Received: 20 November 2018 | Revised: 28 January 2019 | Accepted: 2 February 2019

DOI: 10.1002/wene.342

WIREs ENERGY AND ENVIRONMENT WILEY

ADVANCED REVIEW

A review of international practices for energy efficiency and carbon emissions reduction and lessons learned for China*

Xu Liu[1] | Bo Shen[1] | Lynn Price[1] | Ali Hasanbeigi[2] | Hongyou Lu[1] | Cong Yu[3] | Guanyun Fu[3]

[1]China Energy Group, International Energy Analysis Department, Energy Analysis and Environmental Impacts Division, Energy Technology Area, Lawrence Berkeley National Laboratory, Berkeley, California

[2]Global Efficiency Intelligence, LLC, San Francisco, California

[3]Energy Efficiency Center, Energy Research Institute of the National Development and Reform Commission of China, Beijing, China

Correspondence
Xu Liu, China Energy Group, International Energy Analysis Department, Energy Analysis and Environmental Impacts Division, Energy Technology Area, Lawrence Berkeley National Laboratory, Berkeley, CA 94720.
Email: xuliu@lbl.gov

Funding information
Energy Foundation China

China's industrial sector dominates the country's total energy consumption, and improving energy efficiency in that sector is crucial to help China reach its energy and carbon dioxide emissions reduction goals. There are many energy efficiency policies in China, but the motivation and willingness of enterprises to improve energy efficiency has weakened. This article first identifies barriers that enterprises face to be self-motivated to implement energy efficiency measures and then categorizes these barriers into four categories: awareness, information, technical capacity, and financial availability. It then reviews international policies and programs to improve energy efficiency, and evaluates how these policies have helped to address the barriers identified. We found that policies and programs in energy efficiency and carbon reduction need to go hand in hand to incentivize companies, and that those policies and programs send clearer signals and help change enterprises' decisions when they are persistent but dynamic. Our specific policy recommendations to China fall under three key categories: identification of energy efficiency potential, workforce development, and market channels for energy efficiency financing.

This article is categorized under:
Energy and Climate > Economics and Policy
Energy Efficiency > Economics and Policy
Energy Efficiency > Climate and Environment

KEYWORDS
China, energy efficiency, industry sector, international, program, Top-10,000

1 | INTRODUCTION

China's industrial sector dominates the country's total energy consumption, accounting for about 70% of total primary energy use and energy-related carbon dioxide (CO_2) emissions (Figure 1) (Intergovernmental Panel on Climate Change, 2003; National Bureau of Statistics, 2016; U.S. Energy Information Administration, 2016). Compared with levels in most advanced economies, China's overall energy efficiency is reported to be almost 10% lower. Energy intensity (energy consumption per unit of production) for power, iron and steel, non-ferrous metals, petrochemicals, and other major industrial products is significantly higher than levels in developed countries (Current Affairs Reports, 2010).

Improving industrial energy efficiency is crucial for China to meet its new 13th Five-Year Plan (2016–2020) goals for achieving energy intensity reduction by 15% and reducing particulate matter ($PM_{2.5}$) emissions in 30% of Chinese cities to

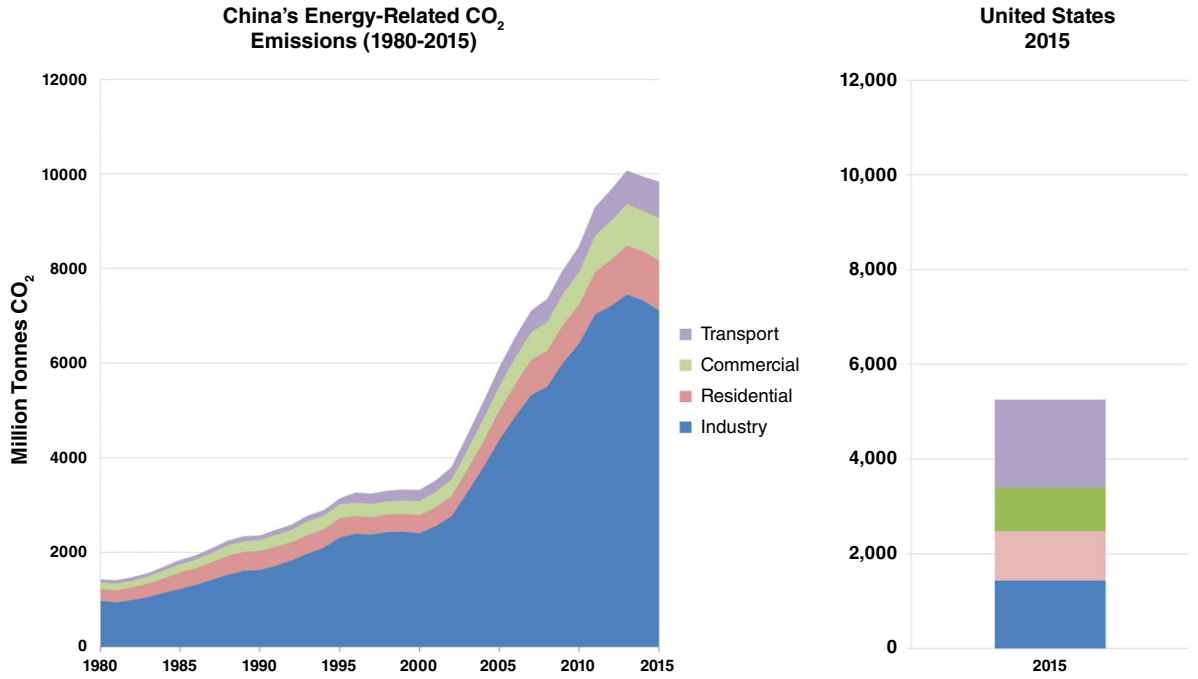

FIGURE 1 China's energy-related carbon dioxide emissions and its comparison with the United States, 1980–2015

below the required level of the national standards. Energy efficiency improvements also are necessary to meet China's Paris Agreement pledges of achieving a CO_2 emissions peak around 2030 or earlier, of increasing the share of non-fossil fuels in primary energy consumption to about 20% by 2030, and of reducing its carbon intensity by 60–65% in 2030 over 2005 levels.

China has implemented a series of policies and programs to improve industrial energy efficiency. Zhou, Levine, and Price (2010) provided a comprehensive review and assessment of energy efficiency policies in China before 2010. They concluded that the energy efficiency policies in China entered a new era after 2006, with the creation and implementation of many related laws, regulations, and new programs. Yuan, Kang, Yu, and Hu (2011) evaluated the achievements of energy conservation and emissions reduction policies in China from 2006 to 2010. A more recent review study by Yang, Hu, and Yuan (2016) analyzed energy efficiency policies in China from 1978 to 2013. The study pointed out that most energy efficiency policies in China are top-down regulations, and that future policy development should be based on market mechanisms.

Among all those policies, the Top 10,000 Program, introduced during the 12th Five-Year Plan (2011–2015) as an expansion and continuation of the Top 1,000 Program during the 11th Five-Year Plan, is the most comprehensive national program in the industrial sector to improve energy efficiency. Total energy consumption of covered enterprises accounted for 60% of national energy use, with 5.5 gigatons of CO_2 ($GtCO_2$) emissions. Even though accumulated energy savings of the Top 10,000 Program has surpassed the program target (National Development and Reform Commission, 2015), the willingness and self-motivation of companies to invest in energy efficiency improvements have weakened.

To help China achieve its ambitious energy and carbon goals given enterprises' decreasing motivation in industrial energy efficiency, it is crucial to explore mechanisms and policies to incentivize those enterprises to improve energy efficiency more proactively. Several review papers have focused on industry sector energy efficiency policies in China and around the globe (Abdelaziz, Saidur, & Mekhilef, 2011; Lo, 2014; Yang et al., 2016; Yuan et al., 2011; Zhou et al., 2010). However, they did not analyze how policies could help to solve problems industrial companies currently face (e.g., a lack of funding/financing, a lack of technical expertise and personnel, a lack of practical information on technologies and products, and difficulties using energy performance contracting; EPC) and why these kinds of policies are necessary. This article provides a framework to organize existing problems into four categories (awareness, information, technical capacity, and financial availability), reviews existing international policies and programs, and discusses how those policies and programs help to address these four types of problems.

2 | THE TOP 10,000 ENTERPRISES PROGRAM

In 2011, China's National Development and Reform Commission (NDRC) initiated the Top 10,000 Energy Efficiency and Low Carbon Action Program ("Top 10,000 Program") for industries, transportation, businesses, hotels, schools, and other key energy consuming enterprises that consume more than 10,000 tons of coal equivalent (tce)[1] of annual primary energy, as well

as some key energy consumption enterprises that consume more than 5,000 tce of primary energy annually. In 2010, a total of 16,078 enterprises were included in the Top 10,000 Program, with a total primary energy consumption of about 2.1 billion tce, which accounted for 60% of national energy use, and resulted in the emission of 5.5 $GtCO_2$. More than 90% of the Top 10,000 enterprises are industrial enterprises (NDRC, 2011).

The Top 10,000 Program enterprises are concentrated in Shandong, Jiangsu, Hebei, Henan, Guangdong, Liaoning, Shanxi, Inner Mongolia, Sichuan, and Zhejiang provinces. In these provinces, enterprises in the Top 10,000 Program consume about 1.3 billion tce, accounting for more than 60% of the total energy consumption of all enterprises under the program and more than 35% of national energy use. Their CO_2 emissions are about 3.3 $GtCO_2$. The 2015 evaluation of the Top 10,000 Program by NDRC included the current 13,328 enterprises (2,750 enterprises had moved away or been restructured, shut down, or eliminated since 2010). By the end of 2014, about 82% of the enterprises evaluated had achieved or exceeded their energy saving targets, 11% basically achieved their targets, and about 7% failed to achieve their targets. From 2011 to 2014, the accumulated energy savings of the Top 10,000 Program was 309 million tce (Mtce), or 121% of the total program target for the full 12th Five-Year Plan period (NDRC, 2015). However, the willingness and self-motivation of companies to invest in energy efficiency improvements has been getting weaker and weaker.

To introduce a market-based mechanism to promote energy efficiency in key energy consuming enterprises, NDRC established carbon trading pilots in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen beginning in November 2011. By June 2014, all seven pilots had started. By the end of March 2015, the total transaction volume of the seven pilots was about 20 million tons of CO_2, with a total transaction amount of 1.3 billion yuan. Top 10,000 Program plants participate in all seven carbon markets, but Guangdong province is the only area where Top 10,000 Program enterprises dominate the carbon market.

On December 19, 2017, China officially launched its national carbon trading market. Starting with the power generation sector, China's national carbon trading market covers more than 1,700 power generation companies that have annual primary energy consumption of more than 10,000 tce, which is the same standard used in the Top 10,000 Enterprises Program. In total, all covered entities emit 3,500 million tons of CO_2, which accounts for one-third of China's total CO_2 emissions (China Dialogue, 2017). The market will establish data reporting, registration, and transaction systems by 2018; start mock trading by 2019; and start real transactions by 2020 (NDRC, 2017). The market is also expected to expand to cover seven more key sectors (i.e., petrochemical, chemical engineering, construction materials, iron and steel, non-ferrous metal, paper, and aviation) (NDRC, 2016).

Another market-based mechanism—energy savings trading programs targeting key energy consuming enterprises or energy efficiency retrofit projects—has also been initiated in Shandong, Fujian, and Jiangsu provinces. Two areas with a large number of Top 10,000 enterprises—Shandong and Jiangsu provinces—participate in these programs.

3 | CHALLENGES TO ACHIEVING ENERGY EFFICIENCY

To better understand the more specific challenges Top 10,000 enterprises face to improving energy efficiency, we conducted surveys to interview local policy-makers and companies in four provinces—Hebei, Hubei, Sichuan, and Jiangsu—which represent west, central, and east China. Questionnaires were collected from 1,307 enterprises. The enterprises' responses revealed some common issues, including a lack of funding/financing, a lack of technical expertise and personnel, a lack of practical information on technologies and products, and difficulties using EPC (Yu & Fu, 2017). These survey findings confirmed that challenges to achieving energy efficiency in enterprises are widespread in China, covering thousands of enterprises and crossing several provinces. It is a nationwide issue to address.

These challenges also have been observed in a variety of studies around the globe. Studies have shown that much of the cost-effective energy efficiency potential around the world is not captured due to obstacles and barriers that hinder the adoption of cost-effective energy-efficient technologies (Brown, 2001; Confederation of British Industry, 2015; DeCanio, 1993; Goldberg, Taylor, & Hedman, 2014; Golove & Eto, 1996; Johansson & Thollander, 2018; Trianni, Cagno, & Farné, 2016). For example, studies in the United States and the United Kingdom have identified the following issues: a lack of broad-level awareness of the benefits of energy efficiency (Confederation of British Industry, 2015; Goldberg et al., 2014), a lack of necessary skills to both build the business cases for energy efficiency investment and to implement energy efficiency measures within businesses (Brown, 2001; Confederation of British Industry, 2015; Goldberg et al., 2014; Golove & Eto, 1996), a lack of appropriate incentives to encourage energy efficiency investments, and difficulties in understanding and accessing finance (Brown, 2001; Confederation of British Industry, 2015; Goldberg et al., 2014).

These common barriers can be addressed by government interventions through targeted energy efficiency policies and programs. For example, to increase the awareness of energy efficiency within businesses, the cost of energy or carbon can be increased, and information on the benefits of improving energy efficiency can be provided to businesses. To fill in the skills

gap, technical assistance or information sharing can be provided. To incentivize energy efficiency investment, information can be provided. And grants or favorable tax treatment can be provided to reduce investment risks, and others. Table 1 lists the obstacles and potential policies or programs that could address these obstacles.

This article summarizes and evaluates international experiences on the policies and programs in Table 1. It also provides policy recommendations to China to design a program to overcome the barriers identified from the survey and to incentivize enterprises to achieve energy efficiency improvements.

"Awareness" stands for awareness of energy efficiency opportunities in enterprises. If a policy or program can address this issue, it means the policy or program could help enterprises be aware of potential energy efficiency opportunities and be willing to consider energy efficiency improvement in their managerial decisions.

"Information" stands for information gaps for enterprises. Such gaps include information on available energy efficiency measures, technologies, or products and their economics; financial benefits; and investment information of implementing energy efficiency measures. If a policy or program can address this issue, it means the policy or program could provide the information above to help enterprises make energy efficiency improvement decisions.

"Technical Capacity" stands for technical gaps in enterprises. Enterprises lack either the technical staff to identify energy efficiency opportunities and implement them, or affordable access to technical support in these areas. If a policy or program could address this issue, then it could either provide training to equip enterprises with the ability to conduct such activities, directly provide support or conduct these activities, facilitate EPC or help the engagement of energy service companies (ESCOs), or improve institutional capacity in the energy efficiency area.

"Financial Availability" stands for financial difficulties of implementing energy efficiency measures, including lack of investment incentives for energy efficiency improvement, difficulties in accessing finance, and others. If a policy or program can address this issue, it means the policy or program could reduce these financial risks or difficulties.

4 | PROGRAMS TO INCENT ENERGY SAVINGS AND EMISSIONS REDUCTION

4.1 | Carbon and energy trading

We review carbon emissions trading schemes (ETS) and energy trading schemes in this section. Carbon ETS have been adopted in a number of countries as a means to price carbon, reduce CO_2 emissions, and save energy (Aflaki, Kleindorfer, Polvorinos, & Sáenz, 2013; Altmann et al., 2013). We review policies and programs under three ETS and discuss how these policies and programs could incentivize energy efficiency. Energy trading schemes are similar, but instead of trading carbon allowances, energy trading schemes use energy savings certificates. We review the white certificate scheme in Europe and the Perform, Achieve, Trade (PAT) scheme in India.

4.1.1 | United Kingdom climate change program

The UK Climate Change Program was established in 2000 to meet both the country's Kyoto Protocol commitment of a 12.5% reduction in greenhouse gas (GHG) emissions by 2008–2012 relative to 1990 and the domestic goal of a 20% CO_2 emissions reduction relative to 1990 by 2010 (Department of Environment, Food, and Rural Affairs, 2006). In November 2000, the United Kingdom implemented the Climate Change Program legislative package, which deployed three interlinked instruments: (a) the UK ETS, the first carbon trading system in the world (International Emissions Trading Association, 2013); (b) the Climate Change Levy (CCL), which is a tax on fossil fuel users in industry, commerce, agriculture, and the public

TABLE 1 Barriers for energy efficiency and potential policies and programs to address them

Program	Awareness	Information	Technical capacity	Financial availability
Energy and carbon trading	X	X	X	X
Voluntary agreements	X	X	X	X
Information on technology costs and savings		X		
Energy audits		X	X	
Third-party participation		X	X	
Benchmarking			X	
Enterprises rating			X	
Green bank			X	X
Public-private partnerships			X	X
Tax incentives				X
Interest-free loans				X

sectors; and (c) the Climate Change Agreements (CCAs), voluntary agreements between the UK's Environment Agency and industry that set energy or emissions targets and provide rebates of the CCL to enterprises that achieved their targets.

These three instruments—ETS, CCA, and CCL—interacted with each other. Six thousand companies with CCAs have participated in the UK ETS. The CCA companies that exceeded their targets and had excess carbon allowances were allowed to trade with companies that did not meet their targets through the UK ETS (Smith & Swierzbinski, 2007). The carbon allowances also could be banked for future periods. CCA companies that did not meet their targets could purchase carbon allowances. Companies that enter into CCAs and meet their agreed-upon targets can receive a discount on the CCL; companies that do not enter into CCAs, or those who are within an agreement but fail to reach their targets, had to pay 100% of the energy tax. The revenues from the CCL are returned to the taxed sectors through a reduction in the rate of employer's National Insurance Contributions and are used to fund programs that provide financial incentives for adoption of energy efficiency and renewable energy.

4.1.2 | EU emissions trading scheme

The European Union (EU) ETS was launched in 2005 and has been extended over four successive phases: Phase I (2005–2007, often called the "pilot phase"); Phase II (2008–2012); Phase III (2013–2020); and Phase IV (2021–2030). The system covers about 45% of total GHG emissions from the 31 countries, including CO_2 emissions from power plants, energy-intensive industry sectors, and commercial airlines; nitrous oxide emissions from the production of certain acids; and emissions of perfluorocarbons from aluminum production (Brown, Hanafi, & Petsonk, 2012; European Commission, forthcoming).

The EU ETS went through a series of adjustments during its different phases. In Phase I (the pilot phase), almost all allowances were allocated for free. In Phase II, free allocation was reduced by 10%, and auctions were introduced. In Phase III, the current phase, all allowances for the power sector are auctioned, and the share of free allowances for industries declines from 80% in 2013 to 30% in 2020. Because of a lack of reliable emissions data before Phase I and decline in emissions due to the global economic crisis during Phase II, the caps set for these two phases exceeded actual demand, which resulted in the EU ETS having little impact on emissions. However, rigorous monitoring and increased awareness, together with a positive carbon price, generated some emissions reductions and also generated verified annual emissions to fill the information gap and created a solid basis for setting national caps for the following phases (Laing, Sato, Grubb, & Comberti, 2013).

4.1.3 | California cap-and-trade scheme

Under California's Global Warming Solutions Act of 2006 (AB 32), California set a GHG reductions target to achieve 1990 level emissions by 2020. A cap-and-trade scheme was implemented starting in 2013 as a measure to achieve the AB 32 goal. The program has three compliance periods: 2013–2014, 2015–2017, and 2018–2020, respectively. The first compliance period covers the industrial sector and first deliverers of electricity, accounting for 35% of California's total GHG emissions. The second and third compliance periods expand the coverage to distributors of transportation fuels, natural gas, and other fuels, representing a total of 85% of California's total GHG emissions (World Bank, forthcoming). The carbon prices that will result from AB 32 implementation and expansion are expected to drive approximately 20% of the reductions required in the covered sectors to achieve AB 32's statewide 2020 goals (California Air Resources Board, 2011).

California's industrial sector accounts for about 20% of the state's total GHG emissions (California Air Resources Board, 2014). California's industrial sector cap-and-trade program covers operators of industrial facilities that exceed annual emissions of 25,000 megatons of CO_2 equivalent ($MtCO_{2e}$) based on their mandatory GHG emissions reporting. Facilities that do not exceed the threshold can voluntarily opt into the cap-and-trade program as opt-in covered entities. Covered industrial subsectors include: (a) cement production; (b) cogeneration; (c) glass production; (d) hydrogen production; (e) iron and steel production; (f) lead production; (g) lime manufacturing; (h) nitric acid production; (i) petroleum and natural gas systems; (j) petroleum refining; (k) pulp and paper manufacturing; (l) self-generation of electricity; and (m) stationary combustion.

4.1.4 | White certificates for energy suppliers or distributors

A white certificate system is a combination of an obligation and a trading system, focused on energy suppliers or distributors. White certificates are documents certifying that a certain reduction of energy consumption has been attained (Brogi & D'Adamo, 2007). One white certificate equals 1 ton of oil equivalent of energy saving. Government bodies set specific mandatory energy saving targets for energy suppliers or distributors. Under these energy-saving obligations, energy suppliers or distributors must fulfill these requirements by implementing energy efficiency measures among their clients (i.e., end-use sectors) within a specific time frame. There are three ways to fulfill their targets: (a) implement energy efficiency measures in end-use sectors; (b) make agreements with other companies to implement projects that are conducted with the help of third-party organizations, such as manufacturers of energy-efficient products, installers, or ESCOs; or (c) purchase white certificates

from the market (Steuwer, 2012). Energy suppliers or distributors that surpass their targets can sell their unused energy efficiency equivalents in the form of white certificates to suppliers/distributors who have implemented fewer measures than required to meet their targets (Energy Charter Secretariat, 2010).

The white certificates system has been implemented in many European countries, including Great Britain (2002), Italy (2005), France and Denmark (2006), and Poland (2011) (ABB, 2013; Labanca, 2008). The designs of the white certificate schemes across various countries are very different. For example, the United Kingdom and France have chosen to impose the obligation on suppliers; while in Italy, the obligation is on distributors. France and Italy allow non-obliged parties to promote energy savings and sell them to obliged parties, while United Kingdom does not. And Italy uses primary energy as the metric for energy savings of the obligation, while the United Kingdom and France use final energy (Bertoldi, 2011; Giraudet, Bodineau, & Finon, 2012). But under all white certificate schemes in the EU, obliged parties have met or exceeded their energy-saving targets (Aaltonen, 2011; Bertoldi, 2011).

Some white certificates systems also include third-party participation in the trading market. For example, the trading component of the Italian white certificates system allows both distribution companies and ESCOs to trade. Since ESCOs have no obligation or targets with the government, they can implement energy efficiency actions for any companies and sell their white certificate to distribution companies to make a profit (Aaltonen, 2011; Bertoldi, 2011; Brogi & D'Adamo, 2007). By doing so, the white certificates scheme can see greater overall savings at a lower overall compliance cost, by virtue of empowering these third-parties to derive value from the white certificates (Friedman, Bird, & Barbose, 2009). This also helps stimulate the growth and development of the ESCO industry (Bertoldi, Rezessy, & Vine, 2006).

4.1.5 | India's perform, achieve, trade scheme for energy-intensive industries

India's PAT program is a market-based, energy efficiency trading scheme that aims to improve energy efficiency in energy-intensive industries. The Indian Government announced this scheme in 2008 under its National Mission on Enhanced Energy Efficiency (NMEEE) in the National Action Plan on Climate Change (NAPCC). The PAT scheme is being implemented on three-year cycles, and during each cycle, the PAT framework assigns energy reduction targets to designated consumers (DCs); the first cycle ran from 2012 to 2015. This phase covered 478 DCs, using about 165 Mtoe per year in total, from eight energy-intensive sectors. Covered facilities accounts for roughly 45% of India's energy consumption and 60% of India's total GHG emissions (International Emissions Trading Association, 2015). By the end of 2015, PAT saved 8.7 Mtoe (11.99 Mtce) in energy consumption, exceeding its targets of 6.6 million tons of oil equivalent (Mtoe) (9.42 Mtce) reduction (Ministry of Power, 2017). Cycle II (2016–2019) covers 621 DCs across 11 sectors, targeting reductions of 8.9 Mtoe (12.70 Mtce) by 2019, and Cycle III (2017–2020) enrolled another 116 DCs to save 1.06 Mtoe (1.51 Mtce) by 2020 (Bureau of Energy Efficiency, forthcoming).

The Ministry of Power's Bureau of Energy Efficiency (BEE) is responsible for setting mandatory, specific targets for energy consumption for larger, energy-intensive facilities (Climate and Development Knowledge Network, 2013). BEE sets energy efficiency targets for each DC by calculating their baseline production and energy consumption, and analyzing their potential for energy efficiency improvement. The government will set stricter target (a percentage of reduction relative to baseline energy consumption) for historically less-efficient DCs than for more-efficient ones. DCs report their energy efficiency efforts and progress to achieve their targets during the compliance period. If DCs save more energy than they targeted, they will receive energy savings certificates (1 certificate = 1 Mtoe) equal to the amount of energy saved minus the amount of targeted savings. These certificates can be traded on two power exchange platforms and a platform developed by BEE specifically for trading energy saving certificates. If DCs cannot meet their targets by the end of the period, they must pay a lump sum penalty of US$20,000 (INR 1 million) in addition to the price of their energy savings certificates shortfall at a price of US$200 per Mtoe (Bhandari & Shrimali, 2018; International Emissions Trading Association, 2015).

4.2 | Voluntary agreements

Agreements to meet specific energy-use or energy efficiency targets are used in the industrial sector in many countries around the world (Bertoldi, 1999; Cagno, Trianni, Abeelen, Worrell, & Miggiano, 2015; Chidiak, 1999; Hansen & Larsen, 1999; Mazurek & Lehman, 1999; Newman, 1998; Paton, 2002; Rezessy & Bertoldi, 2011). Such agreements can be viewed as a tool for developing a long-term strategic plan for increasing industrial energy efficiency that fully engages not only the engineers and management at industrial facilities, but also includes government, industry associations, financial institutions, and others. An agreement or target can be formulated in various ways. Two common methods are based on (a) specified energy efficiency (or energy intensity) improvement targets and (b) absolute energy use or GHG emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such agreements (Price, Worrell, Sinton, & Yun, 2003).

Voluntary agreements on energy savings often exist with the ETS. As a result, in many countries, including Germany, Belgium, Finland, Netherland, and the United Kingdom, voluntary agreements on energy savings also apply to participating enterprises in the EU ETS. There are also countries that use voluntary agreements with non-ETS participants, and the mechanism and benefits are similar. Generally, under a voluntary agreement, participants negotiate a target with the government and by achieving the target, participants can get a variety of support and benefits from the government, including technical assistance for energy efficiency, subsidies for energy audits and energy efficiency investments, and tax relief or reduction.

For example, the Netherlands has implemented the third generation of the Long Term Agreements (LTAs) since 2007. This program covers small- and medium-sized energy users (energy consumption <0.017 Mtce/yr)[2] and includes energy savings throughout the entire product chain. All participants are required to develop Energy Efficiency Plans and implement all profitable measures. The government provides a technology list with payback periods developed at the sector level to assist participants in choosing appropriate energy efficiency measures. Benefits of participating in the program and achieving the targets include regulatory benefits and financial benefits, including being no longer subject to the specific national energy tax and paying the costs of buying carbon credits in the field of the Clean Development Mechanism (CDM) or emissions trading (Institute for Industrial Productivity, forthcoming).

4.3 | Effectiveness of carbon and energy trading, and voluntary agreements

This section summarizes how the programs and policies described above help address the four categories of challenges that enterprises face to improve energy efficiency. These programs could incentivize energy efficiency from all aspects of awareness, information, technical capacity, and financial availability.

4.3.1 | Awareness

It is important to influence top decision-makers at a company because board awareness is found vital to instigating energy efficiency improvements (Confederation of British Industry, 2013). Three factors are important to a company's decision to invest in energy efficiency projects: (a) financial elements of the projects and the company, such as payback periods and return on investment (ROI); (b) obligations on environmental compliance for the company; and (c) knowledge of energy savings opportunities within the company (Elliott, 2007; Reinaud & Goldberg, 2011).

Many evaluations found that the UK Climate Change Program and bundling of CCL and CCAs have raised awareness of energy efficiency potential within the participating sectors to enable businesses to improve energy efficiency, and that they have done more to increase awareness of energy efficiency across industry than any other government Scheme (UK Steel, 2007). The EU ETS has been shown to affect investment decisions, though in limited ways: (a) there have been some small-scale energy efficiency related investments; (b) it helped companies stop major carbon intensive investments and make decisions with longer-term strategic thinking; and (c) it helped climate change gain attention in company boardrooms (Laing et al., 2013). An evaluation on California ETS by the Climate Policy Initiative (CPI) also found that "the carbon price signal is making a difference in how firms approach abatement decisions." Companies that participated in the study also confirmed that "they are currently factoring in an expected carbon price into their investment decisions and emissions reduction strategies" (Kiung & Morehouse, 2015; Zuckerman, Laughlin, Abramskiehn, & Wang, 2014). India PAT is also believed to have a long-term impact of increasing awareness of energy efficiency within companies (Bhandari & Shrimali, 2018).

4.3.2 | Information

The process for setting the CCA targets began with gathering information regarding energy efficiency potential in energy-intensive industries on the part of the government. Once this information was gathered, negotiations took place within each sector. The sector offered a target for the whole sector to the government. Negotiation then moved the process forward, with government often requiring the industry sector to improve their offer to a more challenging level, based on information on cost-effective processes and general energy management standards in the sector (Price, Blok, Nuijen, & Pender, 2005). During the process of negotiating the targets, most companies believed that they were already energy efficient. However, when they actually started to undertake energy management in order to achieve the CCA targets, companies saved more than they thought that they could (Pender, 2008; Price, Galitsky, Sinton, Worrell, & Graus, 2005). As a result, sectors did better than expected because industry underestimated what they could achieve via energy efficiency. The CCA negotiating process made industrial managers aware of the extent of existing cost-effective opportunities for industrial energy efficiency improvements, which they may not have known until the studies leading up to the negotiation process were undertaken (Barker, Ekins, & Foxon, 2007; Ekins & Etheridge, 2006). Similarly, as the key elements of voluntary agreement programs, the assessment of the energy efficiency potential of the participants—as well as target-setting through a negotiated process with all parties—enabled enterprises to better understand their energy efficiency opportunities.

In EU ETS, most allowances are allocated for free for covered energy-intensive industry and aviation sectors and the remaining allowances are auctioned (European Commission, 2011). For a facility, free allowance allocation is the benchmark value (i.e., the arithmetic averages of performance of the 10% most energy efficient factories in 2007 and 2008) for the product it produces multiplied by its historic production. The benchmarks were developed for products, instead of inputs, so that the GHG emissions reductions and energy efficiency improvement can be maximized throughout each production process. To develop these benchmarks, the European Commission consulted with industry as well as different stakeholders of the covered sectors and sub-sectors, including industry associations, member states, and publicly and commercially available sources. These product benchmarks and system boundaries are public available at the European Commission website. Benchmarking encourages economic efficiency in the allowance market and provides the best incentives to minimize compliance costs (Harrison & Radov, 2002). Benchmarking identifies the most energy-efficient and low-emission installations across the EU. For existing installations, benchmarking provides a greater incentive for companies to replace old and inefficient installations Schleich, Rogge, & Betz, 2009).

4.3.3 | Technical capacity

Participating in United Kingdom CCAs brings benefits of technical assistance in energy efficiency. Climate Change Agreement participants can receive services from the UK's Carbon Trust. The Carbon Trust, funded from revenues from the CCL, assists companies in reducing carbon emissions by providing information and technical expertise (e.g., identifying CO_2 emission reduction opportunities and providing resources and tools) to companies and some financial support (e.g., interest-free loans) to small- and medium-sized enterprises (HM, 2008).

White certificate systems provide a platform for ESCOs to provide high quality energy efficiency services**.** To fulfill the white certificate energy savings obligation, energy providers or distributors can enlist ESCOs to help their clients install and implement energy efficiency measures. Bringing ESCOs, which have unique experience and expertise with energy efficiency projects and technologies, into the scheme provides the opportunity not only for enterprises to better access energy efficiency improvement services, but also for the ESCO industry to grow. In Italy, a significant share (80% in the period 2005–2008) of actions were implemented by ESCO companies, and the entry of new companies providing energy efficiency services gradually increased (Aaltonen, 2011). An evaluation of Italy's white certificate scheme found that it helped to promote the growth of energy efficiency actors better than stimulating energy efficiency project implementation did (Di Santo, Forni, Venturini, & Biele, 2011).

The India PAT scheme helped to create an institutional structure to enable online data submission, annual audits, and verification by designated auditors. It could also help to enhance capacity-building in enforcing policies, collecting data, conducting monitoring and verification, and assessing compliance and levying penalties, which are all prerequisites for successfully implementing the scheme (Climate and Development Knowledge Network, 2013). For example, the Knowledge Exchange Platform (KEP) facilitates exchange and learning among DCs, and helps to build the capacity of energy managers, auditors, and other energy efficiency stakeholders.

4.3.4 | Financial availability

Through the Enhanced Capital Allowance (ECA) tax scheme, CCA participants can enjoy 100% first-year tax relief on their income or corporation tax ROIs in qualifying energy-saving technologies. Evaluation of the ECA scheme found that it may have been effective in incentivizing companies to purchase a few specific types of energy efficient equipment (e.g., refrigeration equipment, motors, and drives) (HM, 2008).

Similar to the EU ETS, the California ETS also adopts a combination of free allocation using benchmarking and auctions for allowance allocation. At the end of 2017, California had held 22 quarterly allowance auctions, raising about $6.1 billion for the Greenhouse Gas Reduction Fund (GGRF; California Air Resources Board, 2018). Auction proceeds are reinvested into a variety of activities, including energy efficiency improvements in clean energy, energy efficiency, sustainable communities, public transit, high-speed rail, public buildings, ecosystem protection, and others, to reduce climate pollution and benefit California's economies, health, and environment (Kiung, 2015; California Air Resources Board, 2018). By now, one third of the total GGRF (i.e., about $2 billion) have been implemented in projects, which are expected to reduce more than 23 $MtCO_{2e}$ over the quantification period (California Air Resources Board, 2018).

5 | KEY SUPPORTING MECHANISMS

As described in the previous section, all overarching programs are supported by complementary mechanisms to ensure information and technical and financial assistance could be provided. The section below summarizes key supporting mechanisms

by the types of assistance they could provide. If one mechanism falls under several assistance categories, we review it in the major service type it could serve, but reflect the additional types of assistance in Table 1.

5.1 | Information

High-quality information on energy efficient technologies—as well as high-quality information regarding the overall potential for energy savings and emissions reductions in industrial facilities or industrial sectors—is essential for companies to set realistic energy efficiency targets, establish energy efficiency investment plans, and spur meaningful action. High-quality information on energy efficient technologies includes information on technology performance (e.g., quality, lifetime), upfront capital and installation costs, energy savings compared to conventional efficient technologies, and other benefits such as reduced labor costs for maintenance, reduced product waste, and reduced pollutant emissions. Such information can be provided to decision-makers through guidebooks, technology lists, industry networks, and industrial associations, as well as through high-quality energy audits.

5.1.1 | Direct resources of information

Direct resources of information include guidebooks, criteria, and other supplemental materials to help enterprises understand and utilize the information. They can be provided or managed directly by the government, or by independent entities designated by the government.

The U.S. Department of Energy's (U.S. DOE) Technology Guidebooks[3] and U.S. Environmental Protection Agency's (U.S. EPA) ENERGY STAR program are examples of government-led energy efficiency information sources. They provide relevant information in the forms of guidebooks, energy assessment tools, and technology lists. For example, the U.S. Department of Energy's Advanced Manufacturing Office (AMO) has published series of guidebooks on energy efficiency technologies and measures in different industry subsectors and energy systems (e.g., motor systems, steam systems, process heating systems). The ENERGY STAR program's Industrial Energy Management information center[4] also provides tools and information for energy intensity benchmarking of industrial plants.

The Carbon Trust, an independent entity designated by the UK government, helps businesses and the public sector reduce carbon emissions. The Carbon Trust helps the UK government manage its Energy Technology List, which provides eligible technologies and products that are qualified for tax relief based on the ECA scheme. It also identifies carbon emissions reduction opportunities and provides resources and tools to help enterprises improve energy efficiency.

5.1.2 | High-quality energy audits

An industrial energy audit is a necessary first step for understanding a facility's energy consumption by end-use and for identifying key areas for saving energy in industrial operations. An industrial energy audit can also provide important impetus for industrial facilities to implement energy efficiency measures and technologies.

Energy audits could be performed through a stand-alone energy auditing program, or implemented as a supporting policy tool for policies such as voluntary agreements or emissions trading programs. Price and Lu (2011) have reviewed energy auditing programs around the globe. They found that stand-alone energy auditing programs largely focus on the energy audit itself, while energy audit programs combined with other policy measures can better motivate participants, help decision-makers set reasonable yet ambitious energy-saving targets, and achieve the broader program goals. They also found that other policies, regulations, incentives standards, and guidelines are necessary to support energy audit programs, including energy audits standards and guidelines, the use of certified energy or environmental management systems, energy efficiency improvement targets and energy action plans, financial support for investments, subsidies for energy audits, and recognition labels and awards.

Providing information on economic benefits of an energy efficiency project is key to assist decision-making in financing and investment of proposed industrial energy efficiency improvement projects. Two commonly used methods are including cost and benefits analyses into energy audits and calculating internal rate of returns (IRRs). Investment-grade energy audits incorporate financial information into the audits. They provide not only a detailed account of energy use, but also a cost savings analysis of potential energy conservation opportunities and a project proposal that includes a series of energy conservation measures with plans for financing, implementation, and savings verification (U.S. Department of Energy, 2011). Investment-grade audits typically provide information on the ROI of facility retrofits, so that companies will know the costs, savings, and the financial ROIs of the potential energy conservation measures (U.S. Department of Energy, 2015a).

Investment-grade audits have been used in energy savings performance contracting in the United States. Typically, ESCOs perform investment-grade audits at the facility and develop a project proposal that includes recommended energy conservation measures with financing information and projected annual cash flow. The owner of the facility evaluates the proposal and negotiates an energy savings performance contract with the ESCO based on these results (U.S. Department of Energy, 2015a).

In California, the use of "costs and benefits" in energy assessments is included in law, the California Global Warming Solutions Act of 2006 (AB 32). The largest industrial sources (refineries, cement, hydrogen, and oil and gas production/mineral production) are required to conduct a one-time assessment of fuel and energy consumption, emissions, and emissions reduction opportunities. The energy efficiency assessment not only needs to provide information on the facility's key energy consumers (such as equipment and processes) and their associated emissions, but also needs to identify energy use reduction opportunities and associated impacts. For every potential project identified, the assessment needs to provide a brief project description, estimated cost information (including both one-time capital cost and average recurring annual costs), estimated average annual energy savings, associated average annual GHG emission reductions, criteria air pollutant reductions, and toxic air contaminant emission reductions, as well as estimated annual cost savings. The information on costs and benefits is presented in ranges from low-cost projects to large capital expenditure projects, from projects that can be implemented quickly to mid- and long-term projects, and from simple projects to projects that have extensive facility impacts.

Another way to provide financial information on an energy efficiency project is to use IRR in designing industrial energy efficiency programs. IRR was extensively used by the programs in Belgium. The Auditing Covenant in Flanders, Belgium, which operated from 2005 to 2014 and targeted medium-sized industrial companies, required projects with an IRR of 15% or higher to be implemented within 4 years after the submitted energy plan was approved, and those with an IRR of 13.5% or higher had to be implemented in the following 4 years. The Belgium's Benchmarking Covenant, which operated from 2002 to 2014 and targeted the largest energy-intensive industrial facilities, required companies to conduct an energy audit and implement energy saving measures with an IRR of 15% or higher. Both programs ended in 2014, and were succeeded by the Energy Governance Agreements. The new program required companies to conduct an energy audit every 4 years and implement energy saving measures with a minimal IRR, which was set as 14% for companies under the EU ETS and 12% for non-ETS participants.

5.2 | Technical assistance

Benchmarking, performance rating, and challenge programs are applied internationally in support of energy efficiency and trading programs. In addition, third-party participation, including designated individuals, industrial associations, and networks, is an important channel for providing technical assistance to companies.

5.2.1 | Benchmarking

Benchmarking has been used in a variety of programs, such as allowance allocation in carbon trading schemes, voluntary programs such as Belgium's Benchmarking Covenant, and the U.S. EPA's ENERGY STAR Program. Benchmarking tools are provided by governments to help enterprises understand how their energy consumption compares to other similar facilities. Combined with other programs, benchmarking can be used to help reward the most efficient facilities and encourage enterprises to implement energy efficiency technologies through monetary rewards or financial incentives.

The use of benchmarking to determine the allocation of free allowances in ETS rewards the efficient facilities and encourages companies to implement energy efficiency measures. For example, Belgium's Benchmarking Covenant aimed to bring participating industrial companies to the top 10% of most energy efficient plants worldwide by 2012 through the use of benchmarking. About 180 companies were included in the Benchmarking Covenant, accounting for 80% of the total industrial energy consumption in Flanders (Benchmarking Commission, 2004). Benefits for participants that fulfilled the Covenant obligations included free allowances in line with the committed energy efficiency improvement, and exemption from additional measure or policies on energy use or GHG emissions reductions (Cornelis, 2014).

It is helpful to provide tools to help companies conduct benchmarking, and it is necessary to update the benchmarking indicators periodically. For example, under the U.S. EPA ENERGY STAR program, benchmarking tools are provided for manufacturers to compare their manufacturing plants' energy performance with similar facilities nationwide. The benchmarking tools include Energy Performance Indicators (EPIs) unique to each type of manufacturing. The U.S. EPA tracks the progress and updates industry-specific EPIs, in order to evaluate the energy efficiency improvements within a particular industry.

5.2.2 | Enterprise performance rating systems

Many enterprise performance rating programs in the United States help enterprises save energy and costs, through providing technical assistance or by requiring adoption of a standardized energy management system. Enterprises that participate in the program can get assistance, guidance, or training on identifying and understanding energy efficiency opportunities. For example, the U.S. DOE's Superior Energy Performance (SEP) Program certifies industrial facilities that implement an energy management system that meets the ISO 50001 global energy management system standard and achieves improved energy performance. An independent third party audits each facility to verify achievements and qualify it for recognition at the Silver, Gold, or Platinum level, based on performance. The ISO 50001 certified energy management system can identify current

energy practices and energy improvement opportunities, and hence inform decision-making. It not only helps companies make better decisions on energy improvement, but also documents their performance and increases their recognition and credibility (McKane, 2013). The SEP program provides guidance, tools, and recognition, which is essential to the implementation of energy management. To date, program participants have achieved annual savings of $87,000 to $984,000 using no-cost or low-cost operational measures, with an average of 10% reduction in energy costs within 18 months of SEP implementation and 6% to 25% improvement in energy performance over 3 years.

5.3 | Third-party participation

The monitoring, reporting, and verification (MRV) components of many programs need third parties to participate in the process. In the United Kingdom's CCA program, verification of the company reports was based on sample audits by an independent agency (paid for by the government); to minimize costs, full verification of all results was not undertaken. Data on progress toward sector targets were also collected from member companies and reported by the sector associations. Sector associations were required to demonstrate to the auditors that they had maintained the accuracy of the data obtained from operators and that they had a system in place to ensure its continuing accuracy.

Designated professionals in the areas of audit, verification, and energy management also help to ensure the success of associate energy efficiency programs. For example, the U.S. DOE Industrial Assessment Centers (IACs) are state and local solution centers that support state, local, tribal, and K–12 school district leaders by providing resources to advance successful, high-impact clean energy policies, programs, and projects. Since 1976, IACs have offered free energy audits to SMEs if the manufacturers meet certain requirements. IACs are located at 24 universities around the country and conduct energy audits to identify opportunities to improve productivity, reduce waste, and save energy. Since 1976, more than 16,000 manufacturing firms have participated in the energy audits, and an average of 50% of the recommended measures were implemented. Since 2006, IAC assessments have identified more than US$595 million in energy savings and nearly 4.0 million metric tons in CO_2 emissions reductions. A typical IAC plant will receive more than US$47,000 in annual benefits from each assessment (U.S. Department of Energy, 2015b).

Industrial representatives, associations, and networks, such as industry trade groups in the United States, Japan, and Europe, are very important, as they speak for the enterprises, provide a platform for enterprises to share information, and influence government decision-making. For example, the UK Confederation of British Industry (CBI) was founded in 1965 and is a membership organization. It is the UK's premier business lobbying entity. It provides a voice for employers at a national and international level for a competitive policy landscape to promote the conditions of all sizes and sectors of businesses in the United Kingdom. It generates reports on energy efficiency policy and strategic areas to help businesses realize energy efficiency opportunities and help influence government decision-making. It identifies recommendations for both government and businesses to raise awareness of the benefits of energy efficiency, drive demand for energy efficiency measures, and shape a holistic energy efficiency strategy that benefits all (Confederation of British Industry, 2013, 2015).

5.4 | Financial assistance

Here, we review commonly adopted mechanisms and approaches that can reduce energy efficiency risk, including green banks, public-private partnerships, loans and grants, and tax incentives.

5.4.1 | Green banks

Green banks are financial institutions that assist their customers with purchase of clean energy technologies. Green banks have been established to address cost concerns and administrative complexities associated with direct incentive programs such as grants and rebates (Belden, Clemmer, & Wright, 2015). The UK Green Investment Bank (GIB) is the first green bank to provide funding for green and profitable infrastructure projects. Supported technologies in the energy efficiency area include building retrofits (e.g., lighting, insulations, glazing), on-site generation (e.g., combined heat and power, renewable heat, heat pumps), industrial process (e.g., motors, pumps, kilns), and infrastructure (e.g., streetlighting, heat networks). From 2014 to 2015, funding of $332 million (£260 million)[5] was provided to finance energy efficiency projects, including a sheltered housing boiler replacement, street-lighting project, data center retrofit, and a small- and medium-sized enterprise (SME) energy efficiency platform. The total investment in energy efficiency projects accounted for 14% of the bank's total investment (Green Investment Bank, 2015).

Government can play an important role in facilitating green banks. Belden et al. (2015) evaluated six U.S. state governments (Connecticut, New York, Pennsylvania, Kentucky, Iowa, and Massachusetts) and one national government (Germany) that have developed green banks. The study shows that green banks have helped promote investments in clean energy and these clean energy financing programs have successfully engaged diverse stakeholders to help mobilize capital. The study also

provides important insights on the role of government administrators, including utilizing their in-house expertise in the energy efficiency area, educating the financial sector, and enabling a broader group of stakeholders to achieve energy savings.

5.4.2 | Public-private partnerships

Public-Private Partnerships (PPPs) are also used to mobilize energy efficiency investment. PPPs for energy efficiency finance are "mechanisms that use public policies, regulations, or financing to leverage private-sector financing for energy efficiency projects" (International Energy Agency, 2011). There are three main forms of PPPs in the energy efficiency area: (a) dedicated credit lines, (b) risk-sharing facilities, and (c) EPC.

Dedicated credit lines are mechanisms to encourage local financial institutions (LFIs) to offer sub-loans to implementers of energy efficiency projects. Public entities such as government, international financial institutions, and donor organizations provide funds to private-sector organizations such as banks and LFIs at a low interest rate to encourage them to provide and lend more funds for energy efficiency projects, which usually have higher interest rates. LFIs earn profits from these loan transactions. Dedicated credit lines help LFIs improve their awareness of the benefits and characteristics of energy efficiency financing. Public entities leverage dedicated credit lines to encourage LFIs to provide funds to expand the scale of the fund available for financing from public entities. Governments also provide technical assistance to LFIs to build and enhance their capacity (International Energy Agency, 2011).

For example, Thailand initiated the Energy Efficiency Revolving Fund (EERF) in 2003 to incentivize financial institutions in Thailand to lend for energy efficiency measures (Grüning, Menzel, Panofen, & Shuford, 2012). The source of funding for the EERF was the government budget collected from a tax on petroleum products. The EERF was successful in stimulating financial institutions in Thailand to finance energy efficiency, and also represented a shift in the role of government from "enforcer and regulator to facilitator and supporter" (Grüning et al., 2012; U.S. Agency for International Development, 2009). Success factors included: (a) simplified procedures for project application, appraisal, reporting, and loan processing; (b) offering loans with interest rates lower than the market rate to attract commercial banks; and (c) technical assistance and education from the Department of Alternative Energy Development and Efficiency (DEDE; Grüning et al., 2012; International Energy Agency, 2011; U.S. Agency for International Development, 2009). Streitferdt and Chirarattananon (2015) explain, however, that an external financial mechanism such as an EERF can damage the market and impede it from becoming mature. They also noted the lack of demand for energy efficiency projects and finance from customers, which may result from a lack of mandatory regulation on energy efficiency improvement or a lack of implementation and enforcement of these regulations.

Risk-sharing facilities are mechanisms where a public entity offers guaranteed product to reduce energy efficiency project financing risks to the private sector. Government, multilateral banks, or donor organizations absorb some energy efficiency project financing risks by providing a partial guarantee that covers a percentage of the loss due to loan defaults. Risk-sharing facilities also include some technical assistance and capacity building, as in the case of dedicated credit lines (International Energy Agency, 2011).

Two examples of risk-sharing facilities are the Commercializing Energy Efficiency Finance (CEEF) Program in Europe that operated from 2003 to 2008, and the Partial Risk Sharing Facility for Energy Efficiency (PRSF) in India since 2015. The CEEF was launched by the International Finance Corporation (IFC) and the Global Environment Facility (GEF). The PRSF was an agreement between the World Bank and the Indian government, with funding from GEF and the Clean Technology Fund (CTF) under the Climate Investment Fund (CIF). Both programs have a risk sharing component where IFC or the Small Industries Development Bank of India (SIDBI) guaranteed a certain amount of project risk to the participating financial institutions. The CEEF offers 50% of the project risk and PRSF guarantees the partial credit to 40–75% of the energy efficiency loan (International Energy Agency, 2011; World Bank, 2015).

The two programs also have technical assistance and capacity building components, which help financial institutions market and develop their energy efficiency financial services, prepare projects for investment, improve capacities for energy efficiency project financing, and help ESCOs to develop energy efficiency projects and their business capacities. Technical assistance is considered very important, and participants appreciated the trainings and seminars provided. It is also very important to have a local presence from the granting agency in the countries where the program is implemented, as local agency staff can help participants to continue their work and ensure project launch (International Energy Agency, 2011).

The market maturity of energy efficiency and general acceptance of the guarantee product is also very important. The International Energy Agency (IEA) points out that the CEEF has been more successful in countries with more-developed energy efficiency markets than in the countries where financial institutions are less interested in energy efficiency financing and there are fewer ESCOs (International Energy Agency, 2011).

EPC is a mechanism that uses private-sector investment and expertise to deploy energy efficiency retrofits in buildings, industries, and other types of facilities. ESCOs and public agencies will make performance-based agreement, and ESCOs will get payments contingent on demonstrated performance (International Energy Agency, 2011).

About 40 countries around the world have ESCO activities. ESCOs started in the United States, Canada, Sweden, and the United Kingdom in the 1970s and early 1980s, and were then established in many other countries in the late 1980s, 1990s, and even today (Goldman, Hopper, & Osborn, 2005; Vine, 2005). Studies on the experiences of these countries have identified the following success factors and actions to further promote ESCOs, including training to energy managers and financial institutions, accreditation system establishment, funding and financing sources development, standardization of EPCs, and measurement and verification (Bertoldi et al., 2006; Vine, 2005).

These three approaches—dedicated credit lines, risk-sharing facilities, and EPC—can be applied in different market environments. Dedicated credit lines are most suitable in financial markets that are less mature, and LFIs are needed to provide better understanding of the benefits and characteristics of energy efficiency projects. Dedicated credit lines also require greater funding from public sectors, as they have to finance LFIs. Risk-sharing programs are applicable to markets that are somewhat mature and when LFIs want to finance energy efficiency but are worried about the high risks associated with those projects. EPCs are most useful in mature financing markets with enough liquidity of LFIs and enough awareness and capability to provide energy efficiency financing. EPCs have the potential to scale up LFI financing, which is difficult to achieve through dedicated credit lines and risk-sharing programs (International Energy Agency, 2011).

5.4.3 | Tax incentives

Many countries have utilized tax incentives and tax relief to boost investment in energy efficient products, equipment, and technologies. The IEA identified 13 IEA countries that have implemented tax relief programs for industrial equipment: Belgium, Canada, France, Germany, Ireland, Italy, Japan, the Republic of Korea, Netherlands, Norway, Portugal, the United Kingdom, and the United States (International Energy Agency, forthcoming).

The most common tax incentive is a tax rebate program in which companies deduct the cost of energy-efficient equipment from their annual profits. For example, in the Republic of Korea, a 5% income tax credit is available for energy efficiency investments such as replacement of old industrial kilns, boilers, and furnaces; installation of energy-saving facilities, co-generation facilities, heat supply facilities, or energy-saving equipment; alternative fuel using-facilities; and other facilities that reduce energy use by 10%. In Japan, there is a "Green Investment Tax Reduction" program to provide SME business operators that purchase eligible energy savings or CO_2 emissions reduction equipment with a special depreciation of 30% against the standard purchase prices or a 7% tax deduction. In the Netherlands, under the Energy Investment Deduction program, originally 40% (and now 55%) of the annual investment costs of energy saving equipment can be deducted from the fiscal profit of the calendar year in which the equipment was procured, up to a maximum of US$116 million (€107 million). Qualifying equipment is provided on an "Energy List," and the costs associated with obtaining advice for purchased equipment can also be included. In UK's ECA Scheme, enterprises that invest in energy-saving technologies specified in the "Energy Technology List" can deduct the capital costs of those technologies against their taxable profits for the investment year (HM, 2008).

However, the real effectiveness of tax relief is difficult to measure because of limited data and free-rider issues[6] (Price, Blok, et al., 2005; Price, Galitsky, et al., 2005; Ryan, Jessula, & Rozite, 2012). Programs should be designed such that they avoid providing tax relief for technologies that are already profitable (De Beer et al., 2000).

5.4.4 | Loans and grants to provide financing

Government or government-designated third-party organizations could also provide loans and grants directly to finance energy efficiency and clean energy technologies. The U.S. DOE Loan Guarantee Program was created in 2005 under Section 1703 of Title XVII of the Energy Policy Act of 2005 to support innovative clean energy technologies that are typically unable to obtain conventional private financing due to high technology risks. These technologies include: biomass, hydrogen, solar, wind/hydropower, nuclear, advanced fossil energy coal, carbon sequestration practices/technologies, electricity delivery and energy reliability, alternative fuel vehicles, industrial energy efficiency projects, and pollution control equipment (U.S. Department of Energy, forthcoming).

In Europe, the UK's Carbon Trust provides interest-free loans to SMEs. Interest-free loans are now available to eligible SMEs in Wales and Northern Ireland that wish to upgrade to more energy efficient equipment and renewable technologies (Carbon Trust, n.d.). In Australia, the Clean Technology Investment Program, started in 2012, provided $583 million (800 million AUD)[7] grants for more than 7 years for capital investment in energy efficient equipment and low-emissions technologies, processes, and products. Manufacturers that meet a minimum energy or emissions threshold can apply (International Energy Agency, forthcoming).

6 | DISCUSSION AND POLICY RECOMMENDATIONS

Based on the review of a series of international energy efficiency policies and programs, it is recommended to design various policies targeted at overcoming different barriers, to incentivize enterprises to improve energy efficiency. In addition, the synergy between those various policies is beneficial to amplifying their effectiveness. Policies are also effective if they can provide a long-term and clear signal to enterprises for energy efficiency improvement and can be adjusted as the situation changes.

Different policies and measures target different needs and apply under different conditions. Voluntary agreements are effective especially when regulations are difficult to enforce. Government grants are very effective for the development and commercialization of new technologies and should support both high risk with potential high pay-off projects and lower risk with incremental improvements projects. Financial incentives are effective for new technologies that are newly commercialized and have high capital cost but have a good prospect of cost reduction as the technology's market expands or learning occurs (Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006).

Specific policies and programs need to go hand-in-hand to incentivize enterprises to improve energy efficiency. Few single instruments can overcome all barriers for energy efficiency. As shown through international experiences, policies and programs usually use a combination of several instruments to amplify their effectiveness. For example, the market-based ETS programs in the EU and United States not only put a price on carbon, but usually include measures to provide information and technical assistance, such as energy efficiency assessments to help enterprises identify cost-effective opportunities, as well as some financial incentives such as tax relief to further incentivize enterprises. Voluntary agreements in the EU also come with financial incentives, technical assistance, and regulatory benefits or punishment. Similarly, measures to provide information, such as the technology promotion lists, energy audits, and the U.S. ENERGY STAR program, also need to be complemented with financial incentives and voluntary agreements to become more effective (Geller et al., 2006). Designing a suite of policies also can help overcome some of the shortcomings with certain policies. For example, energy audit programs may cause some free-ridership, which could be overcome by targeting specific customers. In many countries like Denmark, the Netherlands, and Sweden, energy audits are provided as a benefit for participants in voluntary agreements (Price, 2005). Different types of measures help enterprises increase awareness and equip enterprises with the capability to improve energy efficiency both technically and financially, and also improve the effectiveness of the programs.

It is also worth noting that better coordination between different policy mechanisms is very important. Currently, China is exploring both a carbon emissions trading system and an energy saving trading mechanism. A double counting issue arises if both programs are implemented in the same industry. To avoid this issue, China starts its national ETS in the power sector, while piloting the energy saving trading program in key industrial sectors. Moreover, these two programs are managed by different institutions in China—carbon ETS by the Climate Change Department of the Ministry of Ecology and Environment, and energy saving trading by the Resources Conservation and Environmental Protection Department of NDRC. As a result, it requires additional high-level design and institutional coordination to align these two trading programs. However, both trading systems can coexist with a target-based voluntary program or mandatory program, such as the Top 10,000 program, because the trading system provides a flexible and effective instrument for companies to achieve their targets in a voluntary or mandatory program, as seen in the white certificates program, for example.

Long-term and dynamic energy efficiency policies and programs are needed. Policies and programs for energy efficiency need to be in place for more than 10 years and evolve accordingly to make sure the energy efficiency market can be established in an orderly manner (Geller et al., 2006). For example, it requires substantial time, money, and effort to establish the appropriate institutional framework and enabling environment to convert energy efficiency potential into real investments, and it has also taken many years and substantial support for ESCOs to become mainstream in North America and elsewhere (Sarkar & Singh, 2010).

Persistent policies and programs provide a clear and stable signal to enterprises, which help them take these policies and programs into account in their long-term management and investment decisions. Concerns about whether a policy is going to last can impede enterprises from investing in new technologies, as their payback period may be longer than the policy's duration. In addition to keeping policies stable and predictable, policy revisions that adjust to market changes are also necessary. For example, financial incentives need to keep pace with the level of commercialization and deployment of energy efficiency technologies. When the technology is well established and already cost-effective in the market, financial incentives may be removed and provided to other emerging technologies. Many international experiences have shown this pattern. For example, the ETS in both the EU and California started with pilot periods and gradually became more active as the scheme was modified and participants become more prepared. Voluntary agreements in many EU countries have also existed for two decades, evolving over time to better enable enterprises to improve energy efficiency.

Careful design and information transparency is essential for market-based mechanisms. For example, for ETS programs, it is very important to set a cap that is stringent enough with full understanding of current emissions and consideration of the changing economy. As we described in Section 4.1.2, the caps set for Phase I and Phase II of the EU ETS were higher than the actual emissions, so the EU ETS had little impact on emissions during those periods. In addition, rules on the trading program, for example, allowance allocation, trading, banking (if any), and compliance in ETS, should all be available to the public, as they are in the EU and California ETS. Clearly illustrated rules and methods of the trading program help enterprises better understand their performance and identify which efforts to make. Third, penalties for non-compliance should be high enough to prevent an enterprise from not complying again.

More specifically for China, in response to the weakening willingness to improvement energy efficiency and top challenges in enterprises that were identified by our survey (i.e., a lack of funding/financing, a lack of technical expertise and personnel, and a lack of practical information on technologies and products), we propose decision-makers in China develop policies and programs focusing on the following areas, to help companies improve energy efficiency more actively and innovatively.

1. Identification of energy efficiency potential

Our survey results show that companies are in need of practical information on technologies and products, even though the Chinese central government and local governments have published a series of catalogues on energy efficiency technologies. This shows that the government or third-party organizations need to provide companies with more customized expertise and detail-oriented services related to energy diagnoses, energy audits, and energy management systems, with economic analysis included.

2. Workforce development

The survey results also show that a key challenge for companies is a lack of technical expertise and personnel in the energy efficiency and energy management areas. Training and workforce development is needed in different industrial sectors and for different levels of personnel within a company, and on a continuous basis. Different industrial sectors have different requirements and measures for energy efficiency improvement, so specific training targeting a particular sector is most practical and valuable to the sector. Similarly, different levels of employees in the company have their own duties and responsibilities. For example, technicians need to understand the equipment and operations, mid-level managers need to understand the technologies and analysis of different measures, and high-level executive leadership needs to understand the overall importance and the policies.

3. Market channels for energy efficiency financing

The most important issue that companies raised in the survey is a lack of funding and financing methods. This problem may worsen under China's economic "new normal" as many energy-intensive companies are facing over-capacity and bad financial conditions. This situation makes it difficult for them to obtain financing from traditional financial institutions to implement energy efficiency measures. Learning from international experiences, it could be effective to establish and explore market-based financing channels for energy efficiency financing, such as EERFs.

7 | CONCLUSION

China's industry sector remains the largest contributor to the nation's energy consumption and CO_2 emissions. It is essential to continue energy efficiency and carbon reduction efforts in China's industry sector. This article reviews international experiences on energy efficiency programs and policies in the industry sector, to provide insights on directions that could be taken to further improve energy efficiency improvement policy and program development in China.

When the Top 10,000 Program ended in 2015, we found that China's industry enterprises face challenges of improving their energy efficiency in terms of information, technical capacity, and financial supports. The willingness to implement energy efficiency investment has decreased as well. To address these issues, we reviewed the most popular comprehensive programs addressing industry-sector energy efficiency and carbon emissions the around the globe, as well as the supporting policies and mechanisms that can be used to facilitate those programs. We categorized their impacts into four types—awareness, information, technical, and financial—which are consistent with the challenges we identified in China's companies.

Based on international experience, we found that overarching programs, energy and carbon trading programs, and voluntary agreement programs are effective ways to increase awareness of energy efficiency issues in a company's high-level management board. In addition, participating in those programs help companies get additional support from the government and third-party organizations, which provides information, technical assistance, and financial benefits. More specifically, the pilot phase and MRV of the EU ETS and California ETS help build an emission inventory and fill information gaps. White certificates provide an accounting tool to represent the amount of energy savings and a trading mechanism. Target-setting process for CCAs and voluntary agreements, energy efficiency assessment in California ETS, benchmarking used of EU ETS allowance allocation, help enterprises realize unknown opportunities of energy efficiency and carbon reduction investment. Participating in the UK CCAs brings benefits such as financial incentives and technical assistance in energy efficiency. And auction proceeds from the California ETS help the state move toward an energy efficient, low-carbon economy.

As China has finished its Top 10,000 Program and is in the process of establishing a national carbon emissions trading market and exploring energy trading programs, it is important to consider how other countries designed their energy and carbon trading, as well as their voluntary agreement programs. China should first build its capacity to understand its current and future energy consumption and carbon emissions at government, third-party, and enterprises levels. It is especially important for implementing the national ETS program to design a stringent emission cap. The Chinese government also should provide sufficient supporting mechanisms to help companies conduct energy and carbon audits, by government-designated staff or third parties, or by the enterprises themselves, in order to set reasonable targets for companies. Specific rules of each policy and program, benchmarking tools, technology lists, and guidebooks also should be available to enterprises so they have enough information to make informed energy efficiency investment decisions. At the same time, financial support, in the form of tax relief, loans, and grants are all applicable methods that China could use to overcome companies' financial barriers to improving energy efficiency. In addition, since China is developing its green bank and ESCO industry, more research is necessary in these areas to explore the best way the green banks and ESCOs could help China achieve its energy efficiency and carbon reduction goals.

ACKNOWLEDGMENTS

The authors thank Nina Khanna at the China Energy Group of LBNL for providing valuable comments. This study is sponsored by Energy Foundation China through the U.S. Department of Energy under Contract Number No.DE-AC02-05CH11231.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DISCLAIMER

ENDNOTES

[1]*tce* is the standard unit for energy used in China, and 1 tce is equivalent to 29.27 gigajoules (GJ).

[2]Large industrial energy users (companies with an energy consumption of at least 0.5 petajoules per year) were covered by the first-generation LTAs from 1992 to 2000 and then were covered by the Benchmarking Covenant until 2012. They are now covered by the LTA on Energy Efficiency (LEE), which is specifically designed for enterprises that participate in the EU ETS.

[3]Software tools published by AMO: http://www.energy.gov/eere/amo/software-tools

[4]The Industrial Energy Management Information Center: https://www.energystar.gov/buildings/facility-owners-and-managers/industrial-plants/industrial-energy-management-information-center

[5]1 British pound = 1.28 U.S. dollar as of November 19, 2018.

[6]The free rider issue "is a market failure that occurs when people take advantage of being able to use a common resource, or collective good, without paying for it, as is the case when citizens of a country utilize public goods without paying their fair share in taxes" (Investopedia, n.d.).

[7]1 Australian dollar = 0.73 U.S. dollar as of November 19, 2018.

RELATED WIREs ARTICLES

The recent history and successes of China's energy efficiency policy
Global overview—the systems approach to energy efficiency in industry

ORCID

Xu Liu https://orcid.org/0000-0002-5784-1244

REFERENCES

Aaltonen, P. (2011). *Systems and their applicability to Finland.* Report to Ympäristöpooli at Finnish Energy Industries.

ABB. (2013). *Energy efficiency country report – Poland,* February.

Abdelaziz, E., Saidur, R., & Mekhilef, S. (2011). A review on energy saving strategies in industrial sector. *Renewable and Sustainable Energy Reviews*, *15*(1), 150–168.

Aflaki, S., Kleindorfer, R., Polvorinos, M., & Sáenz, V. (2013). Finding and implementing energy efficiency projects in industrial facilities. *Production and Operations Management*, *22*(3), 503–517.

Altmann, M., Zerhusen, J., Maio, P., Lanoix, J., Trucco, P., Egenhofer, C., ... Theiss, J. (2013). *Energy efficiency and the ETS.* European Parliament.

Barker, T., Ekins, P., & Foxon, T. (2007). Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK climate change agreements, 2000–2010. *Energy Economics*, *29*, 760–778.

Belden, A., Clemmer, S., & Wright, K. (2015). *Financing clean energy: Cost-effective tools for state compliance with the clean power plan.* Union of Concerned Scientists.

Benchmarking Commission. (2004). *Annual report on the year 2004 – Evaluation report 2002–2004.*

Bertoldi, P. (1999). The use of long-term agreements to improve energy efficiency in the industrial sector: Overview of the European experiences and proposal for a common framework. *Proceedings of the 1999 American Council for an energy-efficient economy summer study on energy efficiency in industry.* Washington, DC: ACEEE.

Bertoldi, P. (2011). *Assessment and experience of white certificate schemes in the European union.* IEA.

Bertoldi, P., Rezessy, S., & Vine, E. (2006). Energy service companies in European countries: Current status and a strategy to foster their development. *Energy Policy*, *34*(14), 1818–1832.

Bhandari, D., & Shrimali, G. (2018). The perform, achieve and trade scheme in India: An effectiveness analysis. *Renewable and Sustainable Energy Reviews*, *81*, 1286–1295.

Brogi, A., & D'Adamo, C. (2007). Impact of end-use energy efficiency on the distribution network. *CIRED 19th International Conference on Electricity Distribution*, Vienna, 21–24 May 2007.

Brown, M. (2001). Market failures and barriers as a basis for clean energy policies. *Energy Policy*, *29*(14), 1197–1207.

Brown, M., Hanafi, A., & Petsonk, A. (2012). *The EU emissions trading system: Results and lessons learned.* Washington, DC: Environmental Defense Fund.

Bureau of Energy Efficiency. Government of India. (forthcoming). *PAT cycle.* Retrieved from https://beeindia.gov.in/content/pat-cycle

Cagno, E., Trianni, A., Abeelen, C., Worrell, E., & Miggiano, F. (2015). Barriers and drivers for energy efficiency: Different perspectives from an exploratory study in The Netherlands. *Energy Conversion and Management*, *102*, 26–38.

California Air Resources Board (CARB). (2011). *Overview of ARB Emissions Trading Program.* Retrieved from http://www.arb.ca.gov/newsrel/2011/cap_trade_overview.pdf

California Air Resources Board (CARB). (2014). *2020 Business-as-Usual (BAU) emissions projection: 2014 edition.*

California Air Resources Board (CARB). (2018). *Annual report to the legislature on California climate investments using cap-and-trade auction proceeds.*

Carbon Trust. (n.d.). *Interest free energy efficiency loans in Wales.* Retrieved from http://www.carbontrust.com/client-services/technology/implementation-and-finance/interest-free-loans-wales/

Chidiak, M. (1999). Voluntary agreements for energy efficiency in five EU countries. In *Energy efficiency and CO_2 reduction: The dimensions of social change: 1999 European council for an energy-efficient economy summer study*, May 31–June 4, Mandelieu, France 1999.

China Dialogue. (2017). *Five things to know about China's national carbon market.* Retrieved from https://www.chinadialogue.net/blog/10303-Five-things-to-know-about-China-s-national-carbon-market/en

Climate and Development Knowledge Network. (2013, January). *Creating market support for energy efficiency: India's Perform achieve and trade scheme.*

Confederation of British Industry (CBI). (2013). *Shining a light uncovering the business energy efficiency opportunity.*

Confederation of British Industry (CBI). (2015). *The future of the energy company obligation.*

Cornelis, E. (2014). Lessons learnt from two long-term agreements on energy-efficiency in industry in Flanders, Belgium. *ECEEE Industrial Summer Study Proceedings.*

Current Affairs Reports. (2010). *Gap of energy intensity between China and developed countries* (in Chinese).

De Beer, J., Kerssemeeckers, M., Aalbers, R., Vollebergh, H., Ossokina, J., de Groot, H., … Blok, K. (2000). *Effectiveness energy subsidies: A study of the effectiveness of several subsidy and fiscal instruments in the period 1988–1999*. Utrecht, The Netherlands: Ecofys.

DeCanio, S. (1993). Barriers within firms to energy-efficient investments. *Energy Policy*, *21*(9), 906–914.

Department of Environment, Food, and Rural Affairs (DEFRA). (2006). *Climate change: The UKProgramme 2006*. London, England: DEFRA.

Di Santo, D., Forni, D., Venturini, V., & Biele, E. (2011). *The white certificate scheme: The Italian experience and proposals for improvement.* European Council for an Energy Efficient Economy (ECEEE) Summer Study.

Ekins, P., & Etheridge, B. (2006). The environmental and economic impacts of the UK climate change agreements. *Energy Policy*, *34*, 2071–2086.

Elliott, N. (2007). *Energy investment decisions in the industrial sector.* American Council for an Energy-Efficient Economy (ACEEE).

Energy Charter Secretariat. (2010). *Market trading mechanisms for delivering energy efficiency.* Brussels, Belgium.

European Commission. (2011). *Commission Decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council.* Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011D0278

European Commission. (forthcoming). *The EU emissions trading system (EU ETS).* Retrieved from http://ec.europa.eu/clima/policies/ets/index_en.htm

Friedman, B., Bird, L., & Barbose, G. (2009). Energy savings certificate markets: Opportunities and implementation barriers. In *ASME 2009 3rd international conference on energy sustainability collocated with the heat transfer and InterPACK09 conferences 2009*: 1–11. American Society of Mechanical Engineers.

Geller, H., Harrington, P., Rosenfeld, A., Tanishima, S., & Unander, F. (2006). Polices for increasing energy efficiency: Thirty years of experience in OECD countries. *Energy Policy*, *34*(5), 556–573.

Giraudet, G., Bodineau, L., & Finon, D. (2012). The costs and benefits of white certificates schemes. *Energy Efficiency*, *5*(2), 179–199.

Goldberg, A., Taylor, R., & Hedman, B. (2014). *Industrial energy efficiency: Designing effective state programs for the industrial sector.* Institute for Industrial Productivity.

Goldman, C., Hopper, N., & Osborn, J. (2005). Review of US ESCO industry market trends: An empirical analysis of project data. *Energy Policy*, *33*(3), 387–405.

Golove, W., & Eto, J. (1996). *Market barriers to energy efficiency: A critical reappraisal of the rationale for public policies to promote energy efficiency* (Report LBNL-38059). Berkeley CA: Lawrence Berkeley National Laboratory.

Green Investment Bank. (2015). Annual report and accounts 2014–15.

Grüning, C., Menzel, C., Panofen, T., & Shuford L. (2012). *National climate finance institutions support program, case study: The Thai energy efficiency revolving fund.* UNEP and Frankfurt School of Finance & Management.

Hansen, K., & Larsen, A. (1999). Voluntary agreements in industry: A comparative description of the process and a normative analysis. *Proceedings of the 1999 American council for an energy-efficient economy summer study on energy efficiency in industry.* Washington, DC: ACEEE.

Harrison, D., & Radov, D. (2002). *Evaluation of alternative initial allocation mechanisms in a European union greenhouse gas emissions allowance trading scheme.* National Economic Research Associates Report to the European Commission's DG Environment.

HM Revenue & Customs with HM Treasury & Defra. (2008). *Evaluation of enhanced capital allowance (ECA) for energy saving technologies.*

Intergovernmental Panel on Climate Change. (2003). *Revised 1996 IPCC guidelines for national greenhouse gas inventories: Reference manual.*

International Emissions Trading Association (IETA). (2013). *The world's carbon markets: A case study guide to emissions trading - United Kingdom.*

International Emissions Trading Association. (2015). *The World's carbon markets: A case study guide to emissions trading - India.*

International Energy Agency. (2011). *Joint public-private approaches for energy efficiency finance policies to scale-up private sector investment.*

International Energy Agency. (forthcoming). *Energy efficiency policies and measures database.* Retrieved from http://www.iea.org/policiesandmeasures/energyefficiency/

Investopedia. (forthcoming). *Free rider problem.* Retrieved from http://www.investopedia.com/terms/f/free_rider_problem.asp

ISWte for Industrial Productivity. (forthcoming). *Industrial efficiency policy database, Netherland, Long-Term Agreements on Energy Efficiency.* Retrieved from http://iepd.iipnetwork.org/policy/long-term-agreements-energy-efficiency

Johansson, M. T., & Thollander, P. (2018). A review of barriers to and driving forces for improved energy efficiency in Swedish industry–recommendations for successful in-house energy management. *Renewable and Sustainable Energy Reviews*, *82*, 618–628.

Kiung, K., & Morehouse, E. (2015). *Carbon market California: A comprehensive analysis of the Golden State's cap-and-trade program, Year two: 2014.* Environmental Defense Fund (EDF).

Labanca, N. (2008). *White certificates: Concept and market experiences.* Retrieved from http://www.ewc.polimi.it/documents/EWC_brochure.pdf

Laing, T., Sato, M., Grubb, M., & Comberti, C. (2013). *Assessing the effectiveness of the EU emissions trading system.* Centre for Climate Change Economics and Policy.

Lo, K. (2014). A critical review of China's rapidly developing renewable energy and energy efficiency policies. *Renewable and Sustainable Energy Reviews*, *29*, 508–516.

Mazurek, J., & Lehman, B. (1999). Monitoring and verification of long-term voluntary approaches in the industrial sector: An initial survey. *Proceedings of the 1999 American Council for an Energy-Efficient Economy Summer Study on energy efficiency in industry.* Washington, DC: ACEEE.

McKane, A. (2013). *Assessing the costs and benefits of the superior energy performance program.* American Council for an Energy-Efficient Economy Summer Study on energy efficiency in industry. Niagra Falls, NY.

Ministry of Power, Government of India. (2017). *Achievements under Perform, Achieve and Trade (PAT).* Retrieved from https://www.beeindia.gov.in/sites/default/files/Booklet_Achievements%20under%20PAT_May%202017.pdf

National Bureau of Statistics. (2016). *China energy statistical yearbook 2015*. Beijing, China: China Statistics Press.

National Development and Reform Commission. (2011). *Notice on top-10,000 enterprises energy efficiency and low carbon implementation plan* (in Chinese).

National Development and Reform Commission. (2015). *Evaluation of top-10,000 enterprises for the year of 2014* (in Chinese).

National Development and Reform Commission. (2016). *Notice on key tasks of launching national carbon trading system* (in Chinese). Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbtz/201601/t20160122_772123.html

National Development and Reform Commission. (2017). *Plan for National Carbon Trading System Establishment (Power Generation Sector)* (in Chinese). Retrieved from http://www.ndrc.gov.cn/gzdt/201712/W020171220577386656660.pdf

Newman, J. (1998). Evaluation of energy-related voluntary agreements, in Martin et al., (eds.) *Industrial energy efficiency policies: Understanding success and failure: Proceedings of a workshop organized by the international network for energy demand analysis in the industrial sector.* Utrecht, The Netherlands. LBNL-42368.

Paton, B. (2002). Voluntary environmental initiatives and sustainable industry. In P. ten Brink (Ed.), *Voluntary environmental agreements: Process, practice and future use*. Sheffield, England: Greenleaf.

Pender M. (2008). *UK climate change programme: Business and public sector economic instruments, presentation at the UN-energy expert group meeting on advancing industrial energy efficiency in the Post-2012 framework.* Washington, DC. Retrieved from https://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/EPU/Pender.pdf

Price, L. (2005). *Voluntary agreements for energy efficiency or GHG emissions reduction in industry: An assessment of programs around the world.* ACEEE Summer Study on Energy Efficiency in Industry.

Price, L., Blok, K., Nuijen, W., & Pender, M. (2005). *Setting voluntary agreement targets, presentation at the workshop on energy efficiency agreements*, Beijing.

Price, L., Galitsky, C., Sinton, J., Worrell, E., & Graus, W. (2005). *Tax and fiscal policies for promotion of industrial energy efficiency: A survey of international experience.* LBNL report.

Price, L., & Lu, H. (2011). Industrial energy auditing and assessments: A survey of programs around the world. In *Proceedings of the European Council for an Energy-Efficient Economy's 2011 summer study on energy efficiency.*

Price, L., Worrell, E., Sinton, J., & Yun, J. (2003). *Voluntary agreements for increasing energy-efficiency in industry: Case study of a pilot project with the steel industry in Shandong Province, China.* Lawrence Berkeley National Laboratory.

Reinaud, J., & Goldberg, A. (2011). *The boardroom perspective: How does energy efficiency policy influence decision making in industry?* (IEA-IIP Information paper). IEA/OECD, Paris.

Rezessy, S., & Bertoldi, P. (2011). Voluntary agreements in the field of energy efficiency and emission reduction: Review and analysis of experiences in the European Union. *Energy Policy*, *39*(11), 7121–7129.

Ryan, L., Jessula, E., & Rozite, V. (2012). *The European experience with tax relief for energy efficient equipment in industry – All bad or just second best?* ECEEE 2012 summer study on energy efficiency in industry.

Sarkar, A., & Singh, J. (2010). Financing energy efficiency in developing countries—Lessons learned and remaining challenges. *Energy Policy*, *38*(10), 5560–5571.

Schleich, J., Rogge, K., & Betz, R. (2009). Incentives for energy efficiency in the EU emissions trading scheme. *Energy Efficiency*, *2*(1), 37–67.

Smith, S., & Swierzbinski, J. (2007). Assessing the performance of the UK emissions trading scheme. *Environmental and Resource Economics*, *37*(1), 131–158.

Steuwer, D. (2012). *Energy efficiency governance: The case of white certificate instruments for energy efficiency in Europe*. Berlin, Germany: Springer Science & Business Media.

Streitferdt, V., & Chirarattananon, S. (2015). Energy efficiency finance support in Thailand: Lessons learned from the energy efficiency revolving fund. *Journal of Sustainable Energy & Environment*, *6*, 13–16.

Trianni, A., Cagno, E., & Farné, S. (2016). Barriers, drivers and decision-making process for industrial energy efficiency: A broad study among manufacturing small and medium-sized enterprises. *Applied Energy*, *162*, 1537–1551.

U.S. Department of Energy. (2011). *Energy savings performance contracting: The investment grade audit.*

U.S. Department of Energy. (2015a). *Federal ESPC process Phase 3: Project development.*

U.S. Department of Energy (DOE). (2015b). *IAC quarterly updates.*

U.S. Department of Energy (DOE). (forthcoming). *Section 1703 loan program.* Retrieved from http://energy.gov/lpo/services/section-1703-loan-program

U.S. Energy Information Administration. (2016). *U.S. energy-related carbon dioxide emissions, 2015*. Washington, DC: U.S. EIA.

UK Steel. (2007). *UKSteel annual review 2007*. London, England: EEF.

United States Agency for International Development. (2009). *Innovative approaches to financing energy efficiency in Asia.*

Vine, E. (2005). An international survey of the energy service company (ESCO) industry. *Energy Policy*, *33*(5), 691–704.

World Bank. (2015). *India - Partial Risk Sharing Facility for Energy Efficiency (PRSF) project*. Washington, DC: World Bank Group.

World Bank. (n.d.). *Putting a price on carbon with an ETS.* Retrieved from http://www.worldbank.org/content/dam/Worldbank/document/Climate/background-note_ets.pdfhttp://www.worldbank.org/content/dam/Worldbank/document/Climate/background-note_ets.pdf

Yang, M., Hu, Z., & Yuan, J. (2016). The recent history and successes of China's energy efficiency policy. *WIREs Energy and Environment*, *5*(6), 715–730.

Yu, C., & Fu, G. (2017). *Market-oriented energy efficiency mechanism design for key energy-intensive enterprises (in Chinese)*. Beijing, China: China Science and Technology Press.

Yuan, J., Kang, J., Yu, C., & Hu, Z. (2011). Energy conservation and emissions reduction in China—Progress and prospective. *Renewable and Sustainable Energy Reviews*, *15*(9), 4334–4347.

Zhou, N., Levine, M., & Price, L. (2010). Overview of current energy-efficiency policies in China. *Energy Policy*, *38*(11), 6439–6452.

Zuckerman, J., Laughlin, K., Abramskiehn, D., & Wang, X. (2014). *Cap and trade in practice: Barriers and opportunities for industrial emissions reductions in California* (CPI Working Paper).

How to cite this article: Liu X, Shen B, Price L, et al. A review of international practices for energy efficiency and carbon emissions reduction and lessons learned for China. *WIREs Energy Environ*. 2019;e342. https://doi.org/10.1002/wene.342