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# Smart demand response in China: Challenges and drivers

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## ABSTRACT

Smart demand response (SDR) induces change in electricity consumption by end-users, in response to price signals or incentives, via smart infrastructures. In China, SDR programs are instrumental in peak shaving, renewables integration, emissions reduction and grid reliability improvement. Previous literature has not captured the effects of the latest development of electricity market reform on SDR. Our work is distinguished from prior work by (a) comprehensively identifying China-specific SDR challenges, by contrasting these with international experience, (b) identifying effective drivers to overcome new market challenges, and (c) recommending policies and providing insights into China's future SDR development. Our paper identifies three major challenges for SDR development and adoption in China, namely, financial and market, consumer, and infrastructural challenges. In parallel, we identify drivers to overcome these challenges, including electricity market reform, introduction of new market entrants, and development of decentralized electricity systems. Finally, we put forth China-specific policy recommendations, including, continuous market reform, performance-based regulations for national utilities, a level playing field for new market entrants, and investments on consumer-based technologies. These measures aim to create equitable compensations to SDR, align the interests of utilities with SDR initiatives, provide incentives for consumer outreach, and improve the responsiveness of consumers to SDR signals.

## 1. Introduction

Demand Response (DR) is a mechanism that induces change in electricity consumption pattern by offering pricing signals and incentives, thereby reducing peak demand and strengthening power system flexibility (Braithwait and Eakin, 2002; FERC, 2012). DR covers intentional modifications on the end-users' electricity consumption patterns via altering the duration of use, the level of instantaneous demand, and the total electricity consumption (Albadi and El-Saadany, 2007).

DR has traditionally been divided into price-based programs and incentive-based programs. Price-based programs, such as time of use (TOU), real-time pricing (RTP), critical peak pricing (CPP) and peak-time rebate (PTR), provide time-varying pricing to consumers and are often non-dispatchable; incentive-based programs, such as direct load control (DLC), interruptible or curtailable load (IL) and demand side bidding or buyback (DSB) programs, offer incentive payment to load reduction and are often dispatchable (Palensky and Dietrich, 2011; US Department of Energy, 2006).

With the growth in smart infrastructures, DR will increasingly employ smart technologies including: 1) two-way communications interval meters; 2) communication devices that inform customers of load curtailments; 3) energy-information tools that allow baseline and actual usage evaluation, and potential load alerts for utilities; 4) load controller or energy management system (Siano, 2014).

Energy Network Association (ENA, 2012) defines DR invoked in a smart infrastructure as Smart Demand Response (SDR). We elaborate on this and define SDR as any mechanism that induces an intentional shift or passive change of electricity consumption by end-use consumers, in response to price signals or incentives, with the assistance of smart technologies.

There is a rich body of literature covering international SDR programs development. The majority of the literature has focused on specific programs and quantified their effects on peak loads shaving (Benetti et al., 2016; Dlamini and Cromieres, 2012; Lee et al., 2012), changes in aggregate consumption (Bradley et al., 2013; Vanthournout et al., 2015), and electricity cost saving (Faria and Vale, 2011; Hussaina et al., 2015; Venkatesan et al., 2011). The common benefits of SDR described in the literature include reducing system peak loads, postponing infrastructural investments, improving reliability of transmission and distribution networks, and encouraging the adoption of renewable energy technologies (Aghaei and Allizadeh, 2013; Balijepalli et al., 2011; Goel et al., 2006; Sioshansi and Short, 2009).

In China, SDR is particularly relevant in peak shaving, renewables

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integration, emission reduction and grid reliability. China has a painful history of electricity shortage and forced electricity curtailment. To date, in some parts of China, industrial electricity users would still be asked to reschedule their production in peak-demand seasons (Wang, 2016; Yang, 2016). Despite its leading position in renewable energy installation, China also faces acute challenges in integrating the installed renewables to the grid and in ensuring its reliability (Kahrl et al., 2013; Lu et al., 2016). China is also facing increasing pressure to reduce carbon emissions, especially emissions from coal. SDR is instrumental in solving these problems. First, SDR has the potential to replace mandatory load shedding, thereby minimizing the disruption to industrial users during the peak hours; second, SDR enhances the flexibility of the electrical system, which in turn increases renewable penetration and grid reliability; third, SDR can be used to shift the coal-fired electricity which has traditionally been used to support the peak loads, therefore substantially reducing coal-fired generated carbon emissions (Gilbraith and Powers, 2013; Smith and Brown, 2015).

Apart from the above, SDR programs also carry the potential to lessen the challenges that China's electricity sector encounters now or in the near future, such as inefficient pricing, inefficient dispatch and poor capacity planning (Kahrl et al., 2011, 2013). For instance, when a wholesale market emerges in China, SDR programs such as RTP will become instrumental in improving demand-side efficiency; SDR can serve as a capacity resource and contribute to economic dispatch and capacity planning (Aghaei and Alizadeh, 2013; Shariatzadeh et al., 2015; Walawalkar et al., 2010).

Adopting SDR in China presents both challenges and opportunities. On the one hand, challenges in China include the lack of experience, limited investment on SDR, distorted pricing, and the unavailability of advanced technologies (Dong et al., 2016; Li et al., 2016; Ming et al., 2013; Wang et al., 2010; Yu, 2012; Zhong et al., 2010). On the other hand, market reforms that drive SDR adoption have been introduced in China's electricity sector over the last few years, including the newly introduced market-based pricing for coal-fired electricity and renewables such as solar and wind, and the ambitious targets set for smart grid and renewables via regulations, administrative measures and subsidies (Communist Party of China Central Commission, 2015; National Energy Administration, 2016; Xinhua, 2014). Our work is distinguished from prior international literature on SDR by (a) comprehensively reviewing and identifying China-specific SDR challenges, and comparing China's case with international experience, (b) identifying corresponding drivers that can effectively overcome these challenges under the new electricity system in China, and (c) recommending measures that can stimulate the adoption of SDR programs in China. Given that SDR will play an important role in shaping China's future electricity system and market, and the carbon trajectory of the electricity sector in China, our insights, especially on how SDR programs can be further developed in China, will tremendously benefit the future electricity system and market in China.

The rest of this paper is organized as follows. Section 2 presents the economic basis for DR and SDR development and adoption. Section 3 provides an overview of such development in China. Section 4 presents the main challenges and Section 5 identifies the main policy drivers to SDR development and adoption. Section 6 concludes the article and summarizes the policy implications and conclusions for SDR development and adoption in China.

## 2. Economic basis for demand response and smart demand response development and adoption

DR serves as an effective means to reduce the costs of utilities. In the regulated market, utilities are responsible for the whole spectrum of activities covering power generation, transmission and distribution. In return, utilities obtain a regulated price, usually a flat rate for delivered electricity. Since the adoption of integrated resource planning in the 1970s, utilities have been aware of the high system costs incurred from the peak demand (Cappers et al., 2010). Demand response is a means by which utilities use to balance electricity supply and demand by temporarily shifting the peak demand via pricing mechanisms (Hurley et al., 2013). For example, U.S utilities started to deploy direct load control and interruptible/curtailed program from the 1970s (FERC, 2006). Utilities need to demonstrate that the curtailed load could reduce supply costs relative to an all-generation solution, while providing a service equivalent to displaced generation (Ruff, 2002; US Department of Energy, 2006).

After the introduction of electricity market deregulation in most developed economies, electricity market is separated into a wholesale market and a retail market. In the wholesale market, generation companies bid at the marginal costs and obtain a price reflective of the scarcity of the generation resource. In the retail market, consumers purchase electricity at a regulated price set by the government. Hence, consumers in the retail market will purchase electricity at a price unreflective of the price signals of the wholesale market. Electricity demand will remain inelastic no matter how costly the wholesale price is. DR is therefore proposed to address the price inelasticity by introducing the costs of electricity generation to the retail market. With tools like time-varying pricing and demand curtailment at times of high wholesale prices, DR promises to establish a dynamic demand-side electricity market and an efficient equilibrium between supply and demand (Schweppe et al., 1980, 1982; Spees and Lave, 2007).

DR can also be used to alleviate the abuse of market power and improve market efficiency. Players in the electricity wholesale market, especially the real-time market, own more market power than their counterparts in other commodity market (Borenstein and Bushnell, 2000; Wang et al., 2003). This is because electricity market requires that electricity demand must be met at all times. In the absence of demand elasticity, a generator with even a modest market share is able to demand an extremely high price when capacity resource is in scarcity. The abuse of market power by wholesalers was the primary cause of the California electricity crisis between 2000–2001 (Joskow and Kahn, 2002; Wolak, 2003; Woo, 2001). The same phenomenon has been detected in many other deregulated markets (Woo et al., 2006). DR serves as deterrent to prevent generators from excessive market manipulation. It has been demonstrated that the abuse of market power can be substantially removed by DR, even when demand curtailment is very limited (Blumsack and Lave, 2004; Sweeney, 2002).

DR has been playing an increasingly important role in reducing short-term electricity pricing and in deferring investments on capacities and grids. In the United States (U.S.), approximately ten percent of the built capacity has been used to support only one percent of demand hours throughout a year (Feldman et al., 2016). In China, roughly five percent of peak electric load, or about 60 gigawatts, is generated only about 50 hours per year (Greentech Media, 2015). A modest reduction of peak demand can create considerable cost reduction. It is estimated that a reduction of only two to five percent in system-wide demand at peak times can reduce the spot price by at least 50% (Rosenzweig et al., 2003); a five percent reduction in demand during the highest one percent of demand hours can save utilities 5 billion USD per year (Faruqui and Sergici, 2010).

DR is increasingly viewed as a tool to enhance the reliability of the electrical system. In view of the increasing penetration of renewable energy, power supply is expected to become more volatile. Dispatchable demand response can be used to make up for power shortage during contingency events or can even become a regulating resource to provide automated demand reduction (Aghaei and Alizadeh, 2013; Hurley et al., 2013). In areas where ancillary service market is available, programs such as automated interruptible load (IL) can be introduced in the ancillary service market, providing load-shedding service equivalent to that of reserve capacity.