments, such as allowances issued by each jurisdiction, are to be used for compliance with each program.[31]

In California, allowances are distributed via auctions, which are held four times annually, and by free allocation that varies according to sector. Electric distribution utilities and natural gas suppliers, known as consigning entities, receive allowances on behalf of their ratepayers, known as consignment allowances.[32] Consigning entities (utilities) are required to sell consignment allowances at the allowance auctions. The utilities are then required to use the proceeds from the sale of these allowances for ratepayer benefit and for emissions reductions.[33] The amount of allowances granted to the utilities declines over time, effectively decreasing the emissions cap; if the utility generates emissions, other allowances must be purchased to account for those emissions at auction or may be traded.[34]

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[29] Western Climate Initiative, Inc. (2020, April 23). *WCI, Inc. participating jurisdictions overview*. https://wci-inc.org/assets/participatingjurisdiction-comparativetable-en.pdf

[30] Western Climate Initiative, Inc., 2020.

[31] California Air Resources Board. (2020, April 13). *Auction information.* https://ww3.arb.ca.gov/cc/capandtrade/auction/auction.htm

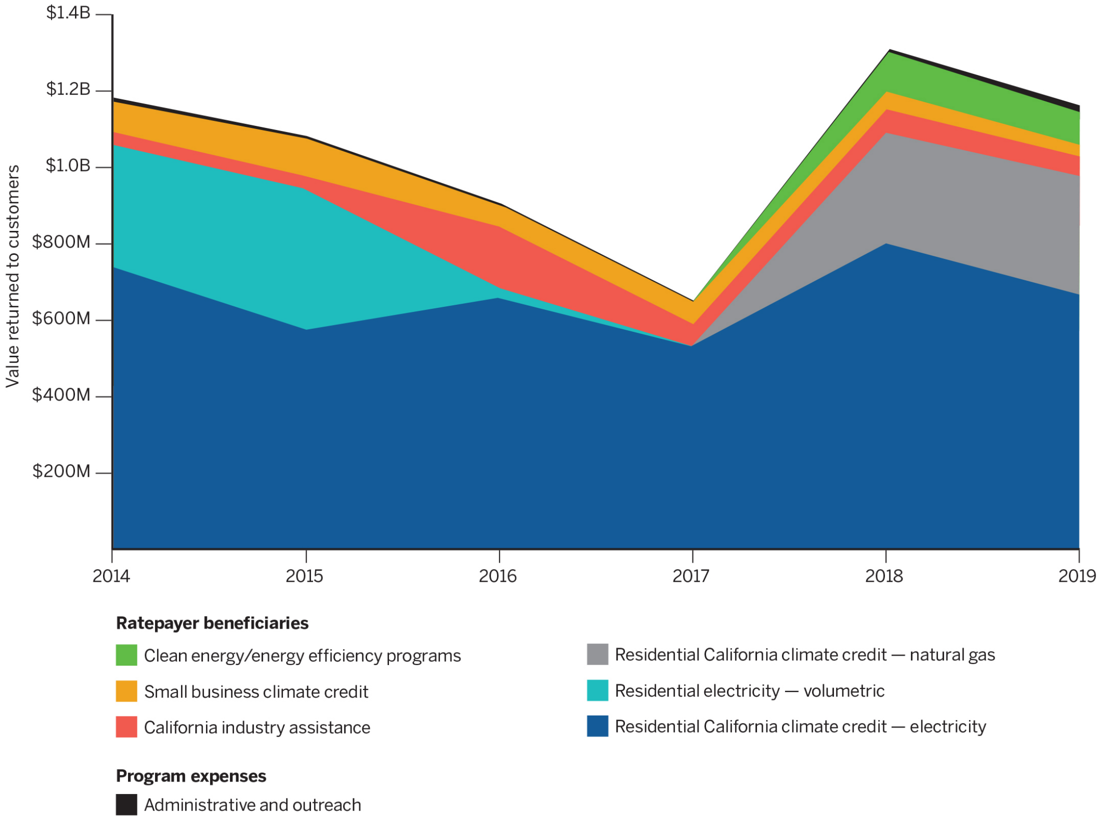
[32] Carmody, C. (2019). *A guide to emissions trading under the Western Climate Initiative*. Centre for International Governance and Innovation. https://www.cigionline.org/publications/guide-emissions-trading-under-western-climate-initiative

[33] Carmody, 2019.

[34] Center for Climate and Energy Solutions. (n.d.). *California cap and trade.* https://www.c2es.org/content/california-cap-and-trade/

Investor-owned utilities in California must distribute the funds generated by the consignment allowances as credits to residential customers, small businesses and industry and for clean energy and energy efficiency programs. Figure 3 shows the various ratepayer beneficiaries of these funds.[35]

Figure 3. Distribution of California investor-owned utility cap-and-trade program proceeds to customers



Source: California Public Utilities Commission. (n.d.) *Greenhouse Gas Cap-and-Trade Program*

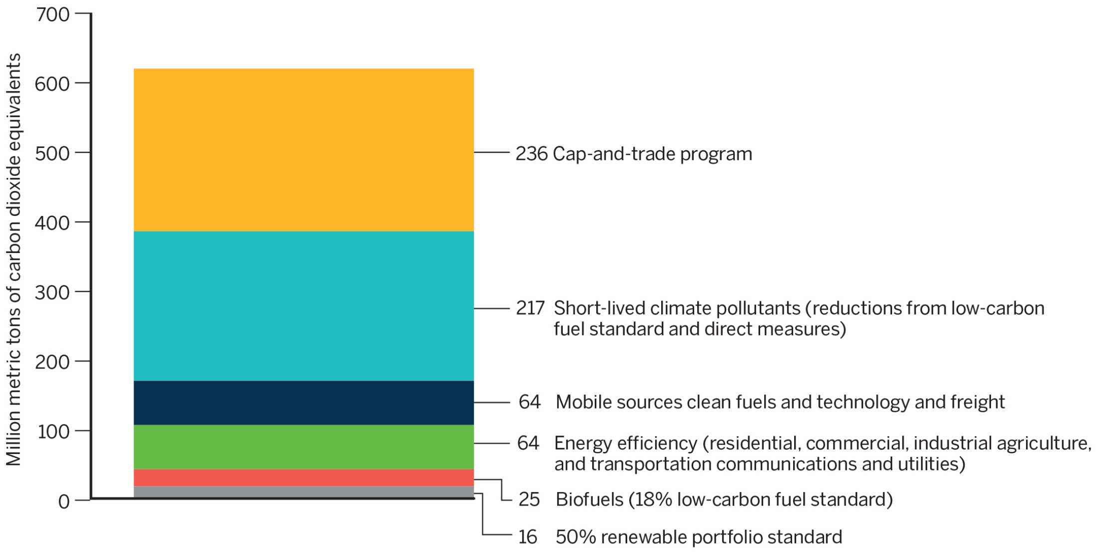
California's cap-and-trade program is only one element of a broader climate change initiative under California law. The state has also implemented an aggressive renewable portfolio standard, a low-carbon fuel standard and a variety of land use and energy efficiency standards and incentives, including an integrated resource planning process.[36] In some respects, the cap-and-trade program in California acts as a backstop to ensure that its overall greenhouse gas target is met, regardless of the performance of these other complementary measures. Figure 4 on the next page shows projected carbon reductions from the cap-and-trade program in comparison with carbon reductions anticipated through the other policies.[37]

[35] California Public Utilities Commission. (n.d.). *Greenhouse gas cap-and-trade program.* https://www.cpuc.ca.gov/General.aspx?id=5932

[36] California Public Utilities Commission, n.d.

[37] California Air Resources Board. (2017, November). *California's 2017 climate change scoping plan: The strategy for achieving California's 2030 greenhouse gas target.* https://ww3.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

Figure 4. Projected cumulative California greenhouse gas reductions by measure, 2021-2030



Source: California Air Resources Board. (2017). *California's 2017 Climate Change Scoping Plan: The Strategy for Achieving California's 2030 Greenhouse Gas Target*

Mitigating the Impacts on Electricity Prices: Conclusions From International Experience

What is needed to drive deep decarbonization in the power sector is the replacement over time of carbon-emitting generation with non-emitting supply and demand resources.

The practice of putting a price on carbon emissions creates political challenges for power sector policymakers. Using carbon pricing to drive deep decarbonization of the power sector would require a carbon price that substantially raises retail prices. The trick for market designers is to motivate the most important results of carbon pricing — more efficient dispatch (operational) decisions, reduced investment in and retirement of emitting generation, and increased investment in non-emitting resources (including demand-side resources) — while avoiding or mitigating higher electricity costs. Put another way, the object should be to abate emissions at the minimum cost and without causing consumers a large amount of pain that might lead to abandonment of the carbon pricing scheme.

In the RGGI states (and now, to varying extents, also in California and the EU), this was achieved through the use of auction revenues to support energy savings measures (which lessen electricity demand), thereby reducing both emissions and consumer bills.[38] In RGGI, this was done primarily by investing the proceeds in cost-effective end-use energy efficiency measures in homes and businesses, reducing demand for wasteful electricity usage. In California, the proceeds were mostly returned to customers as credits on their electric bills; this largely avoided the immediate financial impacts of the carbon price but failed to realize the huge and continuing benefits from investment in end-use efficiency.

[38] For more information on the fraction of revenue devoted to energy efficiency (energy savings) measures, see Santikarn et al., 2019.

The NYISO proposal represents an innovative approach to carbon pricing — in particular, to the problem of mitigating the effects of carbon pricing on consumer bills. This mitigation would be achieved by rules that return the carbon charges to consumers in the form of reduced bills, in a manner similar in principle (if not in the details) to California. The New York ISO's proposal for a shadow carbon price is another approach to reordering dispatch to favor lower-emitting generation and to do so in a way that minimizes the economic impact on consumers. In the short term, it could make some improvements in the dispatch order in New York. And if the carbon charge is persistent and high enough, it could, over time, drive generator retirement and investment decisions enough to substantially affect the future generation mix.

The lesson from international experience here is that carbon markets and electricity markets can interact in subtle ways, and it is important to get the electricity market rules right to make the carbon market as effective and cost-effective as possible. Fortunately, the cases we have discussed show that there are effective models for addressing the impact of carbon pricing on electricity prices and for addressing the windfall profits (the inframarginal rents) that carbon pricing may deliver to polluting generators.

Planning and Public Policy Directives

A mistake that many power sector reform efforts around the world made was to abandon certain long-term planning practices in the expectation that the introduction of competitive markets would deliver investment in desired capacity and produce desired outcomes (e.g., increasing renewables and end-use efficiency, improving air quality, mitigating climate change). However, markets, as we noted in the earlier section on generator compensation, produce only what they are designed to produce, and often they were designed to produce only electricity at the lowest financial cost. This shortsightedness meant, for example, that the Northeastern and mid-Atlantic U.S. power systems are heavily invested in natural gas-fired facilities, given the transformation in the natural gas market caused by hydraulic fracturing, or fracking. This has put those systems at significant risk of fuel supply disruption and price volatility.

In the U.S., state decision-makers, seeing how markets were failing to deal with these and other shortcomings, have adopted a number of policies to manage a broader set of risks. Chief among them are renewable portfolio standards, dedicated funding for end-use energy efficiency investments, retail pricing to incentivize customer investment in clean distributed resources (rooftop photovoltaic arrays), and long-term system planning to identify the least-cost means of meeting the states' energy and environmental objectives. These policies interact with the electricity markets by influencing purchase decisions by both utilities and customers, to which the market ultimately must respond.

Planning and other public policies that establish desired outcomes and put obligations on market participants are not incompatible with markets and competition. They are, in fact, complementary: Planning and policy express what a society wants to achieve. Competitive tools (e.g., wholesale electricity markets, competitive bidding and auctions) make it possible to achieve a society's goals at lowest cost.

China has a long history of planning and implementing its plans. What needs to happen now is for power sector planning to work in an integrated fashion with both carbon market design and electricity market design. Competition is a tool, not an end in itself. Planning and public policy can put it to good use.

Retail Pricing

Internalization of a carbon cost in wholesale prices for electricity will, in principle, lead to higher retail prices, assuming that retail prices are adjusted to reflect costs. However, consumers typically are not very sensitive to changes in retail prices, in the short run at least, and so large price increases are required to spur consumers to invest in energy savings measures.[39] That doesn't mean, however, that retail prices can't give end users important signals about when and how to use electricity. In particular, there are modes of time-based pricing that, if they are reflective of the underlying time-varying wholesale prices, can encourage consumers to modify their usage in ways that will reduce the overall cost of the power system and provide system operators with greater flexibility to integrate renewable and other clean resources into the system.

It is in this alignment of retail prices with wholesale costs (including the carbon price) that the importance of merit order (economic) dispatch lies. As described in the earlier section on power sector dispatch, merit order dispatch reveals the changing cost of production in real time, as demand goes up and down. To the extent that retail prices can reflect these changes in wholesale cost, customers are made aware of the relative value of consumption at different times of the day and can adjust their usage to minimize their costs of using electricity. A cost of carbon included in those wholesale prices will provide further evidence of the real costs to society of consumption at different times. As consumers change their behavior in response to those price signals, the economic efficiency and environmental performance of the power sector should improve.

China has extensive experience with time-of-use pricing in the commercial and industrial sectors. It has also curtailed demand through administrative means when system security (power supply shortfalls) have required it. These actions changed load shapes, but because China's approach to dispatch was not based on the relative variable costs of generating units, they cannot be found to have minimized the total cost of operations or output of emissions.

The steady evolution of China's power sector — its movement toward merit order dispatch and the incorporation of carbon costs in operations — will provide the economic basis on which to develop cost-based rate designs. These in turn will complement the purposes of the market reforms and carbon pricing by encouraging more efficient use of energy.

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[39] Neenan, B., and Eom, J. (2008, January). *Price elasticity of demand for electricity: A primer and synthesis*, p. 20. Electric Power Research Institute. https://www.researchgate.net/publication/269693689_Price_Elasticity_of_Demand_for_Electricity_A_Primer_and_Synthesis

Conclusion

Policymakers and other stakeholders who are closely involved with design and implementation of carbon markets also have an important role to play in discussions about power sector reform and the development of electricity markets. Carbon trading will not be effective without rational power sector reform and electricity market implementation. At the same time, carbon trading can help support the goals of power sector reform, including goals for emissions reduction, cost-effectiveness and new energy transformation. This paper has discussed international experience regarding the interplay of these reform efforts and stressed that carbon trading and electricity markets should not be designed in isolated silos.

Electricity markets and carbon trading have been in place for decades in various places in the world. Even in countries and regions with many years of experience, however, there is ongoing debate and refinement of market rules and coordination mechanisms. As China's policymakers continue to move forward in these areas, there will be much to be gained from continued international sharing of knowledge on these topics.

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