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Assessment of Demand Response Market Potential and Benefits in Shanghai

Executive Summary

Prepared by

Environmental Change Institute & Oxford Institute for Energy Studies
University of Oxford

Prepared for

Natural Resources Defense Council

Supporting Partners

China Prosperity Strategic Programme Fund of the Foreign and Commonwealth Office
The Energy Foundation

July 2015

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ACKNOWLEDGEMENTS

This report was produced by the collaboration of team members from the Environmental Change Institute (ECI) and the Oxford Institute for Energy Studies (OIES), University of Oxford. ECI and OIES worked together to synthesise international experience of using, supporting and valuing DR, while ECI led on the market potential assessment and OIES had the leading role on valuation analysis, with significant input from each other.

We would like to express our gratitude to Ms Hyoungmi Kim and her colleagues at the Demand-Side Management Project Team of NRDC China Programme, for their guidance, support and feedback through all stages of the project. We are very grateful for the valuable support from the Shanghai DR Implementation Team: Shanghai Municipal Commission of Economic and Informatization (EIC), Load Control Centre of State Grid Shanghai Municipal Electric Power Company, NRDC, Shanghai Twenty-First Century Energy Conservation Technology Co., Ltd, Shanghai Electrical Apparatus Research Institute (Group) Co., Ltd, Beijing Nari Smartchip Microelectronics Technology Co., Ltd, Hangzhou Telek Technology Co., LTD, Tongji University, Honeywell and LY Enerlytics. We would like also to extend our gratitude to these experts who have provided highly valuable and insightful comments and guidance: Mr Pierre Bull and Ms Jennifer Chen from NRDC, Mr Steve McCarty from Energy Solutions, Dr Fredrich Kahrl from Energy+Environmental Economics, Professor Yanmin Han from Tongji University and Dr Shaodi Zhang from Shanghai Electrical Apparatus Research Institute. Last but not least, we would like to thank NRDC Science Centre, China Prosperity Strategic Programme Fund (SPF) of the British Embassy in Beijing, and the Energy Foundation for their generous sponsorship of this study.

CONTENTS

EXECUTIVE SUMMARY

The electricity systems in China are changing. The need for large-scale integration of intermittent renewables and penetration of electric vehicles, as implied by the low-carbon energy transition, poses challenges to system operation and network management. Moreover, the ever-increasing electricity consumption and peak demand, and the emerging policy objectives of reducing environmental impacts and improving economic efficiency, underline the urgency to change the way electricity systems are operated and planned in China. There is a growing interest, particularly from high-level policy makers, to explore the potential for demand side resources to contribute to the supply-demand balance and to meet the key objectives of carbon emission reduction, environmental protection and economic efficiency.

Demand response (DR) is increasingly seen as an important demand-side resource in achieving these objectives. By definition, DR refers to programmes to reduce electricity use, especially at times of system peak, by exposing customers to pricing signals that reflect system marginal cost of generation or give them financial incentives in return for their commitment to reduce demand when asked to do so. As part of the orderly electricity use programmes, utilities in China have some experience running administrative load management programmes, including load shifting and avoidance projects, as well as restricted use and demand curtailment in the event of severe power shortage. However, without the market-based mechanisms typically employed in DR, administrative load management often lacks the ability and flexibility in promoting the willingness of customers to participate, and may not be 'fit-for-purpose' for the long-term development of demand-side resources.

The development of DR has increasingly become more important in China. In 2014, Shanghai became the first pilot city in China, as designated by the National Development and Reform Commission (NDRC), to trial municipality-level DR programmes. Focusing initially on commercial and industrial (C&I) customers, the pilot aims to explore market-based mechanisms to support the procurement of DR resources. While the Shanghai DR pilot is under way, the NDRC has issued a notice to four cities in China (i.e. Beijing, Suzhou, Tangshan and Foshan, referred to as demand-side management (DSM) cities), requesting them to plan and undertake DR pilots. Since the experience of implementing DR is limited in China, especially with models based on market mechanisms, there is immense value in learning from leading international experiences in countries (e.g. the UK and the US) where DR has been successfully used to address electricity system needs.

This study contributes to the DR pilot in Shanghai and similar efforts in other parts of China, by synthesising international experience in using and supporting DR resources, and by conducting a very preliminary assessment of the market potential and values of DR Shanghai. To share international experience, this report reviews the background and current situation of using DR resources, the existing efforts in the UK and the US to estimate the potential and value of DR, and the regulatory and policy enablers for promoting efficient DR. Given the difference in terms of regulatory and market conditions of electricity systems between China and OECD countries, this report also highlights a number of implications and caveats for interpreting evidence from OECD countries. To estimate the potential and the benefit of DR, the study first outlines the general framework and methodology for the assessment, before continuing to use international evidence and local data in Shanghai to gauge the DR potential and benefit there. This exercise provides an example of how to conduct such assessments and offers a number of recommendations for future research in the same area.

INTERNATIONAL EXPERIENCE

CHANGES IN ELECTRICITY SYSTEMS CREATE NEEDS AND OPPORTUNITIES FOR DEMAND-SIDE RESOURCES LIKE DR

Since electricity is difficult and expensive to store, supply and demand need to be matched at all times. Traditionally, the burden of maintaining the supply-demand balance largely falls on the supply side, with the demand side being treated essentially as passive. This is mainly due to the characteristics of electricity supply that are perceived to be most significant, such as controllability and reliability, relative ease in coordinating and aggregating supply-side, and the economics of supply-side flexibility.

Emerging changes in the electricity system have however sparked interest in using DR and other demand-side resources as complements or even alternatives to supply-side solutions. These changes include the increasing penetration of intermittent renewables and distributed generation as well as smart meters and appliances, market liberalisation and reliance on pricing signals for system balancing, declining costs of smart technologies for monitoring and managing demand, and government policy objectives of energy decarbonisation and environmental protection.

In the US, the history of DR can be traced back to the 1970s when regulated utilities offered DR programmes to deal with rising summer peak demand. After the electric industry restructuring, a number of issues such as the power crisis in 2000-2001 and sharp electricity price spikes led policymakers and regulators to see the value of DR for the efficient functioning of wholesale markets. In Europe, while policy has traditionally focused on energy efficiency, new trends such as growing peak demand, ambitious targets for renewables, lower costs of smart metering and other enabling technologies, and the potential of an 'active' demand-side have heightened the importance of DR in EU energy policy.

DR RESOURCES CAN BE USED TO DELIVER DIFFERENT SYSTEM SERVICES

Supply-demand balancing occurs at different timescales (e.g. yearly, daily or hourly). In light of this, a variety of DR products have been designed to meet different system needs. The nature and importance of these DR products depends very much on the specific nature of the electricity system concerned (characteristics such as peak demand period and drivers of system peak demand, needs for different system services, etc.). A further distinction can be made between DR resources for helping overall system balancing or resource adequacy and those for addressing geographically specific network constraints.

RESOURCE (CAPACITY) ADEQUACY

the biggest potential savings to the system come from long-term reduction in capacity requirements, particularly for generation. In the US and Europe, many unbundled systems[1] have introduced, or are setting up, capacity markets to give incentives for the construction or retention of the generating capacity needed to fulfil resource adequacy obligations (e.g. load serving entities in the US are required to contract for capacity that is 10-20% above forecast peak demand), and to balance the system at a time of growing importance of intermittent renewable energy sources, notably wind and solar PV. In a number of cases, these markets allow the participation of DR resources. Such schemes are generally based around ensuring a level of generating capacity or DR to ensure that expected demand could be met, via guarantees from the bidders to provide generation supply or demand side resources. Examples include forward capacity markets of ISO-NE and PJM[2], the Great Britain (GB) Capacity Market and other capacity mechanisms in NYISO and MISO[3].

ECONOMIC RESPONSE

Economic or price-responsive DR refers to a straightforward situation of customers responding to electricity prices by reducing (or increasing) consumption, of their own volition and in their own direct interests rather than because they have undertaken to provide a particular service for a payment. In periods when system prices are higher, normally at times of system peak demand, consumers are expected to reduce their demand to save money; they may shift some of that demand to periods when prices are lower. Economic or price-responsive DR can include retail time-based programmes

1.The term "unbundled" refers here to the separation of transmission (and sometimes distribution) network assets from generation, allowing for competition among generators (and sometime also in the retailing of electricity). "Bundled", on the other hand, refers mainly to vertically integrated utilities that are typically regulated monopolies that carry out generation, transmission and distribution activities in a specific region.

2.PJM is currently re-examining its approach to demand response in the light of a Court decision last year (http://www.pjm.com/~/media/documents/reports/20141007-pjm-whitepaper-on-the-evolution-of-demand-response-in-the-pjm-wholesale-market.ashx).

3.Regional transmission organisations (RTOs) or independent system operators (ISOs) in the US: Independent System Operator New England (ISO-NE); PJM Interconnection (PJM); New York Independent System Operator (NYISO); Midcontinent Independent System Operator (MISO).

offered by utilities (e.g. time-of-use tariffs, critical peak pricing). In some unbundled markets in the US (e.g. PJM, ISO-NE and NYISO), DR resources can also bid directly into wholesale energy markets, and reduce the power drawn from the grid during hours of high wholesale prices. With the penetration of intermittent renewables (e.g. wind and solar), DR resources may be used to increase demand in the event of high generation output and low wholesale prices, especially coupled with storage.

ANCILLARY SERVICE

since the electricity system often experiences short-term changes in the supply-demand balance, ancillary services are necessary to ensure system reliability. In the US, for regions with an unbundled electricity sector, independent system operators (ISOs) or regional transmission operators (RTOs) offer ancillary service markets to help manage the operation and balancing of transmission systems; for other regions with a bundled structure, it is the vertically integrated utility companies or balancing authorities that provide or buy such services. Eligible DR resources can be offered into these ancillary service markets (e.g. reserve services in ERCOT[4] and PJM). In the UK, National Grid, the system operator for Great Britain, maintains the Balancing Services (e.g. for Reserve Services and Frequency Response) to support the supply-demand balance of the GB Transmission System; DR resources have been successfully participating in these markets, with most of them found in the Short-Term Operating Reserve.

NETWORK CHARGES AND REGULATION

the electricity sector in the UK is unbundled, with transmission and distribution networks separated legally from each other and from other segments (e.g. competitive generation and retail markets). Regulated network charges are levied on energy suppliers and are then passed on to consumers to recover the cost of maintaining and upgrading transmission and distribution networks. Currently there are a number of opportunities in the network charges to enable the participation of DR resources from large customers (e.g. TRIAD avoidance[5], distribution use of network charges, and bi-lateral agreements with network operators).

4.Electric Reliability Council of Texas.

5.Large commercial and industrial customers can reduce their electricity demand for the three half-hourly periods with highest system peak demand in a year, so as to reduce their payment for transmission network use of system charges (TNUOS).

DR RESOURCES CAN MAKE MEANINGFUL CONTRIBUTIONS TO SYSTEM OPERATION AND PLANNING, AND PROGRAMMES IN DIFFERENT COUNTRIES HAVE UTILISED DR RESOURCES FROM VARIOUS SECTORS AND END-USES

Assessments have estimated significant DR potentials in different countries. For example, the National Assessment of Demand Response Potential in 2009, which was commissioned by the US Federal Energy Regulatory Commission (FERC), estimated that under the most optimistic scenario[6], 188GW of peak demand reduction could be achievable by 2019 in the US, representing a 20% of reduction in the projected peak demand without DR in that year[7].

In accordance with the US Energy Policy Act of 2005, FERC conducts biennial national surveys of progress in advanced metering and DR development in the US. The reported potential peak demand reduction of DR programmes increased from 29.7GW in the 2006 survey to more than 66GW in the 2012 survey (Figure ES 1). For the NERC regions in the US[8], this also marks an increase in the ratio between total reported potential peak demand reduction of DR programmes and total non-coincident summer peak load[9], from 3.9% in 2005 to 8.5% in 2011[10]. During the period of 2006-2012, significant increase is seen in the reported potential peak demand reduction of wholesale and C&I DR programmes, each of which takes up around 40% of the total potential peak demand reduction of DR programmes in the 2012 survey. Residential DR programmes grew by 40% in their reported potential peak demand reduction over the same period.

Dispatchable resource adequacy DR like curtailable programmes[11] and direct load control (DLC) programmes[12] contribute markedly more reported potential peak demand reduction, while some price-based programmes grew rapidly within the period between the 2006 and 2012 surveys (Figure ES 2). In the 2012 survey, curtailable programmes and DLC represent nearly 70% of the total reported potential peak demand reduction. Most of the C&I DR resources are enrolled in curtailable programmes and price-based DR programmes (mainly time-of-use tariffs). The bulk of wholesale DR resources in the US have concentrated on curtailable programmes and demand bidding & buy-back programmes, while they also participate in ancillary markets such as markets for spinning and non-spinning reserves. In comparison, the residential DR resources mainly participate in DLC and price-based DR programmes (mainly time-of-use tariffs), while DLC programmes also suit small C&I customers.

6.The most optimistic scenario assumes universal penetration of smart metering, with time-based tariffs being offered as the default option and with the use of enabling technologies.

7.Based on the NERC assessment, 2008 Long Term Reliability Assessment, for national (non-coincident) summer peak demand, which considers energy efficiency but not DR.

8.Only the US portion of North American Electric Reliability Corporation regions are covered (i.e. Hawaii and Alaska are excluded).

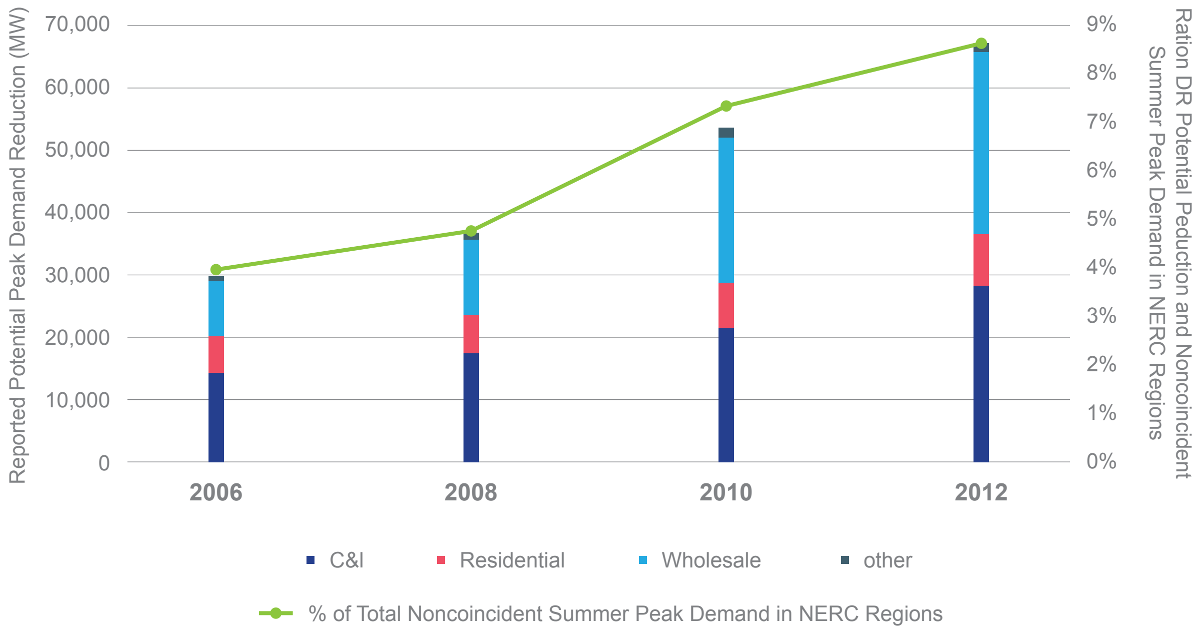
9.Sum of summer peak demand of NERC regions in the US. It is on the non-coincident basis since the peak demand of NERC regions occurs at different hours in the summer months.

10.Calendar year 2005 is the reporting period of the 2006 FERC survey and calendar year 2011 is the reporting period of the 2012 FERC survey

11.Curtailable programmes refer to dispatchable DR programmes (e.g. interruptible load, emergency DR and load as a capacity resource) that require customers to reduce their electricity demand when instructed by utilities or system operator. Interruptible load refers to load subject to curtailment or interruption under tariffs or contracts that provide a rate discount or bill credit for agreeing to reduce load during system contingencies. Emergency DR Programmes give customers a financial incentive to commit to reduce load if pre-defined emergency conditions are triggered. Load as a capacity resource refers to DR that commits to make pre-specified load reductions when system contingencies materialise.

12.In DLC programmes, customers allow utilities or system operator to remotely control their electricity demand in return for DR payment.

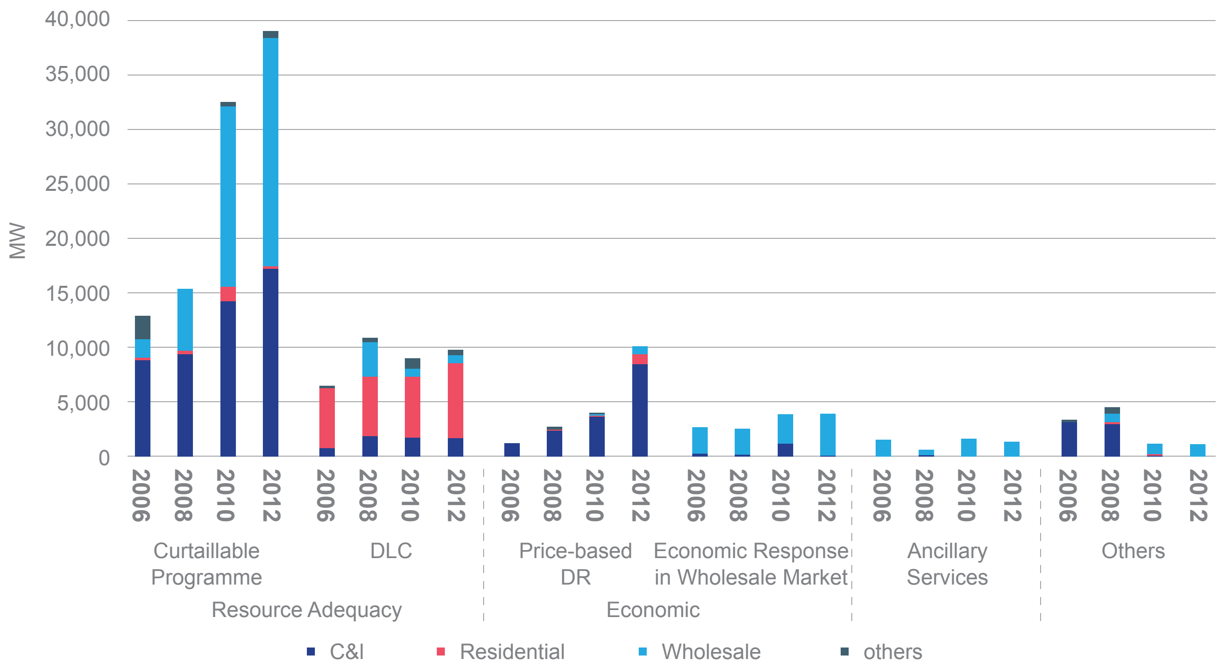
Figure ES 1 Reported potential peak demand reduction of DR programmes in the FERC surveys



Note: % of Total Noncoincident Summer Peak Demand in NERC Regions represents the ratio between reported potential peak reduction of DR programmes in the US portion of NERC regions (i.e. excluding Alaska and Hawaii) and total noncoincident summer peak load in the US portion of NERC regions.

Source: Based on EIA (2013); FERC (2006, 2008, 2011a, 2012)

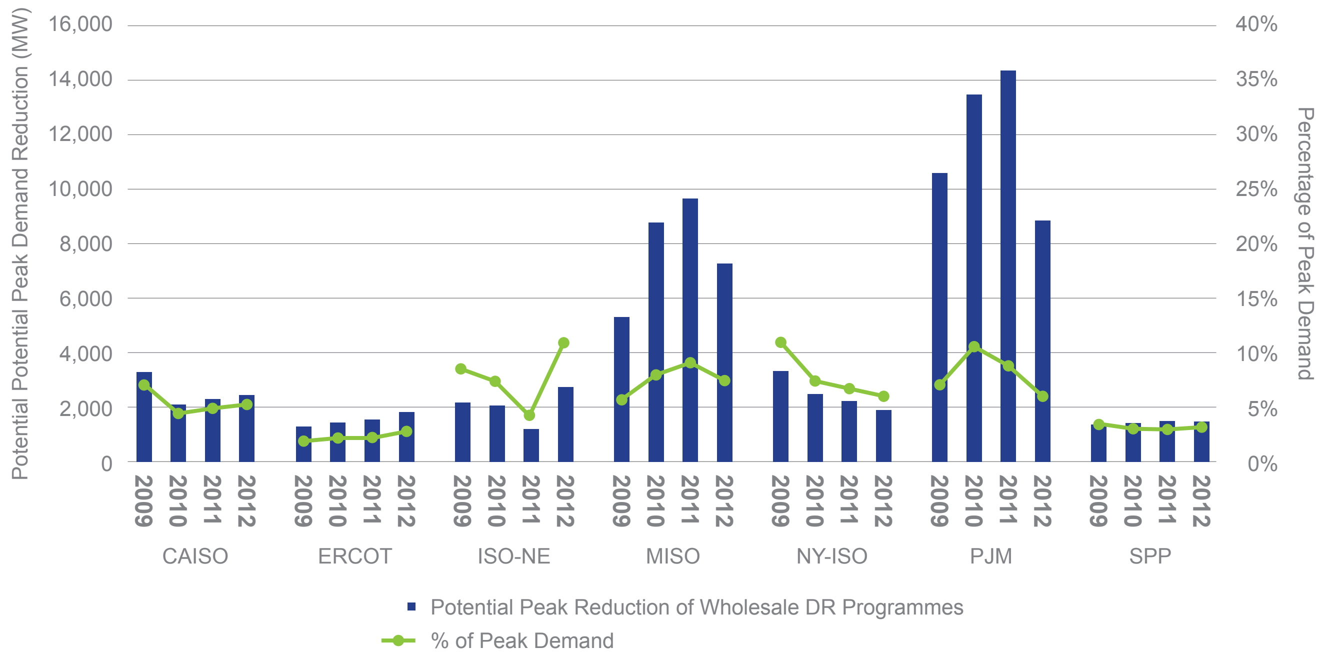
Figure ES 2 DR programmes and their potential peak demand reduction in the FERC surveys



Source: Adapted from FERC (2006, 2008, 2011a, 2012)

The size of existing DR resources in the wholesale markets differs between RTOs/ISOs (Figure ES 3). Compared with other regional system operators, PJM and MISO have markedly higher reported peak demand reduction of DR resources[13]. The reported peak demand reduction of DR constitutes 5-10% of the total peak demand of CAISO, ISO-NE, MISO, NYISO and PJM, while their contribution is lower in ERCOT (2-3%) and SPP[14] (3-4%).

Figure ES 3 DR resources in wholesale markets of RTOs/ISOs and their reported potential peak demand reduction



Source: Based on data in FERC (2011b, 2014)

DR resources can come from a variety of end-uses. For example, in the US, on-site generation, HVAC and manufacturing are the predominant means of load-reduction (70-90%) for the Emergency DR in PJM forward capacity market, while there is some notable participation of lighting and refrigeration as well. As for the source of DR, around 50% of the peak reduction potential comes from industrial or manufacturing sectors, followed by 20% from some commercial and public customers and 15% from residential end-uses.

13.This may partly reflects the larger number of customers (and thus size of loads) they serve. But advocacy and regulatory efforts to capture DR resources and utilise their system benefits are greater in scale may have contributed to the more significant role of DR in these markets.

14.Southwest Power Pool (US).

As for Great Britain, which is a winter-peaking system, The *Demand Side Response in the Non-Domestic Sector* in 2012 estimated 1.2-4.5GW (or 3-8% of system peak demand) of DR potential[15] in non-residential buildings. Moreover, the GB Electricity Demand project indicated 18GW (or 34% of system peak demand) of loads could be regarded as technically suitable for DR in 2012. This potential would rise up to 25-32GW (or 37-55% of projected system peak demand) in 2025.

However, the current DR participation in markets is modest in the UK. Ward et al. (2012) estimated a size of 1-1.5GW of the DR participation in 2012, with the 'true' load reduction (as opposed to demand reduction enabled by back-up generation) amounting to around 400-600MW. Even considering the new DR capacities as procured in the DSBR[16] and the GB Capacity Market, the DR participation is at most 2GW, which makes up only around 3% of the maximum winter peak demand of around 58GW. In the Short-Term Operating Reserve of National Grid, which has taken up most of the existing DR resources so far, demand-side resources have contributed 1.4-2GW in recent seasons, representing around 50% of the total STOR resources. However, most of these demand-side resources are in fact supply solutions (e.g. embedded generation), while 'true' load reduction has only contributed 110-237MW of capacity, which makes up 4-7% of the resources in recent STOR seasons. Moreover, for the moment, there is also limited DR participation in other balancing services of National Grid and the GB Capacity Market.

DR CAN BRING SIGNIFICANT BENEFITS TO THE ELECTRICITY SYSTEM

The benefits of DR are of many kinds, including avoided capacity cost, avoided energy cost, avoided network cost, avoided environmental externalities, participant bill savings and other benefits like system security (Table ES1). As the 'avoided costs' are not directly observable, assumptions have to be made about what costs would have been incurred in the absence of DR, which nonetheless involves uncertainty. It must be borne in mind that the value of DR resources can vary significantly from one power system to another, depending on the configuration of the power system, on the methodology used in the evaluation of DR, and especially on the basis for building capacity. Where generation and networks are built to meet peak demand, demand may be 'peakier' than is optimum if prices do not fully reflect the cost of supply at peak times. In this case, demand response may effectively substitute for the inadequacy of price signals and may avoid the construction of unnecessary capacity.

A number of international studies have estimated the benefits of DR. For example, for the UK, Element Energy and RedPoint (2012) estimated the potential benefits of DR from households and small & medium enterprises at £500m per year in the high demand scenario in 2030. Ofgem (2010) provides another estimation of the potential to avoid generation and network capacity costs in the UK through DR. If 10% (or 4.6-5.7GW) of the peak demand could be shifted, the Ofgem study estimated the annual avoided capital cost savings and the annual network investment savings at £265-536m and £28m respectively. For the US, the Brattle Group used a simulation-based approach to estimate the impacts of DR (power curtailment by 3% at each Mid-Atlantic zone's peak load) on the PJM energy market in 2005. It concluded that the benefits of DR to the entire PJM system were between $65 and $203 million per year, depending on market conditions. Moreover, regulatory bodies and other stakeholders have used the Avoided Cost Calculator developed by Energy and Environmental Economics to assess avoided cost savings.

15. Amount of end-use demand that is regarded as technically suitable and flexible to be reduced during the system peak period, without considering the economic or other factors likely to influence customers' participation.

16. Demand Side Balancing Reserve offers payment to large electricity users to reduce demand or use embedded generation between 4pm and 8pm of winter weekdays following the instruction from National Grid. National Grid launched it in 2014, alongside the Supplemental Balancing Reserve (SBR), to address the medium-term anticipated decline in capacity margin during winter periods for the next few years before the first delivery year of the GB Capacity Market in 2018.

Table ES 1 Potential benefits of DR to different activities of the electricity system

	Operation	Expansion	Market[1]
Generation	• Reduce energy generation in peak times: reduce cost of energy and possibly emissions[2] • Facilitate balance of supply and demand (especially important with intermittent generation) • Reduce operating reserves requirements for increase short-term reliability of supply	• Avoid investment in peaking units • Reduce capacity reserves requirements or increase long-term reliability of supply • Allow more penetration of intermittent renewable sources[3]	• Reduce risk of imbalances • Limit market power • Reduce price volatility
Demand	• Consumers more aware of cost and consumption and even environmental impacts • Give consumers options to maximize their utility • Opportunity to reduce electricity bills or receive payments	• Take investment decisions with greater awareness of consumption and cost	• Increase demand elasticity
Transmission and distribution	• Relieve congestion • Management contingencies, avoiding outages • Reduce overall losses • Facilitate technical operation[4]	• Defer investment in network reinforcement or increase long-term network reliability	
Retailing[1]			• Reduce risk of imbalance • Reduce price volatility • New products, more consumer choice

Note: [1] Only applicable in liberalized systems; [2] Depends on the electricity mix; [3] It can be considered a benefit in system where renewable generation is encouraged; [4] Keep frequency and voltage levels, balance active and reactive power, control power factor, etc..

Source: Conchado and Linares (2012), Table 3

TECHNICAL AND SOCIOECONOMIC ENABLERS ARE IMPORTANT FOR THE LONG-TERM DEVELOPMENT OF DR MARKET

A number of regulatory and market enablers for the development of DR markets are summarized here. To create the market for DR, utilities and system operators should face incentives for using DR as a resource and have confidence in its reliability, while customers need to have sufficient benefits and support for their long-term participation. While this summary draws mainly on examples where wholesale markets exist and final prices are determined through competition in retail markets, many of the considerations are also relevant to other electricity system structures (e.g. vertically integrated utility). However, market regulators and policymakers should take into account the specific conditions in the system of interest in designing enabling regulatory and policy environment.

BUSINESS MODELS OF DR PROGRAMMES

there should be opportunities and mechanisms for DR to provide system services. Depending on the ownership structure and characteristics of the electricity sector, different business models can be used to procure DR resources, including retail price-based DR programmes, incentive-based dispatchable programmes managed by system operators, and participation of consumers in wholesale electricity markets (Table ES 2).

Table ES 2 Business models of DR under different electricity industry structures

Market Structure	Sponsoring Entities	DR Programme Offerings[1]			
		Non-dispatchable Programmes		Dispatchable Programmes	
		Types	Implementation	Types	Procurement
Vertical Integration	Vertically integrated utility	Demand-based tariff TOU and CPP	Administrative tariff	DLC and curtailable programmes	Bilateral contracts Administrative offerings Dedicated auctions
Single-Buyer Model	Single-buying entity' (or system operator)	Demand-based tariff TOU and CPP	Administrative tariff	DLC and curtailable programmes	Bilateral contracts Administrative offerings Dedicated auctions
Wholesale Competition	System operator Distribution utilities	Demand-based tariff TOU, CPP and RTP[2]	Administrative tariff Response to/ integration with wholesale energy market	DLC and curtailable programmes Wholesale market participation	Bilateral contracts Administrative offerings Dedicated auctions Wholesale markets ('multiple resource auctions')
Full Competition	System operator Distribution network operators Retail suppliers	Demand-based tariff TOU, CPP and RTP Time-based network charges	Administrative tariff Response to/ integration with wholesale energy market	DLC and curtailable programmes Wholesale market participation	Bilateral contracts Administrative offerings Dedicated auctions Wholesale markets ('multiple resource auctions')

[1] Generally speaking, non-dispatchable DR refers to price-based DR, while dispatchable DR typically means incentive-based DR. However, the degree of 'dispatchability' may differ amongst resource types, depending on factors such as the stringency of the non-performance penalty.

[2] In principle, real-time pricing may also be offered under vertical integration or single-buyer model but this is not common.

ENABLING REGULATORY INCENTIVES FOR STAKEHOLDERS LIKE UTILITIES TO PROMOTE DR

regardless of the market structure, one vital prerequisite for the long-term development of DR is that key stakeholders recognise the value of DR (e.g. economic, reliability and environmental benefits) and face appropriate incentives to capture these benefits. Financing (at least from private capital) requires that the value stream from DR is reasonably predictable and can be captured by the actors making the investment. For regulated utilities, regulatory incentives (e.g. cost-effectiveness in resource procurement) should exist to encourage them to capture the financial and operational benefits of DR. Moreover, for the long-term viability of DR programmes, regulated utilities should be able to recover programme costs and lost revenues that can be justified. Regulators may even allow additional incentives for these utilities based on their performance in promoting DR. For wholesale markets and restructured electricity industries, predicting and capturing the value from DR may be more problematic as there may be a number of value streams, some of which (e.g. network benefits) may not naturally come directly to investor. In that case, even cost effective DR may not happen because no single actor can capture its value. In short, if there isn't a market in the relevant value, it will be difficult to know what the real value is, and certainly difficult for any private actor outside the utility to capture it. This points to the importance of a stable, transparent market structure that allows DR to be valued and the benefits to be captured. Regulatory efforts should remove barriers for DR resources to participate in these markets, ensure that pricing signals and market rules provide the stakeholder incentives for engaging in DR, and support the opportunities for DR to earn appropriate returns.

AGGREGATION CAN PLAY ENABLING ROLES FOR DR RESOURCE PROCUREMENT

aggregation can build on innovative business models, delivering 'value-adding services' to system operators, utilities and customers. Three main aggregation business models include curtailment service providers, support of direct DR procurement of system operator/utilities, and provision of other energy-related services. Benefits of aggregation are multiple, including tapping small DR resources, customer engagement and market development, and performance risk management and providing scope for innovation. More importantly, aggregators should have the 'natural' incentive for maximising DR procurement, whereas utilities may earn less revenue when consumers engage in DR. To support aggregators, regulatory authorities and policymakers should promote their access to customers and DR opportunities, create market for aggregated DR products and ensure the financial viability of the business model when the service helps to lower system costs.

CUSTOMER TECHNICAL CAPABILITY, INCENTIVE AND EDUCATION ARE IMPORTANT

for customers to engage with and participate in DR programmes in the long term, they need the technical capability to deliver DR, appropriate financial benefits to participate in DR programmes, and some awareness of why DR is important and how best to participate. Customers should have access to resources for identifying DR opportunities and enabling technologies. This includes access to aggregators or other sources of technical advice, two-way metering and communication, and energy management and feedback systems to monitor the delivery of DR. Programmes may consider offering subsidised or free technical support and incentives for enabling technologies. Depending on the needs of systems and the familiarity of customers with DR, the programmes on offer should also be diverse to fit with different needs and characteristics of electricity use. Moreover, customers should earn adequate benefits to justify the costs incurred in participation (e.g. direct cost in enabling technology and transactional costs), while the programme payment needs to be in line with the value of DR to the system. In light of this, DR programmes need to give customers confidence in the potential financial returns, and ensure that customer can see the value of DR (e.g. the impact of DR payment on the consumers' electricity bill). Finally, sustained customer education and outreach are essential for the long-term development of DR programmes. This has largely to do with the different needs customers may have at different stages of the 'customer journey' towards understanding how to be a smarter consumer. When customers are not familiar with DR, education and engagement are important to address concerns they may have about the risks of participation. Once customers gain some experience and have a better understanding of the benefits of participation, engagement and outreach can provide opportunities for encouraging them to develop DR capabilities even further.

RELIABILITY OF DR RESOURCES

electricity utilities and system planning authorities need to have confidence in the reliability of DR resources, with specific requirements depending on the service characteristics (e.g. frequency response or as a capacity resource). This is essential for treating DR as an alternative to supply-side solutions. While specific programme designs (e.g. penalty for under-performance in delivering DR commitment) can give incentives for reliability, technologies that promote controllability of end-uses also have an enabling role. Moreover, it is equally important for programme sponsors to undertake regular evaluation, measurement and verification (EM&V) to strengthen the evidence for the reliability of DR resources. This is especially valuable for non-dispatchable DR programmes, since they do not typically involve incentives for reliability.

ENABLING TECHNOLOGIES

Advanced Metering Infrastructure (AMI) is one essential technology for market-wide DR programmes, especially the price-based (non-dispatchable) programmes. Other technologies (e.g. smart appliances, energy management systems or process control systems for C&I customers) are also important enablers for the DR programmes, in particular those that require quick response and automation. Moreover, the granular data about real-time demand for various end uses may also be useful in increasing the 'visibility' of the impacts of DR actions, and in identifying the potential to provide different DR programmes. Finally, the ownership of on-site generation could strengthen the motivation and ability of customers to provide DR, although on-site generation is really an alternative supply-side resource and could well involve emissions and energy costs that are as great as, or greater than, those avoided by the system.

DIFFERENCE IN SYSTEM OPERATION CREATES BARRIERS FOR DR IN CHINA, BUT ONGOING ELECTRICITY MARKET REFORM PROVIDES OPPORTUNITIES

While the drivers for promoting DR and its potential benefits are relevant to China, the experience from OECD countries may not be directly transferable, essentially because the Chinese power system has developed very differently from systems in OECD countries. This difference highlights the need to design DR programmes to reflect the specific regulatory context in China as well as to change the practices and institutional framework governing electricity system operation. It also implies several practical considerations in estimating the potential and value of DR resources.

ADMINISTRATIVE DEMAND PLANNING IS NOT COMPATIBLE WITH MARKET-BASED DR

While originating from the 1970s when electricity supply was short, the practice of annual demand planning still exists today. There are a number of limitations to demand planning, such as the economic losses of administrative measures, inadequate incentives for individual customers to change their electricity demand voluntarily, and limited scope for developing DR products to meet different system needs (e.g. beyond system emergency, such as ancillary services to promote the integration of intermittent renewables). The transition from administrative demand planning to market-based DR requires not only regulatory changes, but also appropriate customer engagement and programme design. Moreover, administrative demand planning and its effect of demand suppression can undermine the value of market-based DR.

A RIGID INSTITUTIONAL AND GOVERNANCE FRAMEWORK FOR RESOURCE PLANNING AND DISPATCH CAN CREATE CONSTRAINTS FOR DR

As discussed further in Kahrl and Wang (2014), annual generator output plans and unit commitment plans, together with grid operating plans, form the basis for generation dispatch planning[17]. Annual generator plans typically require the maintenance of certain hours of operation for generation capacities. Together with the fixed schedule for interregional and interprovincial power exchange[18], this dispatch model risks constraining the scope for using DR, to the extent that the deployment of DR can have significant impacts on the operating hours of generation plants. Moreover, the multi-level hierarchy of dispatch model may also introduce complexity in the potential sharing of DR resources (and the costs and benefits) amongst provinces.

17. Annual generator output plans are drawn by provincial-level planning agencies to guarantee hours of operation for generators. For provinces using energy efficiency dispatch, unit commitment plan is made based on the dispatch order table mandating the order for dispatching generation. Grid operating plan incorporates transmission system security considerations and constraints.

18. Interregional and interprovincial power exchange schedule is fixed before provincial dispatch organisation makes the dispatch plan.

INADEQUATE DRIVE FOR ECONOMIC EFFICIENCY IN RESOURCE PLANNING AND DISPATCH MAY DISADVANTAGE DR

Unlike the UK and the US, the incentive for economic efficiency is largely absent in the electricity system of China. For example, the lack of optimised economic dispatch (e.g. day-ahead and operating reserves) across all generation types (e.g. coal, gas, hydro and renewables), or even the ad hoc approach to dispatch in some cases, means that less economically efficient units may be running at the expense of more efficient ones. The implication for DR is two-fold: first, the potential benefits of cost-effective DR may not be fully realised in the existing model of system dispatch and operation; secondly, there is little incentive for considering DR as an alternative resource in the electricity system planning.

LACK OF PRICING SIGNAL IN ELECTRICITY SYSTEM OPERATION MAKES IT DIFFICULT TO ASSESS DR VALUE

It is often possible to value DR resources in the UK and some US states by referring to what they (or an alternative resource) can earn in competitive wholesale markets for capacity, energy and ancillary services, financial transmission rights and CO2 emission permits. For systems with competitive market mechanisms, DR resources may compete directly against supply-side and other demand-side resources, or be procured by a competitive mechanism to determine the price for specific DR services. For systems without competitive market mechanisms, there is usually some economic information that allows the administrative price for DR to reflect an estimate of avoided costs. By contrast, the electricity system in China is still mostly subject to central planning, with prices, operating hours of power plants and peak demand pre-defined. Since the competitive market mechanism does not exist to determine prices, DR forms part of the planning process rather than being driven by price signals. The inadequate pricing signal makes it difficult to assess the full economic benefits of DR. Moreover, as customers do not face marginal prices that reflect system operation conditions and economic costs, they may see less benefit than otherwise from participating in DR, and have limited incentives.

HOWEVER, A NUMBER OF RECENT REGULATORY PROVISIONS IN CHINA SHOULD BE ABLE TO SUPPORT DR DEVELOPMENT IN THE MEDIUM- OR LONG-TERM

In the Opinions on Further Deepening the Power System Reform as issued in 2015, the State Council has not only heightened the importance of DR and other demand-side solutions in ensuring the supply-demand balance, but also highlighted its objectives for electricity pricing reform and introducing market-based mechanisms. Further development in these areas will contribute to the strengthening of pricing signals in system operation, and the flexibility of resource planning and dispatch. Moreover, there is also an intention to cut back on the practice of administrative demand planning in an orderly manner, and to allow voluntary interruptible contracts between customers and utilities. In principle, these efforts should create a more enabling environment for DR.

A 'PHASED' APPROACH FOR DEVELOPING THE DR MARKET LOOKS APPROPRIATE

given the specific regulatory characteristics of the electricity system in China. At the early stage, DR programmes may consider simple designs (e.g. curtailable programmes for resource adequacy to targeted customer groups), even on a pilot basis, to promote customer interest and understanding of this market-based approach, which is different from the administrative demand planning. Once customers gain more knowledge of participating in DR programmes, opportunities may arise for introducing more DR programmes to fit with the diverse customer characteristics and different system needs. From the viewpoint of the 'customer journey', this approach has value in enhancing customer engagement and learning, and sustained customer education and assistance should support it. Utilities and aggregators have very important roles to play in this. Moreover, it is important to conduct regular programme evaluation to develop the evidence of DR reliability, to share 'best practices' and to understand where improvement is needed. Meanwhile, on the regulatory level, it is advisable to leverage the opportunities of ongoing electricity market reform to 'familiarise' customers with 'market characteristics' of electricity prices. Examples can include the introduction of time-of-use tariffs or critical peak pricing to increase the potential benefits for delivering DR during high-priced periods. Regulators and utilities should also improve the accounting system and system service definitions to enable accurate assessment of the value of DR to system operation. This should complement the regulatory incentives for more cost-effective resource procurement and the engagement of utilities.

DR MARKET POTENTIAL AND VALUATION IN SHANGHAI

Estimating the potential and benefits of DR resources in specific markets is an important part of efforts to promote the utilisation of such non-supply-side resources to provide system services in China. The analysis can help utilities, system operators, government and other key stakeholders in identifying the scale and source of DR resources that can be expected, and their potential values to the electricity system as well as the targets and strategies for DR development.

FRAMEWORK AND METHODOLOGY FOR ASSESSING DR MARKET POTENTIAL

Market potential refers here to the level of potential to reduce demand at times of system peak[19], after taking into account practical considerations (e.g. programme design, incentive, customer engagement, characteristics of electricity use, regulatory and market conditions) that can affect the participation of customers in providing DR resources and/or the level of response in reducing electricity demand. International studies for DR market potential are heterogeneous in their analytical approach. However, they share some common features in the overall framework for conducting the potential analysis,

19.It is important to note that DR can be used to address system issues not necessarily occurring during system peak periods (e.g. when large generation capacity unexpectedly becomes unavailable, or the need to integrate intermittent renewable energy).

one of which is the 'bottom-up' approach in assessing DR potential. There are strong reasons to support the use of such 'bottom-up' approaches. For example, the potential of various customers to reduce demand and thus deliver DR largely depends on their characteristics of electricity use, which are likely to vary across different customer segments. The existence of specific end-uses and the ownership of enabling technologies can influence the amount of DR individual customers can deliver. Moreover, customer segments may have different capabilities and willingness to participate in DR programmes, given their specific participation requirements, incentives and other programme characteristics. Figure ES 4 shows the framework and steps for the 'bottom-up' approach in estimating the DR market potential.

Figure ES 4 Key steps in analysing the DR market potential

FRAMEWORK AND METHODOLOGY FOR ASSESSING DR BENEFITS

The benefits flowing from DR are calculated by reference to the costs which the DR programmes enable the utility to avoid (known as avoided cost) – i.e. the costs that it would have incurred in meeting the extra demand which would have existed in the absence of the DR programmes. Different types of avoided costs are often considered.

AVOIDED COSTS OF NEW GENERATION CAPACITY

this is derived from the reduction in generation capacity that would have been needed to satisfy peak demand (including a planning reserve margin[20] – PRM – and taking account of the avoided incremental T&D network losses) without DR. The estimated DR potential (usually in MW) can be used as a reference point to calculate the relevant capital costs of power plant that would provide equivalent generation capacity. We adopt the generation cost model developed by Energy and Environmental Economics (E3) to calculate the avoided generation capacity cost. Figure ES 5 describes the steps for calculating generation capacity costs.

20.We have added a reserve margin to the calculation of capacity avoided but that in future analyses the question would require more detailed consideration in the context of the planning and operation of the Shanghai system.

Figure ES 5 Steps for calculating the avoided generation capacity cost

AVOIDED ENERGY COSTS this can be calculated in various ways, for instance, by using historic and estimated future load profiles along with a forecast of the average value of wholesale energy (or of wholesale market prices where these exist). In a region without a wholesale energy market, avoided energy costs can be determined by comparing the energy costs under two circumstances: one with DR and one without DR. However, it is difficult to estimate avoided energy costs because there is no true counterfactual.

AVOIDED COSTS OF ANCILLARY SERVICES these are equally open to the difficulty of defining the counterfactual. In some countries, there are markets for these services; the prices in these markets may provide a reasonable estimate of their value to the system.

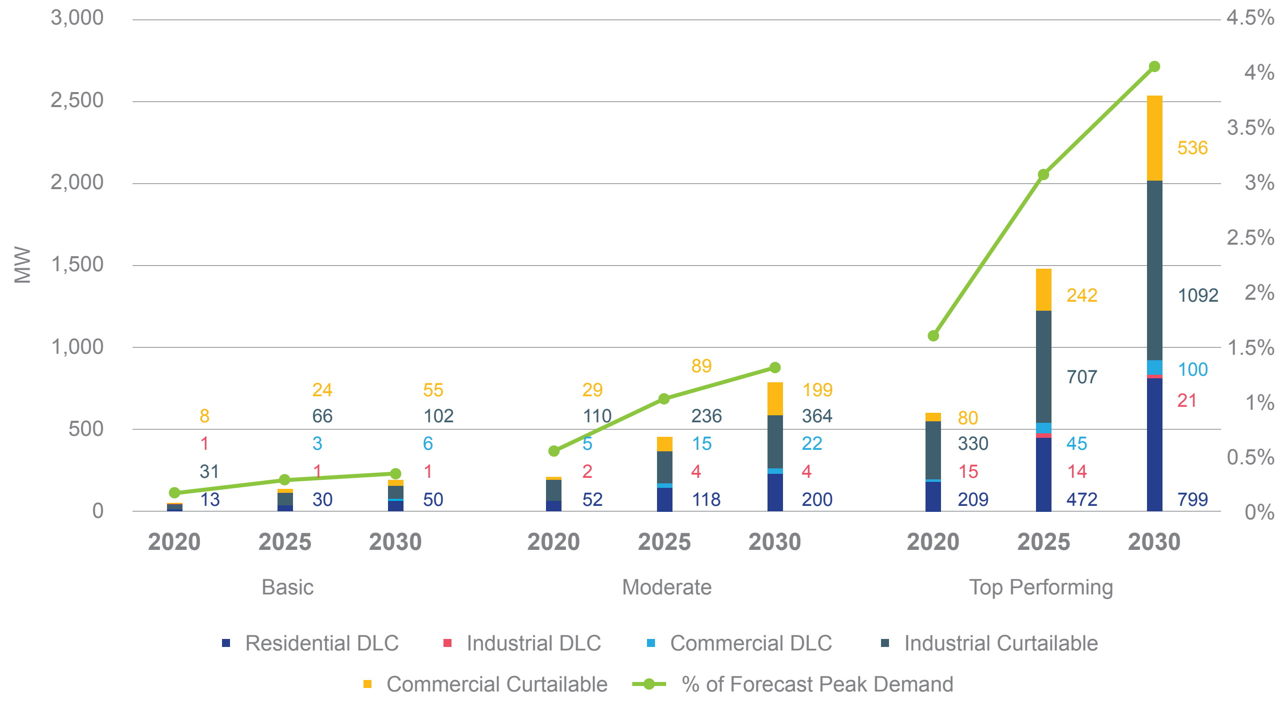
AVOIDED TRANSMISSION AND DISTRIBUTION COSTS in practice, avoided transmission costs are difficult to estimate because they depend on the time period, the specific location and the overall configuration of system. The starting point is usually to identify future potential network congestion and consider the capacity needed to relieve that congestion in the absence of DR.

POTENTIAL COSTS OF IMPLEMENTING DR it must be borne in mind that there are also potential expenses when implementing DR. For instance, the capital expenditure involved in the installation of DR equipment. The balance between costs and benefits will depend on the nature of the system concerned. In our analysis, due to the absence of information, we do not estimate the potential costs of implementing DR.

ESTIMATED DR MARKET POTENTIAL IN SHANGHAI

This study focuses on the DR market potential of direct load control (DLC) for air conditioning (AC) programmes and curtailable programmes up to 2030, based on three scenarios designed to reflect the different levels of participation rate and average per-customer DR load impact. Figure ES 6 shows the assessment results of DR market potential in future milestone years (2020, 2025 and 2030). Under the 'top-performing' scenario, the analysis shows that the market potential of DR resources could reach 2.5GW in 2030, representing 4% of the forecast peak demand in that year. The 'moderate' scenario assessed the market potential at 790MW in total or 1% of the forecast peak demand in 2030. As for the more conservative 'basic' scenario, the DR market potential was estimated at a low end of 214MW or 0.3% of the forecast peak demand in 2030.

Figure ES 6 Assessment of DR market potential in Shanghai



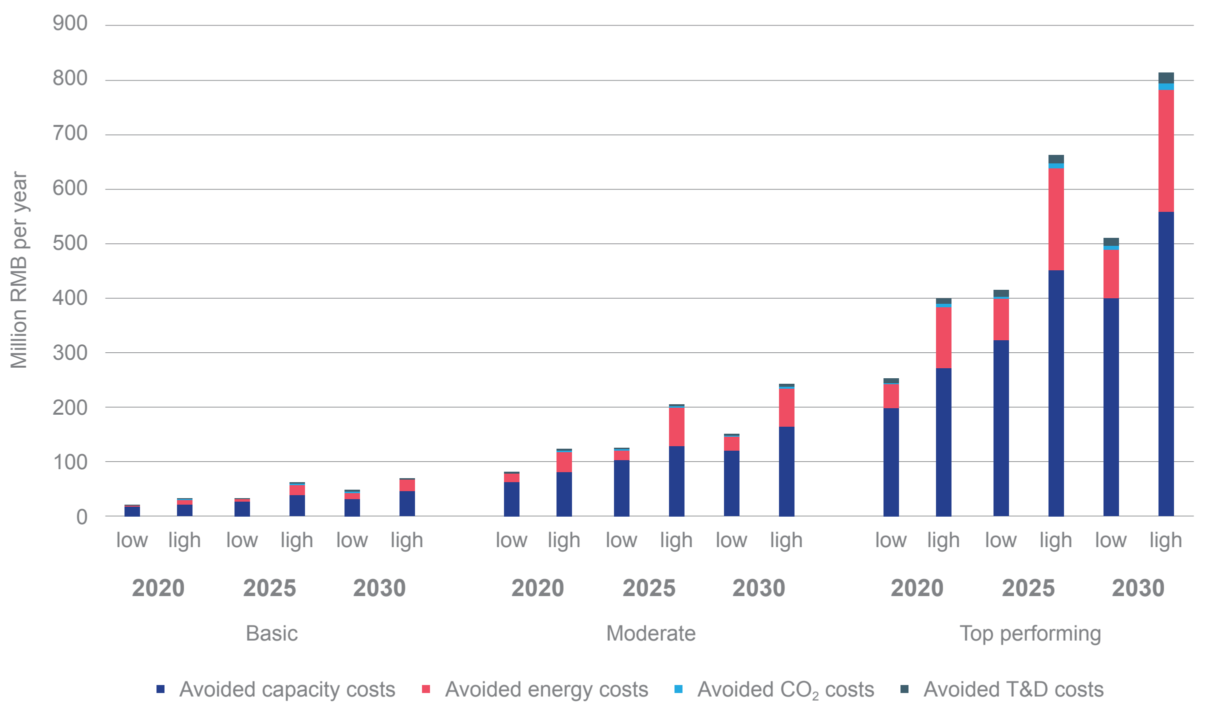
C&I CURTAILABLE PROGRAMMES CONTRIBUTE A PREDOMINANT SHARE IN THE ESTIMATED DR MARKET POTENTIAL In the assessment, around 64-73% of the DR market potential is coming from curtailable programmes in the C&I sectors in Shanghai. Industrial curtailable programmes, in particular, may contribute 43-59% of the total DR market potential as estimated for individual milestone years under different scenarios. Under the 'top-performing' scenario, out of the 2.5GW of total DR market potential in 2030, curtailable programmes for commercial and industrial customers may respectively deliver 0.5GW and 1.1GW of peak demand reduction.

RESIDENTIAL DLC FOR AC PROGRAMMES CAN MAKE A SIGNIFICANT SHARE OF THE CONTRIBUTION While DLC programmes for AC for small- and medium-sized C&I customers may make only a minimal contribution, residential DLC for AC programmes constitutes 23-33% of the estimated DR market potential for milestone years under different scenarios. Under the 'top-performing' scenario, residential DLC for AC programmes may be reducing peak demand by 0.8GW in in 2030.

ESTIMATED VALUE OF AVOIDED COSTS FROM DR IN SHANGHAI

The total avoided costs of DR in Shanghai include both the avoided generation capacity costs associated with the hypothetical gas-fired plant and the other avoided costs (including avoided energy costs, avoided CO2 emission costs, and avoided T&D costs) associated with the reference plant. This study assumes that the estimated DR market potential is achieved by load shedding only, and not by load shifting or on-site generation[21]. Figure ES 7 shows the estimated annual total avoided costs between 2020 and 2030. It shows that total avoided costs could reach 811.2 million RMB in 2030, when future cash flows are discounted at 7%. Avoided generation capacity costs contribute most to the total avoided costs (their share ranges between 68.3% and 79.7%), and are followed by avoided energy costs (between 17.8% and 28.1%). Avoided T&D costs and avoided CO2 costs together account for between 2.5 % and 3.8% of the total avoided costs.

Figure ES 7 Total avoided costs between 2020 and 2030



21.This is mainly due to the limited evidence as uncovered by this study to show the relationship between load shedding, load shifting and use of on-site generation in contributing to the peak reduction on the programme-level.

However, there are a number of caveats. On the one hand, the assessment only considers dispatchable DR (i.e. incentive-based programmes). Furthermore, due to inadequate information, we have not attempted to estimate the avoided costs of network expansion. For these reasons, our results may under-estimate DR market potential and value. On the other hand, there are reasons why our analysis may overstate the value of DR. First, since the valuation assumes that all market potential is achieved from load shedding only, the avoided costs[22] may be lower if part of the potential DR is actually achieved from load shifting or on-site generation respectively. Second, the practice of administrative demand planning has suppressed demand. This may well reduce the ‘real’ economic benefits of DR since capacity may be less than the optimal level to meet peak demand. Third given the lack of detailed projections of peak demand and electricity use (e.g. for 2020-2030), this study made very simple estimates, which may not accurately reflect the future trend of peak demand and electricity use. Finally, we have not estimated the costs of introducing DR.

AREAS FOR FUTURE RESEARCH

Finally, this study also identifies a number of areas where further research will be valuable:

STRENGTHEN LOAD PROFILE RESEARCH

One key challenge of this study is the lack of typical load profiles for different customer segments. Future research will benefit from more rigorous analysis of customer load profiles, especially covering a large sample and maintaining long metering duration. This will help researchers in identifying key patterns in electricity use, and thus refining the customer segmentation. Since AMI has a very high penetration in Shanghai, there are great opportunities to leverage it to improve the understanding of customer load profiles. The load profiles of various end-uses (e.g. lighting, AC, plug loads and refrigerator) will also facilitate the analysis of customer potentials to deliver DR.

DEVELOP A MORE ROBUST EVIDENCE BASE FOR PARTICIPATION RATE AND DR LOAD IMPACT

Many factors may influence the acceptance and capability of customers in delivering DR, including the flexibility potential of business activities and their electricity use, the availability of enabling technologies and their functionality, the cost-benefit case for participating in DR programmes and other solutions (e.g. on-site generation or fuel switching). As the DR pilot develops, more locally specific evidence or data will emerge to show how these factors may differ amongst various customer segments. This will inform future research in considering the market potential for different customer segments. To achieve this goal, comprehensive and regular evaluation of DR programmes is necessary.

22.From a system perspective

ANALYSE EMPIRICALLY THE RESULTS OF THE 2015 SUMMER DR PILOT PROGRAMME IN SHANGHAI

The data from this pilot programme could be very useful in identifying the impact of DR on different customer categories and specific end uses. This information could be studied in detail to guide the design of DR programmes in Shanghai and other cities or regions.

UNDERTAKE ANALYSIS ON THE RELATIVE POTENTIAL OF DIFFERENT DR STRATEGIES

There is value from future research to consider the strategies customers are likely to follow to deliver peak demand reduction (e.g. load shedding, load shifting or use of on-site generation) in Shanghai. Such information will support the valuation analysis in terms of making informed assumptions about avoided energy and CO2 costs and system-level avoided capacity costs. This involves better understanding of the characteristics of business activities and their electricity use, the role of enabling technologies in supporting different DR strategies, and the cost-benefit considerations for customers.

DETAILED ASSESSMENT AT THE END-USE LEVEL AND FOR OTHER DR TYPES

Due to data limitations, this study could not undertake an assessment of the potential for different end-use categories (e.g. air conditioning, industrial process or refrigeration) or other DR types (e.g. non-dispatchable price-based DR). Future research will benefit from the availability of end-use-level granular load profiles for different customer segments, and more evidence showing the price elasticity of customers regarding their electricity use.

FURTHER DEFINE DR PRODUCTS

With the role of DR in system operation and planning becoming more important, it is useful to assess the potential and value of individual DR products, thus offering a more detailed gauge of the DR potential and value for system planning and operation. However, this may add to the need for evidence or data to indicate how different customers are likely to participate and deliver response for various DR products. In other words, this requires a more robust understanding of customers as noted above.

DEVELOP LONG-TERM PEAK DEMAND FORECAST

The largest benefits of DR are most likely to be the avoided costs in generation and network capacity over the long term. DR programmes typically have a ‘ramping-up’ period before certain levels of participation rate or load impact can be achieved. For these reasons, it is worthwhile to consider the DR potential and valuation over the medium or long term. This requires extending the timeframe for peak demand forecast to a longer term, by taking into account the likely changes that may be expected to materialise in the electricity system and influence peak demand.

DEVELOP A CUSTOMER ENGAGEMENT STRATEGY

As indicated above, sustained customer education and outreach are essential for the long-term development of DR programmes, and there needs to be provision for them in any comprehensive DR plan. A review of international experience in customer engagement would be a useful initial contribution to this.

DEVELOP BETTER INFORMATION ON SYSTEM COSTS IN ORDER TO BETTER ESTIMATE SYSTEM BENEFITS

More accurate measures of avoided cost require more information on which generation plant will be affected by DR and on the specific incremental cost of those plants. In the longer term, in a market-based system or one where prices reflect marginal costs and dispatch is based on marginal cost, the system’s avoided costs could be calculated by forecasting the hour by hour avoided system electricity costs. Furthermore, it is important to determine whether and to what extent DR would contribute to the avoidance of network capacity expansion.

DEVELOP ESTIMATE OF DR PROGRAMME COST

Assessing the cost of DR programmes is essential for understanding the true value they can bring to the system operation and planning. It allows us to estimate the net value of DR programmes and make informed decisions as to how programmes should be designed (e.g. how to reduce programme cost) or whether particular programmes should be launched at all (e.g. cost-effectiveness of DR).

CONSIDER ADDING OTHER ENVIRONMENTAL EXTERNALITIES

The current estimates include CO2 as potentially important avoided cost. Future research might include other avoided environmental externalities, including PM10 emissions.