

PROSPECTS for DISTRIBUTED ENERGY SYSTEMS in CHINA



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PROSPECTS for DISTRIBUTED ENERGY SYSTEMS in CHINA

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- Improve transparency of international markets through collection and analysis of energy data.
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Foreword

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The People's Republic of China (hereafter, "China") is opening a new chapter of its development. Its economy is moving away from a strong reliance on exports and infrastructure-driven growth, towards an economy driven more and more by domestic demand, innovation and services. Reflecting this, China's energy system is also undergoing substantial change. China is seeking a new balance for its energy system.

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This not only means reducing its heavy reliance on coal but also finding more efficient and smarter ways to meet its energy needs. China is not alone in this process. Indeed, the concept of an energy transition has become the paradigm of energy development in a growing number of countries. In this context, distributed energy is receiving increased attention. As for China, the concept features prominently in the 13th Five-Year Plan. However, more efforts are needed to clarify what distributed energy will look like, not only for China's energy transition but globally. We need to move beyond old approaches and concepts to unlock the full potential of technology and market innovation in this area.

This report aims to provide a step in this direction; it presents a vision for what distributed energy systems in the 21st century may look like: integrated solutions that intelligently combine clean-generation options with energy efficiency and solutions that focus on customer's needs for energy services. The report highlights numerous examples from China and around the world, illustrating promising solutions that are already emerging in practice.

Turning the promise of an energy revolution into a reality will require substantial efforts, not only in terms of analysis but also in terms of implementation. To achieve this effectively not just in China but in countries around the world, international collaboration and sharing of best practices have a critical role to play. Recognising the importance of working together in this way, and reflecting the growing importance of China for the global energy system, China joined the International Energy Agency (IEA) family as an Association country in November 2015, laying the foundation for strengthened collaboration.

This report also reflects a new chapter in this collaboration. It is the first report produced as part of the three-year work programme between the China National Energy Administration (NEA) and the IEA that I signed with NEA Administrator Nur Bekri in Beijing in February 2017. I hope that this report will be instrumental in advancing the discussion on distributed energy systems – in China and beyond. It marks another step in a longer journey towards making the IEA a truly global energy agency.



Fatih Birol
Executive Director, IEA

Foreword

China National Energy Administration

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Since the 1990s, the People's Republic of China (hereafter, "China") has been collaborating with the International Energy Agency (IEA) in a number of energy-related fields, and, in late 2015, China became an official IEA Association country. In February 2017, I signed a three-year work programme (2017-19) with IEA Executive Director Fatih Birol in Beijing, thus inaugurating a new chapter in co-operation between the National Energy Agency (NEA) of China and the IEA. One of the top priority activities in this new joint programme of work is distributed energy.

China's economic structure and energy system are undergoing a far-reaching transformation. The progress made in distributed energy technology and the digitalization of the energy industry are creating new opportunities for the development of distributed energy in China. This publication systematically explores the significance of distributed energy and looks closely at China's contributions, technologies, and business models. It evaluates the present-day situation and analyses the obstacles currently facing the development of distributed energy in China, as well as the possible policy choices. China is now capable of developing distributed energy on a large scale, and it is committed to promoting research and discussion on the topic of distributed energy.

I hope that this report will enable the countries of the world to better understand China's energy development, especially its efforts to promote an energy transition, and that it will further strengthen China's ongoing work with IEA.



Nur Bekri
Administrator, NEA

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Comments and questions on this report are welcomed and can be addressed to Simon MUELLER (Simon.MUELLER@iea.org).

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Executive summary

China's energy transition and distributed energy systems

The People's Republic of China (hereafter, "China") is seeking new sources for economic growth while at the same time currently facing environmental challenges such as urban air quality. More efficient and smart ways to upgrade energy supply and consumption are crucial to meet these objectives.

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This structural economic shift, combined with the declining cost of distributed energy technologies and increased digitalization of the energy system, is creating a new opportunity for distributed energy systems (DES) in China. Reflecting this new context, this report defines modern DES as energy systems where local supply and demand resources are combined intelligently to optimise the reliability and affordability of energy service provision, while minimising its environmental impact through higher efficiency and low carbon technologies. Modern DES use an optimised combination of energy efficiency, renewable energy and cleaner fossil-energy resources, combining them dynamically by advanced monitoring and control equipment.

The analysis in this report shows that a systemic, integrated approach to distributed energy can reap the full benefits of this opportunity. This document also contributes to enabling a more integrated approach to distributed energy by combining 1) a comprehensive overview of the technological building blocks and business models for DES, 2) a systematic assessment of the current situation of DES in China and relevant barriers and 3) possible options to enhance policy and regulatory frameworks. Numerous Chinese and international case studies show how DES can be deployed in practice.

Past development trends and main barriers to DES

Many of the possible benefits of DES have long been recognised in China, such as the ability to achieve high energy efficiency through combined provision of heat and power. However, even during the period of the 12th Five-Year Plan (FYP) (2011-15) the anticipated dramatic increase in distributed energy did not take place; particularly distributed natural gas (DNG), struggled in China. By 2015, roughly 120 DNG projects had been built, with an installed capacity of only about 1.4 GW. This number fell short of government targets, which is unusual in China.

A complex set of economic, technical and regulatory challenges have left an immature market for DES. On the economic side, cleaner supply options are still more expensive than coal. An important technical challenge for past DNG projects has been correctly assessing the need for different energy services (electricity, heating, cooling) when designing DES; the poor match between the installed system and demand translates into low utilisation and ultimately poor project economics. On the regulatory side, transparent access to electricity, gas and district heating (and cooling) grids is a recurrent barrier. Grid access is relevant for DES from two perspectives: first, as a way to obtain input fuel and second, as a way to sell electricity and other energy services. For example, in practice it is very difficult for DES projects to receive compensation for feeding in electricity to the main grid. The roles and responsibilities of grid companies and DES project operators are also often unclear.

Because DES link a diverse set of energy resources, coordination of policies and strategies for different energy carriers and between supply and demand policies is crucial. Challenges with coordination between different levels of government and departments responsible for individual DES technology systems have also slowed progress to date.

While these challenges remain relevant, recent progress is encouraging, including improved availability of gas, pricing reforms and the availability of suitable equipment at lower cost. As for

distributed solar PV, the past two years have witnessed the fastest increase in capacity in China so far.

Prospects for DES in China

Several factors are currently reshaping the notion of distributed energy in China. If appropriate policy, market and regulatory frameworks can be put in place, these factors can align to accelerate the uptake of modern distributed energy systems:

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- **The ongoing shift in China's economic structure has implications for energy demand that can favour DES.** An economy relying on a stronger commercial and services sector also features more distributed energy demand, where the importance of very large centralised loads (heavy industries) is reduced and the demand coming from more distributed loads (office complexes and smaller industrial facilities) increases.
- **DES can help alleviate urgent environmental problems, including poor air quality and greenhouse gas emissions.** Distributed energy can significantly reduce emissions of sulphur dioxide (SO₂), nitrogen oxides and particulate matter when compared with the centralised, coal-based power system; natural gas generators have much lower emissions, and renewable energy technologies such as distributed solar PV have zero local emissions. DES can lower carbon dioxide (CO₂) emissions by relying on low-carbon or carbon-free supply options. DES' ability to decarbonise heating and cooling is also a significant benefit: heating demand accounts for around 30% of global energy-related CO₂ emissions, and half of this heat is used in buildings.
- **New technologies improve understanding of demand, enhance system performance and can provide new services.** Increased use of digital sensors and control equipment, big-data applications and new loads such as electric vehicles (EV) are reshaping DES. First, accurate behavioural data on energy consumption allows for better designing of DES to optimally meet customer needs. Second, better coordination of supply and demand technologies, including forecasting techniques and smart controls can raise overall system efficiency and reduce costs. Finally, modern IT combined with smart loads – such as EVs or thermal storage – can help unlock new services, such as providing flexibility for the central grid to help balance fluctuations from wind and solar power plants.
- **New business models can turn technological possibilities into business opportunities.** New business models are emerging both globally and in China to make use of new possibilities of DES. As the case studies in this report highlight, integrating diverse supply and demand technologies consistently can offer customers an optimised set of energy services. The focus of such business models shifts from supplying an energy commodity to providing an integrated suite of energy services.
- **Government targets signal political commitment to DES.** The 13th FYP has several technology targets that constitute the building blocks of DES. The target for installed capacity of natural gas is 15 GW of DNG projects out of a total target of 110 GW of natural gas electricity generation capacity. Solar PV will be the backbone of distributed renewable energy deployment during the 13th FYP Plan, reaching the planning goal of 60 GW of distributed solar by 2020, out of a total solar PV target of 105 GW. Many local governments have also issued supporting policies to reduce air pollution and increase energy efficiency.

In summary, the interplay of the above factors are highlighting new prospects for DES in China: integration of diverse and clean supply options to meet the demand for energy services in an efficient and innovative way. However, these factors alone will not overcome the aforementioned challenges to DES. This requires a coordinated and comprehensive approach to developing DES.

Suggestions to support the development of DES in China

In order to fulfil the ambitious target for distributed energy in the 13th Five Year Plan and prompt the ongoing energy transition, systematic reform and supporting policies should be considered.

For the short term, policies to ensure fair access of DES to relevant infrastructure (gas, electricity) as well as transparent, fair and predictable remuneration of grid infeed are a key priority. Governments could also improve market development by setting clear technical standards ensuring availability of energy data. In turn, this will increase investor confidence and facilitate maturing of the market. For the long term, reform in the relative areas, i.e. the electricity system, the oil and gas sector and the carbon trading market are key to level the playing field for DES in China and unlock the DES contribution to China's energy transition.

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Due to the localised nature of DES, local governments could play a vital role in its development, carrying out a set of different functions which are relevant for DES. As the city planner, local governments could integrate DES into urban development and energy development plans in a coordinated way. As the energy development promoter, local governments could issue support policies combining central government's policy with local characteristics. Considering distributed energy zero or low pollution, local governments could also facilitate access to the heating and cooling networks through pricing and regulations. As the energy regulator, local governments could carry out innovation in the regulation system to fit the needs of distributed energy. Finally, through public procurement, local governments could demonstrate the benefits of distributed energy and prompt its utilisation in the public sector. Further details on possible measures can be found in the main report.

Chapter 1. Introduction and possible benefits of distributed energy systems

Background

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Industrial restructuring and diversification of energy demand are accelerating in the People's Republic of China (hereafter, "China"). In recent decades, China's construction of infrastructure has strongly relied on energy-intensive sectors, mainly the iron and cement industries. However, energy demand in these industries has most likely reached a peak, and is expected to decline until 2040. China's industrial coal consumption decreases as a result in long-term International Energy Agency (IEA) scenarios (IEA, 2016). The transition to an economy geared more towards domestic demand for goods and services is expected to be accompanied by a rising importance of clean energy in the energy system.

Driven by resource and environmental constraints, as well as pressure to reduce carbon emissions, China's primary energy consumption structure is expected to shift in coming decades. According to *World Energy Outlook* projections,¹ growth in energy demand slows down and coal is increasingly replaced by cleaner sources of energy, such as natural gas and renewable energy.

China has several energy targets in the 13th Five-Year Plan (FYP) that aim to adjust and upgrade the energy consumption and supply structure. While moderately expanding the total demand, China plans to cut overcapacity, deleverage, reduce corporate costs and shore up weak spots from the supply side. China is expected to optimise its energy supply by decreasing ineffective sources and increasing effective supply of clean and renewable energy so as to make the energy supply structure more adaptive and flexible. In order to keep total coal-fired power generating capacity below 1 100 gigawatts (GW), the National Development and Reform Commission (NDRC), the National Energy Administration (NEA) and 14 other departments jointly issued the Opinion on Eliminating Overcapacity Risk in the Coal Power Industry through Pushing forward Supply-Side Structure Reform, which outlined cancelling and suspending 150 GW of coal power plant projects in the 13th Five-Year Period (2016-20) (NDRC et al., 2017). By 2020, non-coal energy generation sources are expected to account for 45% of the total installed capacity, among which hydro makes up 19%, wind 10.5%, gas 5.5% and nuclear 2.9% (NDRC and NEA, 2016).

National measures to limit coal and set energy efficiency targets force power enterprises to reconsider their development direction and make new choices. In this context, distributed energy resources (DER) have become an important measure for the survival and development of enterprises. For example, the State Power Investment Corporation – one of the "big five" power enterprises in China – has proposed focusing on clean energy and integrated smart energy, developing distributed natural gas (DNG), and promoting photovoltaic (PV) generation.

China Huadian Corporation has proposed the strict control of conventional coal-fired power and promoting the development of DER as an alternative form of investment.

¹ These projections will be revised in November 2017 with the release of IEA (2017a), *World Energy Outlook 2017*, and IEA (2017b), *China Energy Outlook: World Energy Outlook 2017 Special Report*.

This transition is also an opportunity for the increased adoption of distributed energy systems (DES). An economy relying on a stronger commercial and services sector also features more distributed energy demand, where the importance of very large centralised loads (heavy industries) is reduced and the demand coming from more distributed loads (office complexes and smaller industrial facilities) increases. Addressing this structural demand change calls for a future-proof strategy that meets long-term energy goals. Against this background, it is timely to take stock of what distributed energy means in the 21st century, where its application in China stands today and what its future prospects are.

This publication

This publication is the result of an in-depth collaboration between the IEA and the Chinese NEA. Over the period of one year, experts from the IEA and China worked together intensively during five joint workshops and two sets of site visits. This report condenses the findings of this collaboration. This report is one element of IEA work on both China and distributed energy systems. In the coming months, further analysis will be published in: *World Energy Outlook 2017* (IEA, 2017a), *China Energy Outlook: World Energy Outlook 2017 Special Report* (IEA, 2017b), *District Energy Systems in China: Assessment Methodology and Business Models* (IEA, 2017c), *Digitalization & Energy* (IEA, 2017d), and *Technology Roadmap: Smart Energy Systems* (IEA, 2017e).

DES are a dynamically evolving topic, and many analytical questions remain open on how these systems will develop over coming decades. Nonetheless, stakeholders from individual consumers to entrepreneurs and large utilities are already building and developing DES.

This report aims to advance the analysis on the topic and also provide examples of recent practice. It seeks to take stock of current status and trends, highlight future potential and suggest recommendations on how to unlock this potential. One of the experts interviewed for this study pointed out that DES and their analysis will be relevant as long as 30 years from now. In this sense, this report should be seen as one step along this journey.

The document has four main chapters. This chapter sets out a working definition of DES and introduces DES and their possible benefits. Chapter 2 reviews technological building blocks of DES and different business models combining them. Chapter 3 focuses on the status and possible future role of DES in China, highlighting main barriers for progress. Chapter 4 concludes and provides a set of possible policy recommendations on how to improve the uptake of DES.

Defining DES

The main advantage of DES is the ability to combine different resources locally, using modern information and communication technology (ICT), to best meet customers' needs while providing clean, reliable and affordable energy.

DES are thus defined as energy systems where DER are combined intelligently to optimise the reliability, affordability and environmental impact of energy service provision. As such, some classical forms of distributed energy are **not** covered in this scope. For example, a backup diesel generator or a moderately efficient and polluting district heating system would not be considered as a DES for this publication.

In terms of the building blocks of DES, this report defines DER to include DNG and renewable energy resources that are connected at the electricity distribution network level or physically

located close to load centres, as well as distributed storage (DS), demand response (DR) and energy efficiency technologies.

However, there are many other ways to define DER and systems. Many definitions of DER specify connection at the distribution level; for example, the Electric Reliability Council of Texas (ERCOT) defines DER as connected at the 60 kilovolt level or below. Broader definitions, however, include resources such as combined heat and power (CHP), which may be connected to the transmission network, but are physically located close to demand due to the poorer transport properties of steam and water. The New York Independent System Operator (NYISO) definition takes a narrower view, specifying resources on the customer side of the meter. Some definitions of DER focus on energy-producing technologies, such as the following definition from North American Electric Reliability Corporation (NERC): “A Distributed Energy Resource (DER) is any resource on the distribution system that produces electricity and is not otherwise included in the formal NERC definition of the Bulk Electric System”. This definition encompasses both distributed generation (DG) and DS. Others broaden the scope to include DR, such as Burger and Luke (2016), which includes “more flexible and price-responsive management of electricity demand”. The Smart Electric Power Alliance (SEPA) definition is broader again (SEPA and Black & Veatch, 2017), including DR but also energy efficiency technologies.

Drivers for DER

From early in the history of commercial electricity supply, there has been a push towards large centralised generators connected to end users through a transmission and distribution (T&D) network. This centralised approach has enjoyed dominance based on the economies of scale, as well as the reliability that comes from interconnection.

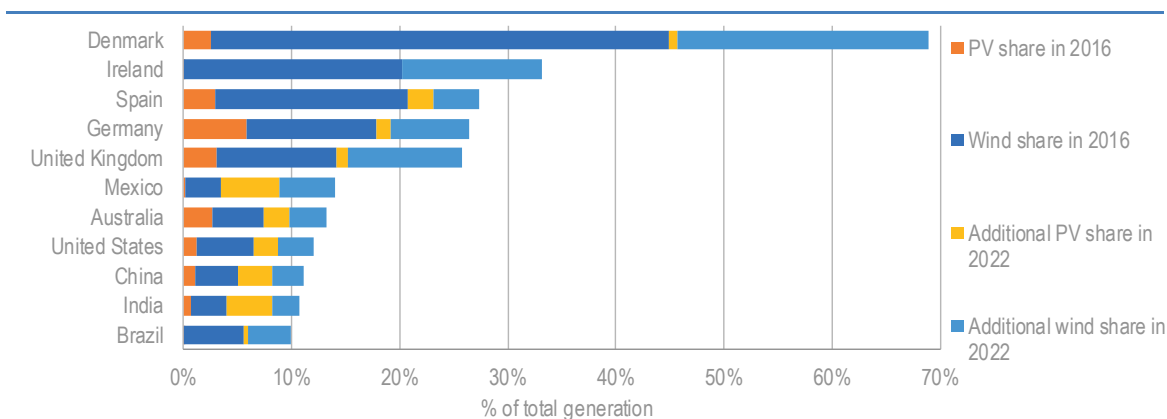
Nevertheless, DG has always been an important component even of mostly centralised systems. The primary role for DG has been as a source of backup power to provide increased reliability in sensitive locations such as hospitals. DG has also been motivated by fuel diversity, for example to take advantage of locally produced biogas. Moreover, DG has been applied to achieve increased efficiency across otherwise separate energy demand sectors, such as in CHP, also known as co-generation. In addition, distributed energy is often the most cost-effective option in remote areas with low-density populations, where building T&D infrastructure is not cost-effective. Finally, where regulations allow self-supply, DG has been used as a hedge for large energy users.

Both policy objectives and technology progress are creating new drivers for DER. In the context of local air pollution, global climate concerns and energy security objectives, a growing number of countries are pursuing increasingly strong renewables targets, often leading to higher amounts of DG. This has translated into substantial deployment in the past and is expected to continue in the future (Figure 1.1). In combination with falling technology costs, this has enabled renewable energy investment to dominate power generation investment, with renewable energy installations consistently accounting for around two-thirds of global power generation investment over the past five years (IEA, 2017f). In some countries, specific support policies target distributed renewable energy, helping to drive in particular rapid uptake of distributed solar PVs.

CHP has also seen increased policy support in recent years, with United States (US) support for industrial level co-generation, targets in China that are expected to deliver 15 GW of distributed co-generation by 2020 (NDRC and NEA, 2016) and policy in Japan also targeting an increase up to 16.9 GW by 2030 (METI, 2016).

On the technology side, several key trends are changing the landscape of distributed energy. Thanks to the modular nature of solar PV, technology learning for large-scale systems also directly benefits small-scale installations: they both use exactly the same solar panels. This is highly unusual in the power sector and one of the many reasons for the rapid decline in the cost of solar PV. Battery storage technologies have likewise undergone rapid cost decline in the last five years; in combination with PV or other DG this can increase the potential for uptake of DES.

Figure 1.1 • Current and projected wind and PV as a share of total generation for selected countries



Source: IEA (2017g), *Market Report Series: Renewables 2017*.

Key point • Variable renewable energy (VRE) takes a growing share in the energy mix of many countries.

Trends in the transport sector are also driving change. Falling costs of electric vehicles (EVs) and strong manufacturing ambitions from major vehicle manufacturers are translating into deployment. The year 2016 saw the highest annual new EV registrations so far with global sales of over 750 000 (IEA, 2017h). In the medium term, this could drive growth in electricity demand in regions that are currently experiencing stagnated or even falling demand. In turn, EVs raise the importance of smart charging and active management of local electricity networks. Similarly, co-generation and the development of heat pump (HP) technology create stronger links between the electricity sector and heating demand. HPs can also be combined with CHP technology to upgrade waste heat, including in climates where the ambient temperature is otherwise too low for efficient HP operation.

Finally, the radical development of ICT also has profound implications for how different elements of the power sector interact. One aspect is the advent of advanced metering infrastructure (AMI), with the potential to enable more dynamic and responsive demand, and the potential for fundamental changes in the business models through which energy suppliers interact with end users. While not strictly a requirement to facilitate DR, AMI does help enable improved adoption. The development of energy management technology at the household, business and community levels also creates the potential for more efficient and reliable system operation, as well as the provision of new services. The possibility for such services is further increased by the application of big-data analytics that exploit deeper understanding of consumer behaviour.

These trends can align to form the modern type of DES as defined above: systems that are focused on the provision of energy services and meeting them with an optimised mix of resources. DES can be conceptualised as systems of energy provision where customer energy services are placed at the centre, and service provision is integrated across supply options to provide the best overall solution, allowing participation of diverse energy resources and business models.

Role in power system transformation

DES have the potential to play a central role in power system transformation (IEA, 2017i). A more integrated, service-oriented approach creates opportunities to increase system efficiency, as well as changing the relationship between end users and service providers. The technologies of DES have a range of impacts that result in both challenges and opportunities for distribution grids. If managed poorly, high local penetrations of PV, distributed batteries and EVs can result in the need for grid upgrades. By contrast, combining these resources with digital monitoring and control into a smart DES can bring net benefits, reducing the need for grid investments while also providing grid services such as reactive power support, peak shaving and other ancillary services. In addition, AMI combined with smart appliances and energy management systems can unlock advanced demand response capabilities with the potential for integrating large amounts of variable renewables without compromising quality of service (Rahimi and Ipakchi, 2016).

From an economic perspective, DES create new value streams and may change financial flows relative to a traditional utility model. This not only brings opportunities, but may also create challenges for established players.

The introduction of new players such as third-party aggregators and energy service companies (ESCOs) can be a source of increased competition within markets that have traditionally had very limited competition. To put this competition on a level playing field, a number of changes to policy and regulation will likely be needed, such as establishing appropriate connection charges, cost-reflective use-of-system charges and incentives to supply ancillary services (Cossent, Gómez and Frías, 2009). At the institutional level, DES present a range of challenges as well as opportunities. Historically, regulatory hurdles have posed a significant barrier to uptake of DER (IEA, 2002). CHP has also faced challenges due to poor strategic planning for heating and cooling infrastructure and local energy market conditions that do not ensure that energy prices are reflective of generation costs (IEA, 2014a). Addressing such issues requires establishing roles and responsibilities that effectively enable new business models. Regulated electricity tariff regimes are also a key challenge. Tariff regimes must be assessed in relation to risk apportionment between utilities and consumers to ensure that pricing is fair, and creates appropriate incentives for both consumers and service providers.

Possible benefits of DES

DES can bring a range of possible benefits, which are briefly introduced in this section. A sound policy and regulatory environment is needed to ensure that DES actually deliver on these possible benefits. Also, a smart combination of DES with large-scale, centralised systems is often instrumental in maximising benefits.

Proximity to the customer

According to the definition of DES, they are located near customer loads. This not only distinguishes them from centralised supply, but also brings a number of benefits.

Localisation of energy development

DES can optimise the supply portfolio according to local resource availability, climate and geographical conditions. A variety of energy resources (such as natural gas, wind, solar, geothermal energy, biomass, ocean energy and industrial waste heat) can be integrated to best meet local needs. This can also help improve energy security (Box 1.1). Furthermore,

localisation of DES brings the potential for much smaller players to take an active role in energy supply, giving customers a greater sense of ownership of the energy system. In turn, this can challenge traditional business models of large utilities.

Reduction of T&D costs

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T&D costs are a significant part of total power system costs, and generally make up around 30% of final electricity bills (IEA, 2014b). Local DG has the potential to avoid losses by bringing supply closer to demand and minimising use of the T&D networks, provided local supply and demand are balanced. Such systems can thus yield considerable capital, labour and time savings in terms of construction and maintenance of large-scale infrastructure. Increased use of DES can reduce revenues for larger-scale infrastructure. Grid tariffs thus need to be set in a way that reflects the overall value of DES to the system.

Box 1.1 • Contribution of DES to system resilience

Natural disasters pose an ongoing threat to physical infrastructure. The interdependency and complexity can make large-scale centralised power systems vulnerable to natural disasters. In recent years, the world has seen many cases of widespread power outages. For example, on the evening of 29 October 2012, Hurricane Sandy caused massive power outages for a total of 8.1 million people in 17 states of the United States, spanning from Maine to Michigan. The progress in electrification and ICTs continues to make human lives and social economies increasingly dependent on electricity. The damage caused by massive power outages can entail significant economic losses, for example in banks, securities institutions, factories and other energy-intensive areas. It can also cause casualties in sensitive locations, such as hospitals.

Compared with centralised power systems, DES can be designed to operate in a relatively independent way, thus improving the resilience of the power system to natural disasters. These systems can quickly restart power generation during emergencies to ensure the continuity of activities in important areas, such as hospitals, communications, media, transportation centres, basic public facilities and financial institutions. Facing Hurricane Sandy, New York University's DES demonstrated excellent reliability, providing the campus with uninterrupted electricity, heating and cooling, as well as making the university an emergency resettlement centre. Furthermore, distributed energy can facilitate the rescue process due to modular design. In case of emergencies such as road damage, distributed devices can be disassembled quickly and relocated to supplement the centralised system by connecting the mobile power system with an important load. This function is of great importance for post-disaster management. Moreover, during post-disaster recovery, a variety of reconstruction works have high power demands that increase power requirements in the short term.

Source: Webley, K. (2012), "Hurricane Sandy by the numbers: A superstorm's statistics, one month later"; Pyper, J. (2013), "Are microgrids the answer to city-disrupting disasters?",

Improved understanding of customer needs

DES can be tailored in response to local energy needs. These vary significantly depending on the end-users' profiles, from industrial parks, business centres, data centres, office buildings, medical facilities and transport hubs, to cultural and sports facilities. A sound DES will build on a full understanding of the load characteristics (including its time profile), heating and cooling needs, and desired reliability levels and use this data to optimise supply.

Box 1.2 • DES of Shanghai Tower, Shanghai

The Shanghai Tower is a 632-metre, 128-story skyscraper in Lujiazui district, Shanghai. The building has installed a DES with two units of 1 165 kilowatt (kW) gas-fired generators, two units of 1 047 kW lithium bromide absorption chillers and two units of 1 368 kW heat exchangers and ancillary systems. The DES is connected to the municipal power grid, as well as an ice storage system, a boiler and electric refrigeration devices to create the building's complete energy system, providing heating, cooling and electricity services to a total area of 279 700 square metres (m²). During the heating season, the peak heat load is 10 megawatts (MW) in January while the minimum is 6.1 MW in December. The annual utilisation time is designed to be no less than 5 360 hours, with electricity generation of 12 489 megawatt-hours, heat supply of 16 651 gigajoules (GJ), and cooling supply of 31 729 GJ on a yearly basis.

Source: China5e (2016), 上海中心大厦天然气分布式能源项目 介绍 [Introduction of the Distributed Energy System of Shanghai Tower], www.china5e.com/news/news-958084-1.html.

High energy efficiency

High energy efficiency is a significant advantage driving the continuous deployment of distributed energy across the world. High energy efficiency is enabled by three applications: multi-generation and cascading energy usage, combination of complementary energy resources, and use of excess heat and residual pressure.

Multi-generation and cascading energy usage

Cascading energy usage entails using waste heat from electricity generation for further power generation as well as for cooling and heating services. The efficiency performance of the whole system can reach 70-90%. DES are well placed to implement this approach, because heating and cooling products are most suitable for short-distance transportation.

Box 1.3 • DES of Shanghai Disneyland, Shanghai

Shanghai Disneyland has an area of 116 hectares hosting nearly 100 buildings. Globally, it is also the first Disneyland to use distributed energy, which offers cooling, heating, electricity and compressed air (for roller-coaster and other game facilities) to the park's recreational facilities, buildings and hotels in a highly efficient and environmentally friendly way. The distributed system also contributes to improving the energy structure of the local power grid and managing the peak load to achieve economic and environmental benefits. Under the traditional model, these four energy products would have been supplied from different energy stations. However, the distributed system acts as an integrated energy processing plant, using natural gas.

The project is working on installing ten units of 4.4 MW gas generators in two phases, the first of which, of five units, is complete. Five units of lithium bromide absorption chillers allow recovery of waste heat, with each chiller providing 3 490 kW of cooling capacity and 3 478 kW of heat capacity. At the same time, the system is equipped with four centrifugal chillers, three gas-based water boilers and thermal water storage to balance peak load and energy demand. As a peak shaving solution, chilled water and hot water can be stored at night in the tank before being used for cooling and heating services during the day. This greatly increases operating hours and improves the efficiency performance of the DES. On a yearly basis, the project generates on average 112 gigawatt-hours as electricity, 399 000 GJ as cooling services (of which 253 000 GJ is from waste heat), 153 000 GJ as heating services (of which 98 900 GJ is from waste heat), and 413.8 million normal cubic metres as compressed air. The system-wide energy efficiency can reach 85.9%.

The project can match energy supply to demand more accurately based on an intelligent optimisation control system and a set of distributed control systems. With the support of temperature sensors, pressure sensors and ultrasonic flow meters, the real-time operations data

in the pipes can be monitored in an integrated control system. In turn, these data can allow the system to manage and optimise the operations of various components in response to changes in energy demand. In addition, this intelligent optimisation function can also incorporate data on the number of visitors in order to forecast the energy demand in advance. Based on this big-data analysis, the system can thus suggest the operational plans of key components to optimise the energy supply to suit conditions.

Sources: Xinhuanet (2017), 分布式能源应用进入“加速度” [The Utilisation of Distributed Energy Should Be Accelerated]; Ye, H. (2017), 上海国际旅游度假区核心区天然气分布式能源站项目 [Introduction of Distributed Energy System of Shanghai Disneyland]; China5e (2015), 探秘上海迪士尼乐园的“动力心脏” - 分布式能源 [Explore the Energy Source of Shanghai Disneyland – Distributed Energy].

Combination of complementary energy resources

Distributed energy can combine and optimise various energy resources, including wind, solar, natural gas, biomass and other options including hydrogen. The best mix can be chosen on the basis of the end user's geographical location, resources endowment and consumption patterns. If this optimisation is implemented well, high overall system efficiency can be achieved through the utilisation of complementary energy resources and technologies.

Box 1.4 • Case of combining complementary energy resources, Gui'an city, Guizhou province

A project combining complementary energy resources, located in Gui'an city, Guizhou province, China, provides heating, hot water, cooling and electricity services to a total building area of about 500 000 m². The project uses a combination of natural gas with three other energy resources: a water-based heat pump, solar thermal and compressed air energy storage. The project design gives priority to the supply of heating services, and the system usually operates off-grid, but can rely on the grid when needed. The power generation capacity is 2.8 MW, cooling capacity is 15 165.4 kW, and heating capacity is 13 303.9 kW. Compared with a conventional central air-conditioning system and boiler heating system, the installed capacity for cooling is reduced overall by about 45-55%, and the power installed capacity reduced by about 30 MW. Compared with split system air-conditioners, the installed capacity can be reduced by about 70 MW. In the near future, Gui'an city plans to set up ten similar distributed energy stations and a smart energy management centre to meet the energy needs in a 43 square kilometre science park.

Source: People.cn (2017), 贵安新区建设国内首座“1+3”多能互补分布式智慧能源站 [The First Combining Complementary Energy Resource Finished in Gui'an City].

Use of excess heat and residual pressure

Excess heat and residual pressure can be a substantial source of untapped energy in various industries (such as iron and steel, nonferrous metals, chemicals, cement, and ceramics). For example, the flue gas in a carbon calcine plant can reach temperatures of 850°C to 900°C. Providing heating, cooling and electricity with excess heat and residual pressure not only helps reduce energy consumption and improve energy efficiency, but also reduces industrial pollution and provides an energy conservation option for industries.

Utilising clean and low-carbon energy sources

Distributed energy can help in the transformation of a predominantly fossil fuel-based centralised energy system to a cleaner, more diversified energy system with a variety of energies including renewable energy, such as wind, solar PV, solar thermal, biomass and geothermal energy, and lower-carbon fossil fuels such as natural gas. This can bring a number of

benefits. These benefits may be direct – such as providing cleaner power generation – or indirect, such as providing flexibility in order to integrate higher shares of variable generation.²

Integration of VRE

VREs, in particular solar PV and wind power, have properties that require a number of specific measures to integrate them into power systems. Most importantly, their maximum output in any moment is constrained by the instantaneous availability of sunlight and wind. Consequently, their output fluctuates, and these fluctuations can be predicted only up to a certain accuracy (IEA, 2017i).

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DES can provide solutions for the cost-effective and secure integration of wind and solar power in a number of ways. First, VRE generation can be included in DES, spreading their deployment geographically, which smooths overall output (when considering multiple DES). Second, by combining wind and solar power in an optimised proportion, their combined variability can be lower (it is often more windy when there is less sun and vice versa). Third, modern DES can utilise digital monitoring and control equipment to dynamically adjust consumption to better match wind and solar availability. Fourth, other generation resources, such as flexible gas generators, can balance remaining variability. Fifth, electrification of end-use sectors such as EVs can help create new, flexible demand that can absorb potential surpluses of wind and solar power.

Reduction of air pollutant emissions

Distributed energy can significantly reduce emissions of sulphur dioxide (SO₂), nitrogen oxides and particulate matter when compared with the centralised, coal-based power system, since natural gas generators have much lower emissions, and distributed solar PV and wind have zero local emissions. For example, on a yearly basis Shanghai Tower's project contributed to reducing 38 tonnes of SO₂ emissions, while the project in Gui'an succeeded in reducing 498 tonnes of SO₂ emissions and 249 tonnes of dust emissions (Box 1.4). Modern DES can also avoid particle emissions linked with traditional use of biomass (REN21, 2016).

Reduction of carbon emissions

DES can lower carbon dioxide (CO₂) emissions by relying on low-carbon or carbon-free supply options. Their ability to decarbonise heating and cooling is also a significant benefit: heating demand accounts for around 30% of global energy-related CO₂ emissions, and half of this heat is used in buildings (IEA, 2014c). With CHP systems based on natural gas, biomass, biogas or low-carbon electricity, the carbon emissions resulting from heating demand can be reduced. For example, on a yearly basis, Shanghai Tower's project can reduce CO₂ emissions by 4 855 tonnes, the Gui'an project by 61 464 tonnes and Shanghai Disneyland's project by 75 542 tonnes.

Reduction of fossil fuel consumption

With clean and renewable resources, distributed energy contributes to decreasing fossil fuel consumption, thus indirectly reducing the energy consumption and ecosystem damage associated with fossil fuel extraction and transportation activities. For example, Shanghai Tower's project can see annual savings of 1 890 tonnes of standard coal, the Gui'an project 24 884 tonnes and Shanghai Disneyland's project 21 883 tonnes.

² It is worth noting that there are multiple options to provide flexibility, across demand-side measures, storage, grids and flexible generation. In the case of generation, large centralised plants – including coal-fired generation – can also provide flexibility in principle.

Box 1.5 • Distributed Energy Resources Program, US Department of Energy

The US Department of Energy instituted the Distributed Energy Resources Program in 2001.

The DER programme goal was to develop and facilitate market adoption of a diverse array of cost-competitive integrated DG and thermal energy technologies in both the residential and the industrial sectors, increasing the efficiency of electricity generation, delivery and use, and improving electricity reliability while reducing environmental impact.

To achieve this goal, the programme undertook research to improve micro-turbines, advanced reciprocating engines and industrial turbines, as well as thermally advanced technologies. The focus of the programme was to improve the efficiency and integration of the equipment.

The programme established partnerships among manufacturers, energy service providers, project developers, state and federal agencies, interest groups, and consumers.

Research and development efforts focused on two main areas: technology development and end-use system and integration. Moreover, the DER programme also involved the digitalization of the distribution sector and demand-side management.

Examples of the achievements of the programme include:

- The final design and field testing of a low-emission turbine.
- The installation of three reversing heat pumps with a coefficient of performance of 1.4.
- The demonstration of a 6% increase in efficiency for an advanced reciprocating engine.
- The final design and field testing of a fully functional CHP system consisting of a turbine, an absorption chiller and a control system.

Source: NREL (2001), "Distributed Energy Resources Program".

Future development perspectives for DES

Consumer preferences

To appreciate the full potential for development of DES, it is necessary to look beyond a purely technical perspective of the services distributed energy can provide. Technology uptake is rarely driven simply by cost-benefit analysis alone. The appeal of innovative products is an essential driver for their rapid uptake; compare to the uptake of automobiles or mobile phones. While the services these technologies provide are a key part of what they offer, they also become a way for people to express their preferences, their values and their identity.

This makes DES stand apart from centralised energy systems. An average homeowner will never own a coal-fired power station, and is unlikely to ever feel that they participated in the decision to build one. Buying power from the grid, there is no control over where the electrons came from. In contrast, the devices of energy consumption – electrical appliances, the majority of heating systems, automobiles – are selected based on consumer choices. With DES, the customer now can participate at all levels: they can own their own generation, their own storage, their own smart appliances. This is also relevant to stakeholders at all levels: increasingly homeowners, businesses large and small, and bodies such as local and state governments are participating in distributed energy solutions as a means to express an identity, whether it is to show a commitment to addressing climate change or to tap into the latest smart trends. Despite the difficulties of quantifying this driver, it may play a role in shaping the future of DES and should at least be acknowledged qualitatively.

This driver for DES uptake also explains why forecasting DES adoption can be challenging. Large utilities have a relatively homogenous decision-making process, mostly based on considerations of profit maximisation. By contrast, the overlay of economic and non-economic factors for decision making of end customers leads to a greater diversity in decision drivers and thus makes it more challenging to anticipate deployment patterns.

Energy services – beyond electricity as a commodity

Companies specialising in DES may find additional value and revenue streams not only by selling electricity and other energy products, but also through other services such as aggregating and monetising the flexibility potential of smart loads and distributed generation. By linking DES, centralised energy systems, intelligent control systems, information management systems and end-user management systems, innovative services can be provided. Ultimately, electricity or energy services are not the only source of value; the data associated with their use are equally valuable.

Energy optimisation services for end users

Intelligent metering technology allows automatic measurement, recording, storage and reading of end users' energy data, such as electricity, heating and gas consumption, serving as a basis for optimising the customer's energy production and consumption patterns. Data mining and analysis supported by big-data technologies can enhance understanding of the energy use profile of final consumers. It is now feasible to address questions such as what is the most cost-effective energy combination, when to use electricity from the utility grid or self-produce electricity, what is the optimal amount of solar PV or natural gas generation, how to dimension energy storage, or how to choose an optimal size HP. When combined with Internet-of-things technologies and wireless communication, modern distributed energy is able to interact and integrate with household appliances, EVs, charging stations and other energy-consuming devices, making demand-side management and energy optimisation a business opportunity.

ESCOs can use the model of energy performance contracts to share economic benefits due to optimal process management within DES. The quality of these services will be in large part determined by the ability to integrate and efficiently allocate different energy carriers.

Box 1.6 • “Smart energy” demonstration project by China Southern Power Grid, Guangzhou province

In 2017, China Southern Power Grid built its first smart energy demonstration project in Guangzhou. The project aims to integrate four networks: electricity, Internet, TV and telephone. The project district covers a total of 21 buildings with around 1 450 households. The composite low-voltage fibre combines optical and power cables. Integrating four operators' networks makes the interaction of power flows and information flows feasible, supporting energy data transmission and intelligent home management. Digitalization of meters for electricity, water and gas is a key to the project. With the support of a centralised collection system and the fibre cable, meter reading in a building can be completed remotely in ten seconds. This significantly improves the accuracy and efficiency of metering. At the same time, the system can conduct remote fault diagnosis and control in real time in order to control system losses and ensure intelligent management of electricity, water and gas meters.

The data recording system can provide detailed time series data for household appliances including lighting, refrigerators, televisions and air conditioners. This will facilitate big-data analysis on consumer demand. Based on four networks and three meters, integrating with distributed energy, charging facilities, intelligent homes and intelligent communities, as well as constructing big data on electricity, water and gas consumption, it is possible to have a better understanding of consumer behaviour and spending. Furthermore, this project can be extended

to other smart home applications and also manufacturing applications. It is likely that energy consumption of manufacturing equipment can also be optimised in response to energy structure and production requirements.

Source: China.com (2017), 广州建成南方五省区内首个四网融合智能小区项目 [The First “Smart Energy” Demonstration Project of Southern China Completed in Guangzhou].

Services for an integrated energy system

The large majority of distributed energy projects are connected to the utility grid, resulting in interactions with centralised energy systems in terms of energy and information flows. Distributed energy supply can create value-added services for centralised energy systems by providing peak shaving, frequency control, backup capacity and power quality improvement. These capabilities can be further enhanced by the use of energy storage and advanced demand-side response.

Digitally enabled connectivity

It has already been pointed out that DES can be tailored to customer demand. Achieving this requires the co-ordinated operation of many dispersed system components. Efficient and effective integration of these components can be achieved only by using ICTs such as digital sensors and controls and smart meters, and further benefits can be obtained by utilising big-data analysis and cloud computing tools.

Hence, DES can facilitate the emergence of new, digitalised approaches, such as virtual power plants and intelligent microgrids. This reinforces the digitalization of the energy system, and enables an advanced integration with end users’ devices and appliances. In contrast to the traditional centralised energy system, in which different nodes of the value chain such as generator, grid, load and storage are entirely distinct from one another, the different nodes in a DES tend to converge. Applications of innovative distributed digitalised trading technology could make it possible for distributed energy to be independent from the centralised trading system in the future. This can lay the foundation for energy transactions at the community level, city level and beyond.

More generally, connectivity allows DES to connect different components of the energy system in a smart way:

- **Time coupling among different DES.** One coupling effect is to integrate supply options such as wind, solar and natural gas at different times to achieve optimal supply with least-cost options. The other coupling effect is to incentivise appropriate use of demand response or energy storage in order to optimally co-ordinate energy supply with demand at different times for the most cost-effective energy use.
- **Spatial coupling among different distributed energy sources.** Different distributed energy owners, such as households, buildings, communities or industrial parks, can synchronise energy supply and demand across various geographical areas by optimising spatial topology of network structure, interacting with one another and possibly conducting peer-to-peer trading.
- **Time coupling among distributed energy and centralised energy.** With the support of the demand-side response, storage, virtual power plants and intelligent microgrids, DES can realise an optimal co-ordination with the centralised energy system and achieve whole system optimisation.

- **Spatial coupling among distributed energies and centralised energies.** In remote off-grid areas, independent energy island projects can be implemented to reduce the costs of T&D infrastructure. More broadly, spatial coupling can contribute to achieving an optimal outcome combining both distributed and centralised energy.

Summary

This chapter has provided a general introduction of DES, based on a working definition and a review of how DES fit in the larger picture of energy system transformation. It also provided insights into the main benefits of drivers for future deployment.

In summary, DES allow the simultaneous optimisation across a diverse range of supply and demand options, in order to best meet specific needs for energy services. This also allows maximising the benefit of energy efficiency from a system's perspective. At the same time, DES can contribute to a more resilient, more reliable and cleaner energy system. The three development perspectives discussed at the end of this chapter are rooted in different technology enablers: DES rely on smaller-scale resources, opening the opportunity for customers to invest directly in the energy system. DES utilise technologies that can couple different energy sectors, allowing the provision of more integrated energy services. Finally, DES are enabled by smarter controls and digital connectivity.

References

- Burger, S.P. and M. Luke (2016), *Business Models for Distributed Energy Resources: A Review and Empirical Analysis*, <https://energy.mit.edu/wp-content/uploads/2016/04/MITEI-WP-2016-02.pdf>.
- China.com (2017), 广州建成南方五省区内首个四网融合智能小区项目 [The First “Smart Energy” Demonstration Project of Southern China Completed in Guangzhou] <http://news.china.com/finance/11155042/20170329/30370819.html>.
- China5e (2016), 一等奖：上海中心大厦天然气分布式能源项目 [Introduction of the Distributed Energy System of Shanghai Tower], www.china5e.com/news/news-958084-1.html.
- China5e (2015), 探秘上海迪士尼乐园的“动力心脏” -分布式能源 [Explore the Energy Source of Shanghai Disneyland – Distributed Energy], www.china5e.com/news/news-908685-1.html.
- Cossent, R., T. Gómez and P. Frías (2009), “Towards a future with large penetration of distributed generation: Is the current regulation of electricity distribution ready? Regulatory recommendations under a European perspective”, *Energy Policy*, Vol. 37/ 3, pp. 1145-1155, <https://doi.org/10.1016/j.enpol.2008.11.011>.
- IEA (International Energy Agency) (2017a), *World Energy Outlook 2017*, OECD/IEA, Paris.
- IEA (2017b), *China Energy Outlook: World Energy Outlook 2017 Special Report*, OECD/IEA, Paris.
- IEA (2017c), *District Energy Systems in China: Assessment Methodology and Business Models*, OECD/IEA, Paris.
- IEA (2017d), *Digitalization & Energy*, OECD/IEA, Paris.
- IEA (2017e), *Technology Roadmap: Smart Energy Systems*, OECD/IEA, Paris.

- IEA (2017f), *World Energy Investment 2017*, OECD/IEA, Paris.
- IEA (2017g), *Market Report Series: Renewables 2017*, OECD/IEA, Paris.
- IEA (2017h), *Global EV Outlook 2017*, OECD/IEA, Paris.
- IEA (2017i), *Status of Power System Transformation 2017*, OECD/IEA, Paris.
- IEA (2016), *World Energy Outlook 2016*, OECD/IEA, Paris.
- IEA (2014a), *Linking Heat and Electricity Systems Co-generation and District Heating and Cooling Solutions for a Clean Energy Future*, OECD/IEA, Paris.
- IEA (2014b) *World Energy Outlook*, OECD/IEA, Paris.
- IEA (2014c), *Heating without Global: Warming Market Developments and Policy Considerations for Renewable Heat*, OECD/IEA, Paris.
- IEA (2002), *Distributed Generation in Liberalised Electricity Markets*, OECD/IEA, Paris.
- METI (2016) (Ministry of Economy, Trade and Industry), “Long-term energy supply and demand outlook”, www.meti.go.jp/english/press/2015/pdf/0716_01a.pdf.
- NDRC et al. (2017), 关于推进供给侧结构性改革 防范化解煤电产能过剩风险的通知 [Notice on Preventing and Eliminating Overcapacity Risk in the Coal-Power Sector through Supply-Side Structure Reform], www.nea.gov.cn/2017-08/14/c_136525062.htm.
- NDRC and NEA (2016), 电力发展“十三五”规划 [The 13th Five-Year Plan on Electricity Power Development].
- NREL (2001), “Distributed Energy Resources Program”, www.nrel.gov/docs/fy02osti/31251.pdf.
- People.cn (2017), 贵安新区建设国内首座 “1+3” 多能互补分布式智慧能源站 [The First Combining Complementary Energy Resource Finished in Gui'an City], <http://gz.people.com.cn/n2/2017/0407/c194827-29981997.html>.
- Pyper, J. (2013), “Are microgrids the answer to city-disrupting disasters?”, *Scientific American*, 11 September 2013, www.scientificamerican.com/article/are-microgrids-the-answer-to-city-disrupting-disasters/.
- Rahimi, F. and A. Ipakchi (2016), “Using a transactive energy framework: Providing grid services from smart buildings”, *IEEE Electrification Magazine*, Vol. 4/4, <https://doi.org/10.1109/MELE.2016.2614181>.
- REN21 (2016), *Renewables 2016 Global Status Report*, www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report.pdf.
- SEPA (Smart Electric Power Alliance) and Black & Veatch (2017), *Beyond the Meter: Planning the Distributed Energy Future, Volume I*, <https://sepapower.org/resource/beyond-the-meter-planning-the-distributed-energy-future-volume-i/>.
- Webley, K. (2012), “Hurricane Sandy by the numbers: A superstorm’s statistics, one month later”, *Time*, 26 November 2012, <http://nation.time.com/2012/11/26/hurricane-sandy-one-month-later/>.
- Xinhuanet (2017), 分布式能源应用进入 “加速度” [The Utilisation of Distributed Energy Should Be Accelerated], http://news.xinhuanet.com/2017-07/17/c_1121328140.htm.
- Ye, H. (2017), 上海国际旅游度假区核心区天然气分布式能源站项目 [Introduction of Distributed Energy System of Shanghai Disneyland], China 5e, <http://news.bjx.com.cn/html/20170417/820385-2.shtml>.

Chapter 2. Technologies and business models for distributed energy systems

Chapter 1 provides a general overview of distributed energy systems (DES) and their deployment drivers. Based on this background, this chapter aims to provide a more in-depth picture from two different perspectives. The first section of this chapter discusses the technological building blocks of DES. In a second step, examples of a number of business models highlight how technologies can be combined into a business offer.

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Technologies

Generation technologies

Co-generation and tri-generation

Co-generation, or combined heat and power (CHP), plants are electricity generators that achieve higher efficiencies by also producing useful heat. CHP plants cover a wide range of sizes, from domestic units at the kilowatt (kW) scale up to hundreds of megawatts (MW) used to supply district heating (DH). Industrial and large building demands tend to be the main markets for CHP (GIZ, 2016). Tri-generation, or combined cooling, heat and power (CCHP), plants achieve an additional level of efficiency by also providing cooling driven by waste heat.

The key elements of CHP plants are a prime mover or drive system, such as a gas turbine; an electricity generator; a heat recovery system; and a control system (IEA, 2008). CCHP plants contain the same elements plus a heat-driven cooling system, most commonly an absorption chiller. Gas turbines, including open and combined-cycle turbines, are the dominant technologies for power generation with natural gas. Gas turbines are a mature technology, and can encompass a wide range of sizes from micro-turbines up to hundreds of megawatts.

Heat recovery systems

The heat recovery system allows a CHP or CCHP plant to make use of the energy from waste heat. These systems are typically based on a heat exchanger, designed to enable efficient transfer of heat from one medium to another.

In the case of a natural gas turbine, a common heat recovery system transfers heat from the exhaust gases to a heat recovery boiler to form steam. The steam can then be used for applications including process heating, DH, steam-driven absorption chillers (described below) or additional electricity generation such as in a combined-cycle power plant. In combined-cycle CHP, waste heat from the steam turbine is then used in a second heat exchanger (Moussawi, Fardoun and Louahli-Gualous, 2016).

The utilisation of waste heat allows CHP plants to achieve much higher overall efficiency than electricity-only generators, with global average efficiency for co-generation in electricity production of around 58% compared with 36% for thermal power plants in 2011 (IEA, 2014a).

Absorption chillers

Absorption chillers enable waste heat to be used for cooling. The principle of this technology is similar to a compressor-based heat pump (HP), using a pressure difference to move heat in the opposite direction to natural heat flow (i.e. from cooler to warmer). In the case of absorption chillers, the pressure difference is generated by chemical absorption. Absorption chillers typically range in capacity from hundreds of kilowatts up to the multi-megawatt scale, although more specialised products can be as low as 5 kW and as high as 20 MW or more (GIZ, 2016).

Role of co-generation and tri-generation in DES

Natural gas is the dominant fuel used for co-generation, but other sources including municipal solid waste and biomass are also common (IEA, 2008). CHP plants are typically sized relative to heating demand since it is more cost-effective to transport surplus electricity than heat.

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Industry is the largest market for CHP and CCHP in many countries, with many applications for heating. CHP and CCHP can also supply hot water and space heating/cooling for larger buildings (GIZ, 2016). Overall, CHP is much more widely spread than CCHP (Moussawi, Fardoun and Louahlia, 2017). Deployment of efficient and cost-effective CHP is one key to reducing emissions intensity of electricity and heat production.

Recent technology progress and current deployment

While global electricity and heat production from CHP has increased on average 1.2% annually since 2000, this represents a declining share of total electricity generation, falling from 11% in 2000 to 9% in 2013 (IEA 2016a). According to NEA data, CHP made up 30% of thermal capacity in the People's Republic of China (hereafter, "China") at the end of 2014 (NEA, 2016). It is difficult to tell whether there is room for increasing large-scale CHP for electricity generation beyond this in China, particularly given existing data limitations. Additionally, growth in CHP capacity is likely to depend on producer capacity to sell heating to the district network within the existing boundaries and heating periods in north urban China.

Current costs and cost trends

While CHP can be highly efficient, this is accompanied by higher initial plant costs than an electricity-only configuration (IRENA, 2012). CHP costs are difficult to compare between projects due to the range of technologies and plant designs. The overall economics of CHP and CCHP plants is also highly dependent on fuel and electricity prices. Overall investment costs for CCHP are also higher than CHP due to more complex equipment (Moussawi, Fardoun and Louahlia, 2017).

Relevant barriers

Regulatory barriers and the lack of a clear mechanism for price formation have been identified as key barriers to expanding CHP in China. In addition, the need to import components as well as employ foreign experts for unit overhaul and maintenance have been a factor in increasing investment and maintenance costs (Yan et al., 2016).

A survey of barriers cited by European Union member states found that fuel prices were the most commonly cited barrier, focusing on the price of gas and its volatility. High gas prices combined with low electricity prices make it very difficult for CHP to compete. The size and predictability of heating or cooling demand was the second-most-cited challenge, followed by legal and regulatory complexity. Other barriers seen include deficiencies in support schemes, electricity grid access, economic justification for projects, access to fuels and lack of financial resources (Moya, 2013).

Solar photovoltaics

Technology and role in DES

Solar photovoltaic (PV) systems convert solar energy directly into electricity. Commercially available PV modules range from as low as 5 watts (W) to over 350 W (RenSMART, 2017). Modules are then connected with other components including inverters and mounting systems to form a PV system. Systems can range from watts to the megawatt scale, offering flexibility to deploy at household, building and community level (IEA, 2011).

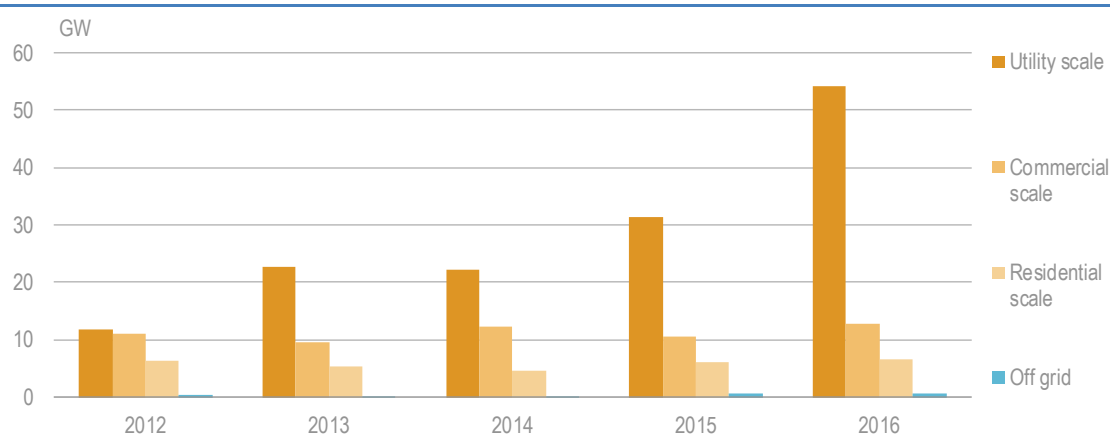
The potential for PV to supply energy locally varies significantly from region to region, depending on both the solar resource and the density of land use. The maximum technical potential for rooftop PV in cities in 2015 was above 5 500 terawatt hours (TWh) per annum globally, and varied as a share of demand from 11% in China to 97% in Africa (IEA, 2016a).

Recent technology progress and current deployment

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Solar PV installations were initially dominated by home- and residential-scale systems, although since 2013 the utility-scale market has dominated new build (Figure 2.1). Nevertheless, installations of distributed PV in the residential and commercial sectors are expected to remain significant over the next five years (IEA, 2017a). The vast majority of these systems are grid connected, with the off-grid market remaining very small in comparison. While over 34 gigawatts (GW) of solar PV was connected in China in 2016, almost 90% of this was utility scale. The remainder consisted mostly of commercial PV (IEA, 2017a).

Figure 2.1 • PV world net additions



Source: IEA (2017a), *Market Report Series: Renewables 2017*.

Key point • Utility-scale PV is the largest component of new additions; however, other applications, in particular commercial PV, remain significant.

Current costs and cost trends

Solar PV modules saw a 20% reduction in the global weighted average price in 2016, driven by increasing manufacturing capacity globally and competitive pricing strategies. Average costs for residential rooftop PV systems in 2016 ranged from around 1 200 United States dollars (USD) per kilowatt in India and USD 1 300 in China to over USD 4 000/kW in the United States (US). Different business models, regulatory environments and available financial incentives are important drivers for cost differences among countries. In addition, balance-of-system and installation costs make up a much larger part of system costs than for utility-scale PV, and are highly specific to different countries, or even states and provinces. System cost reductions are expected to continue over the next five years, due to a combination of decreases in module costs and particularly cost reduction potential in balance-of-system costs (IEA, 2017a; IRENA, 2017).

Relevant barriers

Distributed solar PV can face a range of technical, financial and institutional challenges. Technical barriers can include limited appropriate installation sites, limited solar resources and a range of grid integration challenges. Local voltage and congestion issues can lead to distribution grids imposing limits on grid-connected PV installations, preventing further uptake in some locations.

From a financial perspective, support schemes such as solar feed-in tariffs have been a key enabler for distributed PV markets. The rapid reductions in installation costs seen over the last decade are now enabling continued uptake even in markets where feed-in tariffs are no longer available; however, electricity industries are still trying to develop appropriate mechanisms to value the energy supplied by PV.

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Finally, administrative permitting procedures are often the largest obstacle facing PV developers (EC, 2012) and may be the key barrier to uptake in some markets. For example, distributed solar projects in the Chinese commercial and industrial sectors face both legal and financing challenges (IEA, 2016b).

Solar thermal

Technology and role in DES

Solar thermal technologies range from small-scale solar water heating systems to large-scale DH and industrial applications. These technologies use a collector that absorbs thermal energy from sunlight combined with a heat transfer mechanism often involving a circulating fluid. Fluid circulation can be driven by a thermosiphon system, based on natural convection, or by active pumping.

Evacuated tube collectors dominate the global market due to their prevalence in China, although flat plate collectors are more common in Europe (Weiss, Spörk-Dür and Mauthner, 2017). Most of the global cumulative capacity consists of small systems providing domestic hot water, although larger systems for commercial hot water, combined space and water heating, industrial process heat, and DH are seeing increased deployment (IEA, 2017a). Solar thermal is a means to provide clean, renewable energy-based heating close to demand centres and is an attractive option in markets with high electricity prices and good insolation (IEA, 2016b).

Recent technology progress and current deployment

New global solar thermal installations were 36.7 gigawatts thermal capacity (GW_{th}) in 2016. This was an 8% decrease from the previous year, and the third consecutive year where annual solar thermal capacity additions decreased. China makes up over 75% of the market share, and a rapid decrease in annual installations in China was the main cause of global decline (IEA, 2017a).

Total cumulative installed capacity at the end of 2016 was 456 GW_{th} , with over 70% of this located in China. Over the period 2017-22, global energy consumption from solar thermal is expected to increase by over a third, and this will still be led by China despite annual growth remaining lower than previously. Buildings are expected to be the main source of growth, with a shift from small domestic hot water systems towards larger systems (IEA, 2017a).

Current costs and cost trends

A wide range of investment costs are seen, from as low as USD 175 per kilowatt thermal (kW_{th}) to USD 2 794/ kW_{th} for small domestic hot water systems. Thermosiphon systems without the need for active pumping occupy the lower part of this range, falling between USD 175/ kW_{th} and USD 1 476/ kW_{th} . Another important factor in cost is closed or open loop design, with open-loop designs having lower cost but being most suitable for more moderate climates where freezing is minimal. Systems with the ability to provide space heating as well as water heating are also more complex and tend to have higher costs as a result (IEA, 2016b).

Relevant barriers

Barriers to solar thermal heating include a lack of awareness of the technology and a lack of providers and business models for larger systems. High investment costs can also be a barrier, particularly for more complex applications. Reductions in support schemes have been a key factor in the recent decline in deployment in China (IEA, 2016b).

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Wind energy

Technology and role in DES

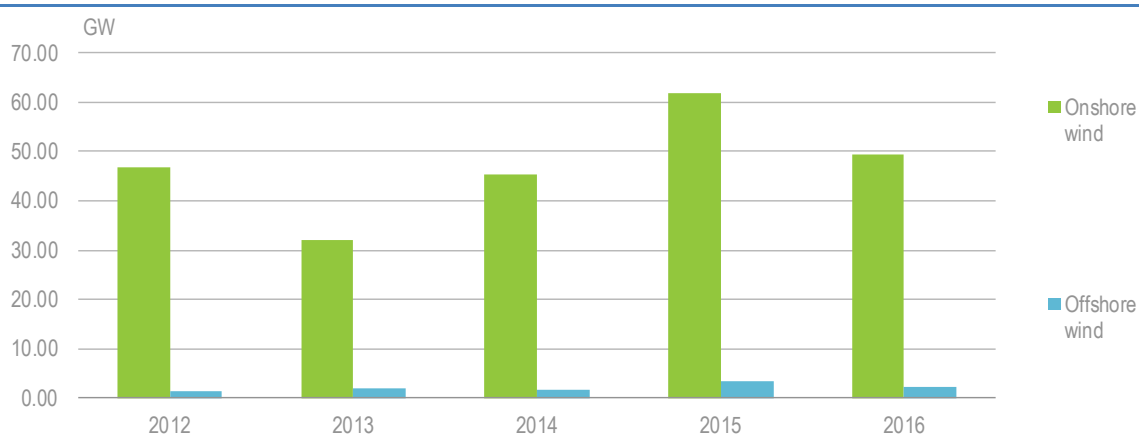
Wind turbines range from very small household-level models in the range of hundreds of watts to multi-megawatt machines. However, small turbines of less than 100 kW remain less than 0.2% of the global wind market on a capacity basis (GWEC, 2017; Pitteloud and Gsänger, 2017) and are likely to continue to play only a minimal role due to cost and potential.

While large wind projects allow developers to take advantage of areas with good wind resources, this approach can lead to challenges in transmission capacity and also increase the likelihood that wind turbines will generate at the same time as they are experiencing the same weather conditions. These factors both lead to increased curtailment. Distributed wind projects benefit from being located closer to load and are less likely to require significant new transmission infrastructure. They can also provide economic opportunities to rural areas, and give local communities the opportunity to participate directly in decisions about the power they consume. For community wind farms, local ownership also helps to facilitate public acceptance (BWE, 2012).

Recent technology progress and current deployment

Global annual onshore wind installations were almost 50 GW in 2016, somewhat lower than the previous year but still making up close to one-third of all new renewables additions (Figure 2.2). China is the world's largest market with 38% of global capacity additions in 2016. Capacity additions are expected to remain consistent out to 2020 (IEA, 2017a).

Figure 2.2 • Additional global wind capacity, 2012-16



Source: IEA (2017a), *Market Report Series: Renewables 2017*.

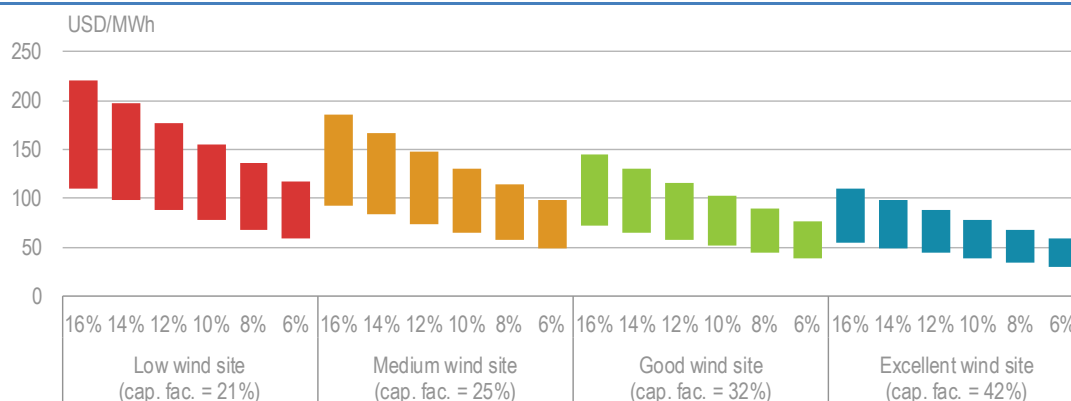
Key point • Onshore wind additions dominate global wind additions.

Current costs and cost trends

Typical investment costs of onshore wind projects for 2016 were estimated at USD 1 050/kW to USD 2 000/kW, with China and India at the lower end of the range. Turbine prices in China were stable, with lower demand for turbines offset by commissioning of more turbines with larger

rotor diameters. Average investment costs are expected to decline around 7% to 2022 due to continued learning and increased competition among manufacturers supplying large-scale projects through competitive auctions (IEA, 2017a). Depending on wind resource, this leads to a range of different costs (Figure 2.3).

Figure 2.3 • Onshore wind generation cost variable and levelised cost of energy ranges



Notes: MWh = megawatt hours. The ranges for each case reflect capital expenditure assumptions from USD 1 100/kW to USD 2 200/kW.

Source: Based on IEA (2016b), *Medium-Term Renewable Energy Market Report 2016* - updated capital cost assumptions.

Key point • Key drivers of wind project costs are site wind speed and weighted average cost of capital.

On a per kilowatt basis, small wind costs vary substantially among different markets, but are consistently higher than for large turbines. In 2013, average installed cost was USD 1 900/kW in China, USD 5 873/kW in the United Kingdom and USD 6 940/kW in the United States (Gsänger and Pitteloud, 2015). While there is a lack of data on LCOEs for small wind, these will tend to be higher than for large wind by a greater factor than the per kilowatt cost, due to lower capacity factors for small wind (Shaw et al., 2008; Encraft, 2009).

Relevant barriers

Permitting procedures are a significant barrier for smaller-scale wind projects such as community wind farms. Complex regulatory procedures will tend to favour large developers with the ability to spread permitting costs across larger projects. Another key barrier to distributed wind projects can be procurement policies that do not take into account locational value of wind generation based on the electricity system. Purely energy-based tariffs tend to incentivise deployment concentrated in areas with good wind resources, which may result in high local penetrations of wind energy. This may disadvantage smaller projects that are favourably located relative to load that have a higher value to the system, taking transmission and distribution requirements into account.

Biomass and waste

Technology and role in DES

Power generation from biomass and waste fuel encompasses a range of both generation technologies and fuels. Co-firing solid biomass with coal in existing power stations is one of the most cost-effective biomass generation options, although this would not be considered to be distributed. Dedicated biomass-based power plants use direct biomass combustion in a boiler to generate electricity using a steam turbine (IEA, 2011), and other technologies for biomass utilisation include gasification and anaerobic digestion. Biomass fuels can include agricultural residues, animal manure, wood wastes from forestry and industry, residues from food and paper industries, municipal green wastes, sewage sludge, dedicated energy crops, coppice, grasses, and

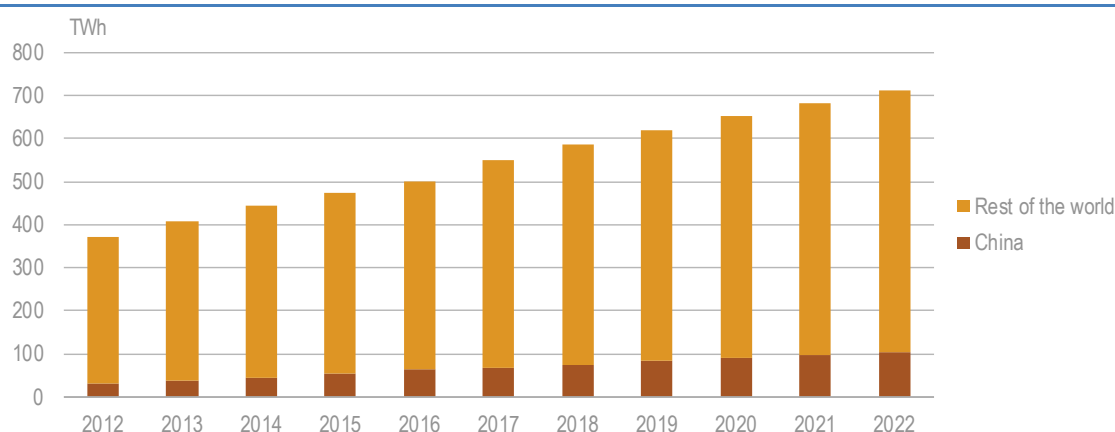
sugar, starch and oil crops (IEA, 2007). Biomass feedstocks tend to have higher transport costs than fossil fuels such as coal as a result of lower energy density.

While bioenergy production does benefit from economies of scale, collocation with the site of fuel production is a driver for smaller bioenergy generators, since transport costs can counterbalance those benefits. Where the site of feedstock generation is also close to heating demand, bioenergy-based co-generation can simultaneously minimise fuel costs and maximise output efficiency, creating a strong case for distributed biomass. On the other hand, energy from waste (EfW) generation is typically primarily driven by the need for waste disposal in areas with limited or only high-cost waste disposal available, with generation of electricity as a co-benefit.

Recent technology progress and current deployment

Global bioenergy capacity was 110 GW in 2016 and is mostly large-scale. Net capacity additions have ranged from around 5.7 GW to 7 GW annually in the last five years, leading to increased generation levels (Figure 2.4). Capacity additions are expected to remain relatively steady in the next few years (IEA, 2017a). China added 1.8 GW of bioenergy capacity in 2016, reaching a total of 12 GW, and is expected to reach 20 GW by 2022 (IEA, 2017a). Bioenergy generation in China is dominated by EfW and agricultural residue (IEA, 2016b).

Figure 2.4 • Biomass and waste generation, historic values and forecast, 2012-22

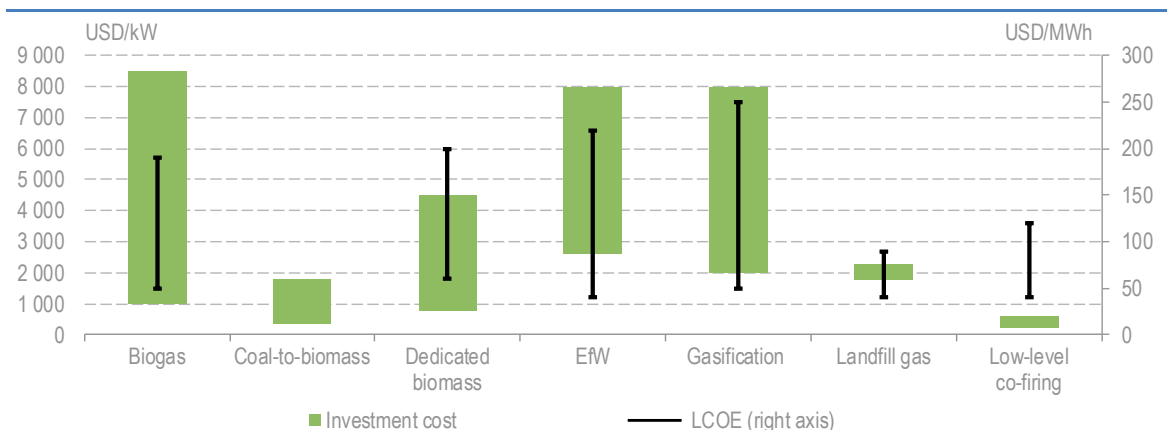


Source: IEA (2017a), *Market Report Series: Renewables 2017*.

Key point • Biomass generation has seen a stable increase over the past five years, and it is expected to continue to 2022.

Current costs and cost trends

Bioenergy plants exhibit a wide range of investment costs and LCOE values both within and among technologies. Important cost drivers are plant size, technical sophistication of plants, cost of capital, costs of regulatory compliance and feedstock cost. The highest investment costs are generally seen for EfW, gasification and biogas, with low-level co-firing, landfill gas and coal-to-biomass requiring the least investment (Figure 2.5). While the investment costs for dedicated biomass are in the middle of the range, the LCOE range is relatively high because of higher feedstock cost. In general, lower-end costs are seen in China and Thailand and higher-end costs in Europe and Japan (IEA, 2017a).

Figure 2.5 • Investment and energy cost ranges for different biomass-based generation technologies

Source: IEA (2017a), *Market Report Series: Renewables 2017*.

Key point • Biomass technologies show a wide range of investment and energy costs even within technology types.

Relevant barriers

Resource availability commonly places a limit on the potential for low-cost biomass generation (Yaqoot, Diwan and Kandpal, 2016). Even where biomass resources do not pose a constraint, for example India, the need for storage due to seasonality of production and logistics of collecting and transporting the feedstock to biomass plants represent challenges for project development (IEA, 2016b).

Higher generating costs than competing fossil fuel technologies are also a barrier to greater uptake, as biomass requires carbon dioxide (CO₂) emissions control to be competitive (Hui et al., 2017). In Indonesia, access to finance, planning and regulatory compliance have constrained uptake of industrial biogas (IEA, 2016b). Negative public perception can also be an issue, for example in Thailand, where previous projects have failed to perform to expected standards (IEA, 2016b).

Technologies for sector coupling

District heating and cooling networks

Technology and role in DES

DH networks enable heat generated centrally or from an existing heat source to be distributed to consumers by pipelines (IEA ETSAP, 2013). Hot water has come to dominate over steam due to factors including better safety and cost savings. Heat sources for DH include co-generation plants as well as different types of boilers, waste heat from industry, geothermal sources and HPs (IEA ETSAP, 2013). DH systems thus allow integrating different sectors of the energy system (i.e. an electric boiler used in DH can couple electricity and heating).

DH can allow substantial energy savings due to utilisation of waste heat and can also take advantage of geothermal and renewable heat (IEA ETSAP, 2013). These advantages must, however, be balanced against significant heat losses within the heat distribution network. Thus the applicability of DH is highly dependent on population density as well as the options for central heat generation and the cost of alternatives.

The application of district cooling follows similar principles to DH, but district cooling is much less widespread. Relative to DH, district cooling requires more specialised conditions and complex design to be economically efficient and deliver energy-efficient solutions (discussed further below) (Euroheat&Power, 2017a).

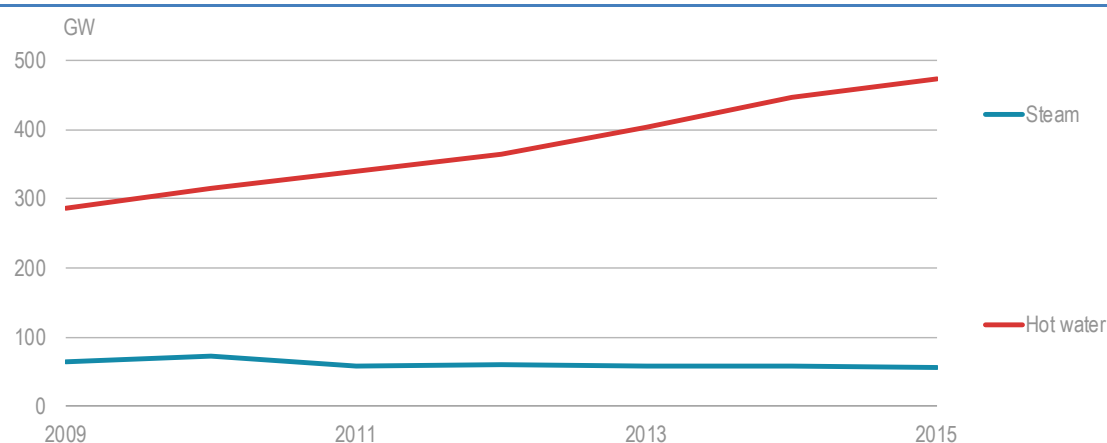
In addition to taking advantage of efficient and low-carbon energy sources, district heating and cooling (DH&C) networks can help increase the flexibility of heating and cooling demand. DH&C involves storing energy in a medium (typically hot or cold water) for transport, and CHP/CCHP usually also have storage tanks for cold and hot water since heating and cooling demand may not coincide with electricity demand (Moussawi, Fardoun and Louahlia, 2017). This storage capability helps to reduce demand peaks and has the potential to add to system flexibility.

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Recent technology progress and current deployment

There are challenges in collecting data on global DH&C due to the local and fragmented nature of these markets (Euroheat&Power, 2017b). However, some data are available particularly for China and some countries in Europe. China has the world's largest district heating network, with more than 90% of residents in northern urban China connected (IEA and Tsinghua University, 2015), concentrated in the north of the country. Total installed DH capacity in Chinese cities in 2015 was almost 530 gigawatts thermal capacity, with almost 90% of this in systems using hot water to distribute thermal energy (Figure 2.6) (NBSC, 2016). County-level district heating is not included in this statistic due to reporting challenges, but is estimated to be over one-quarter of that in cities. Trench length including both steam and hot water networks increased by around 39% between 2011 and 2015 to over 200 000 kilometres, reflecting significant expansion of the network (NBSC, 2016).

Figure 2.6 • District heating capacity in Chinese cities, 2009-15



Source: NBSC (2016), *China Statistical Yearbook*.

Key point • Energy usage for DH in China has grown steadily and is dominated by hot water as the thermal energy carrier.

Relevant barriers

Capital costs for the heat/cooling distribution network as well as the required generators are important barriers to further deployment of DH&C (IEA ETSAP, 2013). A lack of strategic planning for heating and cooling infrastructure is also a barrier. For efficient DH&C it is also important that market conditions allow the real cost of electricity and heat generation to be reflected in prices, in order to promote efficient energy use (IEA, 2014a).

In China, a high proportion of DH depends on coal-fired systems, which contribute significantly to air pollution. More environment-friendly DH faces challenges in the form of gas supply and the cost of gas. A lack of suitable technologies to integrate large-scale renewable energy supply into DH is also a barrier to introducing more renewables-based DH (Euroheat&Power, 2017a).

In Europe, due to the high proportion of CHP in DH (almost 70%), revenue challenges faced by CHP due to low electricity prices are an obstacle to the expansion of DH (Euroheat&Power, 2017b). Like electricity generation and distribution infrastructure, DH&C networks have high up-front investment costs that create investment risk in the presence of uncertain future demand. This creates a requirement for stability in legal and policy frameworks as well as systematic long-term planning for the expansion of DH&C (IEA, 2014a).

Heat pumps

Technology and role in DES

HPs encompass a wide range of technologies that use an electrically driven refrigeration-type cycle to transfer heat from one space (source) to another (sink), and include air-source and ground-source types. Because HPs transfer heat rather than generating it, they are capable of achieving efficiencies much higher than 100%, as they are able to deliver more heating or cooling energy than the input energy required for the heat transfer.

HPs are suitable for supplying heating and cooling demand in buildings. Heating demand in buildings accounts for around half of global heating demand (IEA, 2014b), while space cooling accounts for about 2% of global energy consumption and is growing relatively rapidly (IEA, 2016d). Another application for HPs is to upgrade low-temperature waste heat to higher temperatures, and they also have the potential to compete with gas in the long term for provision of low-temperature heat in industries such as chemicals, food and paper (IEA, 2016c).

With increasing decarbonisation of electricity grids, HPs have the potential to provide both energy demand and carbon emissions savings. In addition, by taking advantage of the inherent thermal storage available in space heating and cooling, with appropriate control technology HPs can represent an additional source of flexible demand.

Recent technology progress and current deployment

Global HP sales in 2016 increased by 28% to over 3 million units, with a 17% increase in total global investment relative to 2015, up from the 7% increase the previous year (BSRIA, 2017). China accounted for around two-thirds of these sales and 95% of sales growth in 2016, supported by city-level policies aimed at reducing local pollution (IEA, 2017b). The remaining market is divided evenly between Japan and Europe, and total sales are dominated by residential applications. In Europe and China, around two-thirds of the market is associated with new buildings, while in Japan the larger share of the market consists of replacements and refurbishments (IEA 2017b).

Current costs and cost trends

HP costs vary significantly by country, with the lowest unit costs in 2016 seen in China at around USD 850 and prices in Europe ranging from more than double to up to nine times those in China. Most countries saw unit cost decreases between 2014 and 2016, from a few percent to as high as 27% in Switzerland (BSRIA, 2017).

Relevant barriers

Investment costs can be a barrier to HP uptake, as they are often higher than for fossil fuel or less efficient alternatives. This may change with increasing economies of scale in component manufacture and as improving building energy efficiency allows smaller systems to provide the same service (IEA, 2017c).

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Batteries

Technology and role in DES

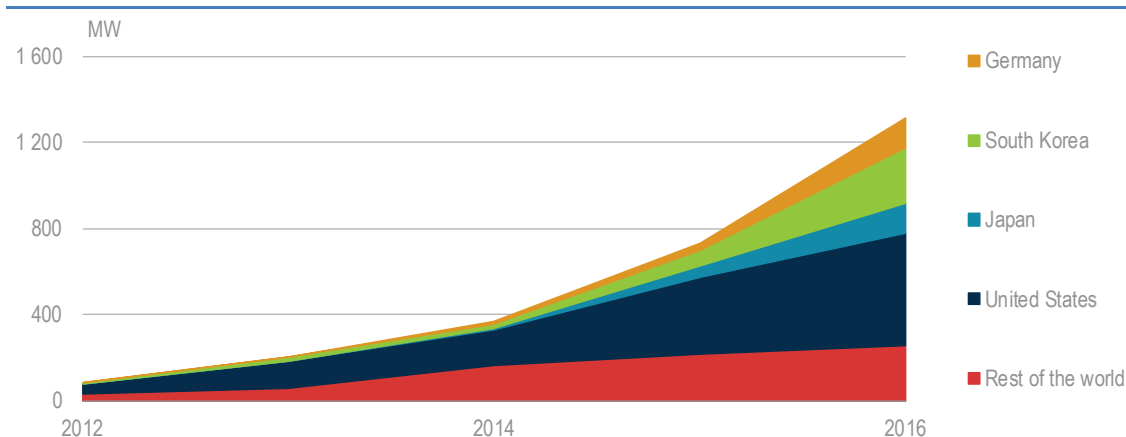
Batteries include a wide range of chemistries and also have a wide range of applications, for example peak load shifting, variable resource integration, load following, frequency regulation, black start and seasonal storage (IEA, 2014c). Different battery system designs are suited to different applications, depending on characteristics such as discharge duration and frequency of cycling.

While batteries combined with distributed generation (DG) such as PV technically have the potential to reduce or even eliminate network requirements, in most applications grid connection is still and is likely to remain the optimal solution. The large discrepancy between winter and summer solar production in temperate climates makes complete network disconnection impractical, and the ability to sell storage services to the grid increases the value of consumer-owned batteries (IEA, 2016d). High levels of reliability can generally also be achieved more cost-effectively with grid connection.

Recent technology progress and current deployment

Batteries can be installed throughout the energy system and have already achieved limited deployment in both distributed and centralised systems for mobile and stationary applications at varying scales (IEA, 2014c). Building-scale power storage experienced 50% year-on-year market growth in 2014, and ongoing uptake is expected as private consumers seek to reduce their electricity bills through maximising self-consumption and minimising both volume and capacity payments for grid electricity (IEA, 2016a).

Figure 2.7 • Cumulative capacity of grid-level batteries



Source: IEA (2017b), *World Energy Investment 2017*.

Key point • Recent capacity additions to grid-level battery storage have been concentrated in relatively few markets.

New additions of non-pumped-hydro utility-scale energy storage are strongly dominated by lithium-ion chemistries, which made up 90% of additions in 2016 (IEA, 2017d). Pumped hydro still

dominates existing global energy storage at over 150 GW worldwide. Of the 3.4 GW of other forms of energy storage worldwide, lithium-ion batteries are the largest contributor at 41% (IEA, 2017d). Capacity additions of grid-level batteries increased each year from 2012 to 2016. These installations are concentrated in a few markets, with most 2016 installations occurring in South Korea, the United States, Germany and Japan (Figure 2.7) (IEA, 2017b).

Current costs and cost trends

Batteries exhibit a wide range of costs depending on technology and application, with different use cases requiring different properties and influencing costs. Lithium-ion technologies have seen rapid cost reductions with a 22% average learning rate³ from 2010 to 2015 (IEA, 2016a), helping to drive their dominance in the market. Capital expenditure and the cost of financing make up the main component of the overall cost of using battery storage, but charging cost also makes up a significant component over the battery lifetime.

Relevant barriers

Battery uptake still faces challenges due to energy density, power performance, lifetime, charging capabilities and costs (IEA, 2014c). Even as battery costs decline, rules that limit participation in electricity markets can prevent financial rewards for developers despite overall system benefits (IEA, 2017b).

Electric vehicles

Technology and role in DES

Electric vehicles (EVs) store electrical energy in batteries to run an efficient electric motor instead of burning fossil fuels. They include battery-electric vehicles (BEVs), which have an electric motor and batteries, and plug-in hybrid electric vehicles (PHEVs), which in addition to these components also have an internal combustion engine (ICE) (IEA, 2017c).

The two key features of EVs that are important to DES are their potential to contribute to transport decarbonisation and their impact on electricity supply networks. Like HPs for heating demand, EVs are inherently efficient and can also allow decarbonisation of the electricity sector to be coupled with reduced emissions from the transport sector. The potential for EVs to be operated as intelligent loads is critical to their low-cost grid integration. A number of innovations in the area of EV charging are under way (Box 2.1).

Box 2.1 • Wireless power transfer in EVs

Wireless power transfer (WPT) is already a mature technology for certain applications, such as wireless charging of smartphones and other handheld devices. The growing EV market may provide further opportunities for this technology. Traditional car manufacturers, alongside new entrants, are striving to explore market opportunities and accelerate the commercialisation of the technology. For example, Daimler collaborated with BMW on developing the standards of EV wireless charging technology in 2014. Daimler plans to launch a WPT prototype in the new S-class Mercedes-Benz models, while the BMW is the first to adopt WPT in the i8 models. WPT in EVs consists of two parts: one is a coil in the vehicle floor; the other is the charging garage floor located underneath the car. When the car is driven over the charging garage floor, electricity is transmitted through the alternating magnetic field between the coils to allow automatic wireless

³ In this case the learning rate refers to the reduction in investment costs for each doubling of cumulative historical installed capacity.

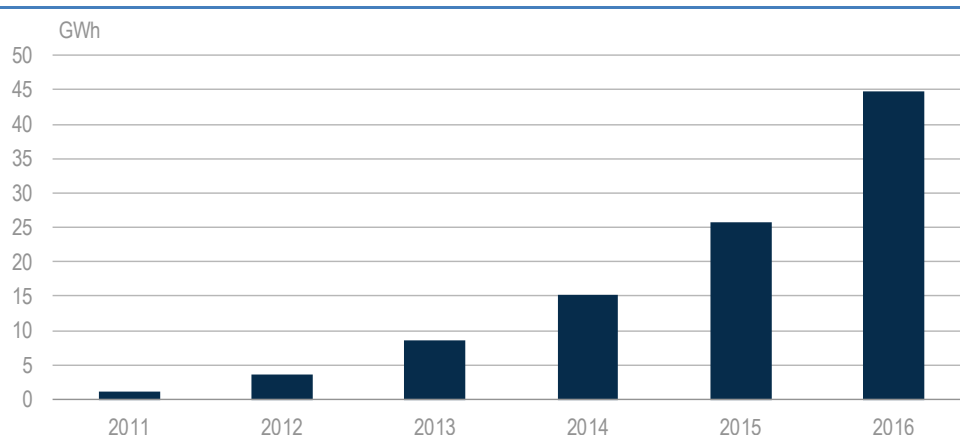
charging. A BMW i8 charge takes less than two hours with rated power of 3.6 kW. Through further progress in the coil design, the WPT output power can reach a capacity of 7 kW, which will continue to be adopted in a series of BMW EVs in the future.

Source: Olivares-Galvan J.C., E Campero-Littlewood and S. Magdaleno-Adame (2016), "Review paper on wireless power transmission," <http://ieeexplore.ieee.org/document/6702725/>.

Recent technology progress and current deployment

Passenger EV sales have been growing rapidly in North America, Europe, China and other regions since 2012, with a cumulative 2 million plug-in passenger cars and light utility vehicles sold by the end of 2016 (IEA, 2017e). This has added a substantial amount of flexible load and storage to the system (Figure 2.8).

Figure 2.8 • Cumulative battery capacity in PHEVs and BEVs sold from 2011 to 2016



Key point • The rapid increase in PHEV and BEV sales is a growing source of potentially flexible load.

In 2016, China was the world's largest passenger EV market for the second year running, with almost half of global sales, and also surpassed the United States as the country with the most EVs on the road network. There are also many more electric 2-wheelers than cars, and China is by far the global leader with an estimated 200 million to 230 million on the roads. China also leads the world in electric bus deployment, with over 340 000 buses now in circulation, according to available statistics (IEA, 2017e).

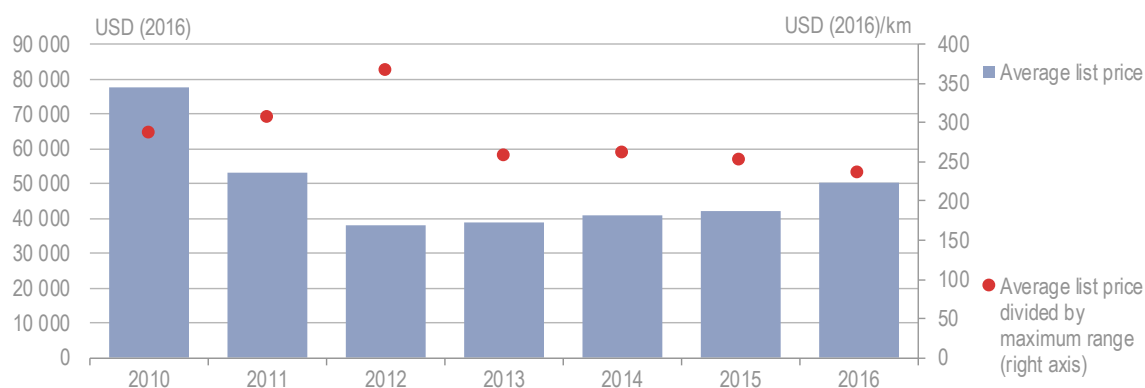
In addition to growing numbers of EVs, there has also been a strong increase in public charging infrastructure. This will play an important role in both the load imposed by EVs on local grids and the ability of EVs to provide long-range travel capabilities similar to ICEs. Public slow chargers increased from 148 000 outlets in 2015 to 212 000 at the end of 2016. Public fast chargers increased from 57 000 in 2015 to 110 000 outlets in 2016, with 81% of these located in China (IEA, 2017e).

Current costs and cost trends

EVs are currently more expensive than comparable ICE vehicles in all regions (IEA, 2017e). Battery costs are the key driver of higher EV costs, making up more than half of the total purchase cost in all regions (IEA, 2017e). Battery costs have declined from over USD 900/kWh in 2009 to under USD 300/kWh since 2014 and levelled off somewhat through to 2016 (US DOE, 2017). Increases in both numbers of units produced and battery pack size have the potential to further reduce battery costs, and further cost reductions are expected into the future (IEA,

2017e). Average EV list price has increased since 2012, but this reflects sales of more luxurious cars, with the average price decreasing relative to maximum range (Figure 2.9) (IEA, 2017b).

Figure 2.9 • Average EV price and driving range



Source: Reprinted from IEA (2017b), *World Energy Investment 2017*.

Key point • While the average list price of EVs has increased since 2012, this is accompanied by a larger increase in the average driving range.

Relevant barriers

Key barriers to EV uptake are the need to compete with ICE vehicles on price and range performance. Analysis of the relationship between EV registrations and changes in support policies in different countries broadly confirms that policy support is the main driver of EV market mechanisms (IEA, 2017e).

As well as the up-front cost of EVs, lack of access to appropriate charging infrastructure can also be an uptake barrier. Public fast charging networks in particular are critical to enable long-range usage of EVs. Private charging, on the other hand, is important for daily usage and may be a barrier, without access to parking facilities that enable home charging.

Technologies to enable smart operations and connectivity

A defining characteristic of modern DES is the intelligent integration of multiple energy sources and loads. In turn, this allows the provision of improved energy services at lower costs and with less negative impacts on the environment. In turn, modern DES require advanced monitoring and control equipment to achieve this task – these are the glue holding together the various pieces.

Advanced metering infrastructure

Technology and role in DES

Advanced metering infrastructure (AMI) typically refers to the combination of customer site smart meters and other technology with communication networks and data reception and management systems that enable a two-way information flow between a customer and a utility. Smart meters are the key enabling component of AMI.

Higher-frequency readings allow smart meter data to be more useful to both the customer and the utility, supporting both energy-saving behaviours and improved network planning. Smart meter functionalities can include: support for advanced tariff systems; remote on/off control of power supply, or flow or power limitation; and import, export and reactive metering for distributed generation (EC, 2011). These functionalities lay the foundation for DES by enabling

more complex tariffs and data flows that incentivise and facilitate system-friendly installation and utilisation of DER.

Building on the first wave of AMI, utilities are looking for ways to implement business models based on big data from highly distributed generation and load monitoring, increase the participation of energy consumers in electricity markets, and enable demand-side flexibility (IEA, 2016a). AMI provides both a means to incentivise more intelligent load control through appropriate tariff design, and the data required to implement control solutions either at the customer level or at higher levels within the grid.

Recent technology progress and current deployment

At over USD 15 billion, smart meters became the largest category of digital electricity infrastructure investment in 2016 (IEA, 2017b). The extent of smart meter deployment varies widely across different countries, ranging from countries without significant deployment goals to countries such as China in the later stages of massive rollouts, to Sweden and Italy with nearly complete smart meter penetration (Kelly and Elberg, 2016). In terms of total installed meters, China is by far the world leader with more than 348 million smart meters at the end of the third quarter of 2016 and 67.1% of tracked installations globally (Kelly and Elberg, 2016).

Current costs and cost trends

Costs per meter vary substantially by region, with approximate hardware plus installation costs in 2016 less than USD 75 in China and India, USD 150 to USD 190 in France and Italy, USD 225 in the United States and around USD 300 in Japan (BNEF, 2016).

Relevant barriers

Consumer acceptance can be a barrier to smart meter deployment, particularly due to data privacy concerns, as well as concerns about cost allocation. A lack of interoperability between different proprietary metering technologies can pose a technical barrier (Balmert and Petrov, 2010). Smart meters also face economic barriers. The uncertainty associated with assessing benefits makes it difficult to accurately perform cost-benefit analysis despite available data on costs. Also, benefits can accrue to different stakeholders, creating a barrier (Balmert and Petrov, 2010).

Regulatory barriers are also a key challenge for smart meter deployment, including provisions within the existing framework that may inhibit deployment or inadequate tariff regimes (Balmert and Petrov, 2010).

Building-level energy management systems

Energy management systems (EMS) are computer-based control systems for energy equipment. These can be at the household level, at the level of commercial buildings and also at higher levels. While the devices connected and the level of complexity and sophistication can vary significantly among different EMS types, the key potential of building-level systems from a distributed energy perspective is in providing a more or less automated system through which electricity demand as well as other DER can be managed (Box 2.2).

Box 2.2 • The Edge building in the Netherlands

Buildings account for a large percentage of global energy use, representing 31% of final energy consumption in 2015. This is expected to continue, with only a slight drop to 30% projected for 2040. While residential buildings account for around three-quarters of this, commercial buildings are also an important contributor to building energy demand. Commercial building energy use is

also an important component of business costs.

The Edge building in Amsterdam in the Netherlands has an extensive range of design features to provide energy savings and user comfort. Smaller openings than would be typical in load-bearing walls help provide thermal mass and shading, and openable panels allow ventilation. The southern facade of the building has solar panels as well as louvres designed to provide shading. The northern facades are transparent to allow in light and have thick glass to reduce motorway noise.

The building collects rainwater from the roof to flush toilets and irrigate green terraces within its atrium as well as gardens around the building. Wells accessing an aquifer allow the use of underground thermal storage. Further PV panels on the roof and on neighbouring rooftops allow the building to be a net energy producer.

While the building accommodates around 2 300 employees, it does so with only 1 000 desks using the concept of hot-desking, where employees are assigned different desks based on day-to-day requirements. This is where the building's smart technology comes into play: employees interact with the building through a smartphone app where they can enter their personal preferences for temperature, lighting and even coffee. A range of different work and social environments can be selected according to the work needs of the individual at any given time. Connected LEDs and sensors then allow the building to customise the environment to that individual's preferences.

Overall, the Edge uses 70% less electricity than a typical office building. The Edge shows how improved building design can enhance occupant comfort while reducing energy consumption and providing cost savings.

Sources: BRE (2017), "The Edge, Amsterdam"; IEA (2016c), *World Energy Outlook 2016*; Randall, T. (2015), "The smartest building in the world".

Innovation in digital technologies, big data and the Internet of things.

Digitalization will permeate the energy system as a result of continuous innovations in information and communication technologies (ICT), cloud computing technologies, big-data analysis and mining technologies, intelligent wind turbine technologies, etc. At the same time, applications of innovatively distributed digitalised trading technology, such as emerging blockchain technology, will make it possible for distributed energy to be independent from the centralised trading system in the future. This will lay the foundation for energy transactions at the community level, city level and beyond.

The role of technology innovation

Technology and innovation remain ongoing in the energy sector (e.g. renewable energies or oil and gas production from shale). Distributed energy presents numerous windows of opportunity for innovation. On the one hand, exploring new energy resources, such as hydrogen, still requires continuous technology innovation and breakthroughs. The commercialisation of emerging technologies will certainly challenge existing business models. In the near future, there is great potential that this will occur in fields such as hydrogen fuel cells and energy storage.

On the other hand, natural gas, solar energy, wind energy, HPs and other technologies will continue to progress. On a different level, there is substantial improvement in the smart integration of energy systems, including sensors, data analytics and control software.

Technological innovation constitutes a key driver of energy system development, which continues to change the energy system of today and shape the energy landscape of the future. Modern DES have been enabled by technological innovation. As an innovation-friendly system, distributed energy is well placed to contribute to an energy transition. Novel business models provide support and promotion for technological innovation, and they also contribute to

extending the application of technological innovations. Technological change and business model innovation can reinforce and support each other.

Business models for DES

Based on the three development trends introduced in Chapter 1 (customer preferences, energy services and digitally enabled connectivity), different categories of business models can be identified. The first reflects a situation where energy consumers become an active part of the energy system – a hybrid between consumers and producers, referred to as prosumers. The second is linked to the model of energy service companies (ESCOs), which shift the focus away from supplying a commodity and towards providing a service. The third trend – digitally enabled connectivity – leads to an enhanced version of the first two: a direct interaction between prosumers via energy transactions that are peer-to-peer based and a smarter provision of energy services by exploiting big-data applications.

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Prosumer model

Distributed energy allows for smaller investments and shorter construction periods compared with the centralised system. Moreover, it can apply modular design to meet energy needs of various magnitudes, from households to communities and industrial parks.

This allows new players to enter the business of energy provision. More and more businesses and households have the option to meet part of their energy needs directly with their own generation.

The main business model underpinning this deployment is savings from energy normally supplied via the centralised system and remuneration of surplus energy that is fed into the grid. Consequently, the feasibility and sustainability of the prosumer model is directly linked to a) the design of electricity prices; and b) the remuneration provided for excess electricity.

Electricity prices

Historically, retail electricity pricing was developed on the assumption that customers did not have any alternative to grid supply. Moreover, it was assumed that electricity demand was relatively inelastic, in particular in the short term, with customer consumption declining only modestly in response to rising prices. In this context, primarily volumetric price recovery was applied, whereby a single per-kilowatt-hour (kWh) tariff charge was designed to recover most or all network and energy costs, including the supplier margin and energy taxes. Inclusion in the volumetric retail price of certain cost elements that do not scale directly on a per-kWh basis, such as network reinforcement costs, was justified by the assumption that users with the highest consumption had the largest impact on overall system costs (IEA, 2017c).⁴

A growing number of end users now have an alternative to grid supply, and they use retail tariffs as a reference to make investment decisions. As the cost of distributed energy resources (DER) continues to decline, uptake will continue to rise. This could become even more relevant in the coming decades if solar PV becomes integrated into building materials, further lowering the additional cost of new installations that coincide with the construction or renovation of buildings.

Increases in distributed solar PV tend to lead to higher levels of self-consumption, and thus lower network flows and, in the absence of tariff reform, lower associated revenues for the grid owner.

⁴ Please note that this section is derived from a discussion found in IEA (2017c), *Status of Power System Transformation 2017*.

Over time, this could translate into higher per-kWh prices for grid consumption for those who do not adopt DER, as the burden of network cost recovery is divided over a shrinking group of customers.⁵

At low penetrations, this effect is likely to have a marginal impact on retail prices (LBNL, 2017). As DER uptake continues, however, this situation raises questions about distributional fairness among different end users, and may lead to a spiralling uptake of DER as ongoing increases in grid supply price continue to improve the economics of self-supply. In addition, sector coupling will link economic signals from other sectors with those of the electricity sector, and make it possible to meet a certain energy service using various sources. For example, a gas-fired CHP generator may dynamically adjust its electricity and heat output according to the price of each commodity and may even choose to generate heat using electricity via an electric boiler. This increases the need for a level playing field among the different resources, whereby energy services are priced similarly and are subject to similar taxes and levies (IEA, 2017c).

As DER generation options become cheaper, retail prices should be designed to provide fair and appropriate incentives to both network users and DER (IEA, 2016e). With modern ICT systems and emerging valuation methodologies, it becomes possible to calculate in greater detail the actual value of a given kilowatt hour of electricity consumption at a specific time and place. The deployment of smart meters makes it possible to communicate this value to end users and use data measurements at more regular intervals to apply them in the billing process. Price signals that accurately capture the impact on overall system cost give a stronger incentive for demand, shaping when and where this is most valuable to the power system.

Remunerating grid injections

The methodology for compensating DER, in particular DG, is a strong driver for uptake of these technologies. Traditional compensation mechanisms, such as net energy metering, were designed on the supposition that the grid can act as a buffer for the differences in timing of electricity production and consumption of individual households. Household production and consumption are brought together on the final electricity bill. Under net energy metering, localised electricity production is implicitly valued at the rate of the variable component of the retail tariff, as the household can bank production both within and between billing periods (IEA, 2016e).⁶ Net billing applies a similar method, whereby injected surplus electricity is deducted from the electricity bill at a predetermined rate. In jurisdictions where a large proportion of retail tariffs consist of volumetric rates, net energy metering has come under pressure as DER owners are able to disproportionately offset their contribution to network cost. A third compensation mechanism for DER is the feed-in tariff. In this arrangement, all electricity injected into the grid is compensated at an administratively determined rate.

Many jurisdictions are shifting to other, value-based compensation for decentralised generation. Methods for such value-based compensation for DER generally fall into two categories. The first category involves taking a snapshot of current DER value, and then providing a long-term compensation guarantee based on that. A value of solar (VoS) tariff assigns fixed-price tariffs based on an assessment of value components, including energy services, grid support and fuel

⁵ It is important to note that the full benefits of distributed solar PV resources are often not realised for many years. While distributed solar PV may lead to immediate-term utility revenue losses, short-term rate increases may be followed by longer-term decreases (resulting from, among other things, deferred or avoided investment costs). Thus, it is important to consider the impact of these resources from both a short-term and a long-term perspective.

⁶ Under net energy metering, banked kilowatt hour credits may eventually expire. When this occurs, they are deemed “net excess generation” and are typically credited to the customer at a predetermined rate, usually set between the avoided utility wholesale energy cost and the retail electricity rate.

price hedging, among others. Minnesota became the first US state to adopt a VoS tariff, with a 25-year inflation-indexed tariff that was determined through cost-benefit analysis and an extensive stakeholder consultation process (Farrell, 2014). The second category of value-based DER compensation involves more granular DER tariffs that reflect market conditions at specific times and locations. Adding price variability based on time and location can contribute to lower system costs by sending appropriate price signals to DER customers.

In developing the system towards a prosumer-friendly arrangement, it is critical to also consider consequences for utilities (Box 2.3).

Box 2.3 • Sacramento Municipal Utility District

California has a strong history of distributed energy and renewable energy support, with state tax credits supporting wind farm development as far back as the 1980s. More recently, California has particularly supported distributed renewables, with the Energy Commission's Emerging Renewables Program. The high penetration of solar in particular in California has led to challenges for the electricity system, with high solar generation reducing net demand in the middle of the day and creating steeper ramp rates between daytime demand and the evening peak. This also results in curtailment of solar energy in the middle of the day, reducing its contribution to emissions savings.

Promoting DER including battery storage and demand response is a key strategy for addressing these challenges. However, the increase in customer- or third-party-owned DER is also a challenge to the business models of incumbent utilities. These resources can create the risk of stranded assets as well as altering the amount and type of the utility's investment needs. The Sacramento Municipal Utility District (SMUD), a community-owned not-for-profit utility providing power to the Sacramento region since 1946, exemplifies this. SMUD estimates that its customers are currently spending between USD 150 million and USD 200 million per year on DER, which outstrips the utility's own expenditure on centralised renewables to meet California's 50% renewable energy target. The challenges of incorporating DER also come with opportunities for customer engagement, offering new products and services, and capturing the benefits of DER.

In order to prepare for increasing levels of DER into the future, SMUD performed an integrated DER planning study to develop a procedure so that the utility could better take into account DER in its own planning and operations.

DER present a set of challenges for utilities relating to the fact that they connect to and have significant impact on the distribution grid, but are not typically under the control of the utility, from either a planning or an operational perspective. As the question arises of whether DER can and should be controlled in a more aggregated manner, it is not certain whether this role falls to the utility or may belong to a new entity such as a third-party aggregator.

The utility is thus faced with challenges relating to how to fulfil its traditional responsibilities, ensuring the safe, affordable and reliable provision of power, in the presence of increasingly significant grid resources that it does not directly control. SMUD's integrated DER (iDER) study is an important attempt to address these challenges while embracing the benefits that DER can offer to the network. The iDER planning study had five main objectives: to forecast DER adoption at the individual customer level, to model the most significant impacts on the distribution system, to quantify the impacts of the growth at the bulk system level, to estimate the net cost/benefit to SMUD of each DER technology and to recommend a more holistic DER planning process across all utility departments, to break down organisational silos. The iDER approach thus addresses the need for utility operational and planning decisions to take into account distributed resources, and begins to address institutional barriers within the utility that inhibit this approach.

The regulatory environment of California is a key enabling factor behind the iDER study. The state has a renewable portfolio standard requiring 33% renewable energy by 2020 and 50% by 2030 that includes incentives for DG. An important aspect to consider is that SMUD is a vertically integrated

utility, owning a combination of generation, transmission and distribution assets as well as managing the retail relationship with the customer. While many power sectors around the world have undergone restructuring in order to introduce competition in the generation and retail segments, there are some planning benefits associated with vertical integration since both control and impacts across the entire electricity sector from generation to retail are within the domain of a single entity.

The integrated DER study performed by SMUD is founded on integrated resource planning, an approach that is generally found within integrated utilities only. This case study is helpful in demonstrating the potential for an integrated approach taking DER into account along with centralised technologies; however, it is to be expected that additional challenges may be faced applying lessons to unbundled industries. Challenges are likely to exist relating to the need to interface between regulated and competitive market segments and due to costs and benefits associated with DER accruing in different parts of the electricity sector.

Sources: SEPA and Black & Veatch (2017a), *Beyond the Meter: Planning the Distributed Energy Future*, Volume I; SEPA and Black & Veatch (2017b), *Beyond the Meter: Planning the Distributed Energy Future*, Volume II.

ESCO models

Under this model, distributed energy developers sell energy products and services to final end users through a power purchase agreement or an energy services contract. Distributed energy actors engage in closer contacts with end-use customers, can provide flexibility to the grid and implement an energy service approach. A distributed energy project owner can create an energy service agreement either through shared savings or guaranteed savings contracts. Under a shared savings contract, the costs and savings are split with a predefined percentage. Under a guaranteed savings contract, the ESCO guarantees a certain level of energy savings. ESCOs focusing on efficiency, CHP and heat tend to form a distinct group relative to those focusing on DR aggregation.

The success of ESCO models heavily relies on market mechanisms, in which energy savings, ancillary services and remuneration coming from additional sources (such as renewable certificates) can be bought and sold. Moreover, ESCOs may establish contracts with multiple parties. For example, they can enter into the partnership with power and gas utilities to mitigate project risks. They can also benefit from the flexibility of collaborating with equipment manufacturers or technology providers to reduce up-front investments and operational costs. They can initiate a risk-sharing and benefit-sharing mechanism to allocate the incentives of increasing renewables to the power network operators.

Box 2.4 • Use of energy performance contracts, Suzhou, Jiangsu province

Energy performance contract (EPC) is a business model wherein an ESCO commits to an energy savings target with an energy user. The ESCO specialises in improving energy efficiency through design, construction, operation and maintenance. The energy user shares a certain percentage of energy savings with the ESCO. Broad, a Chinese company, proposes a series of flexible business models in EPC involving partial investment, total investment and equipment leasing. Broad applied the model of Design-Build-Finance-Operate (DBFO) in the project located at the industrial park of Suzhou city. The project entails recovering the excess heat of a co-generation power plant for DH use, and providing cooling services from steam using absorption chillers. The pipe network covers an area of about 11 square kilometres, with annual cost savings of USD 0.6 million (RMB 4 million).

Source: Broad (2017), 远大 EMC 案例 [Energy Management Contract Case Study of Broad Group].

A variation of this model can be found in the adoption of public-private partnerships (PPP). In this arrangement, private and public entities share the risks and benefits of a project, allocating risks to the party that is best placed to handle them.

Box 2.5 • PPP models

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PPP models engage the public sector as a project stakeholder, and thus reduce the regulatory risks and bottlenecks in third-party access, attracting private investments to the distributed energy market. The success of the PPP models results from allocating the tasks and risks to those parties best able to manage them. Government, the private sector and public utilities create an ownership of long-term energy transition. An integrated structure will make it easier to some extent to look at the energy system as a whole, not just one energy source. PPP models facilitate identification of system opportunities and challenges for enabling the viability of sound business models. They also help address market barriers relating to project boundaries, ownership and responsibilities, thus providing incentives to promote system-wide energy efficiency. As the rule-makers, governments can design the prerequisite requirements for the distributed energy access to transmission networks, according to the specific circumstances of the local region. If the local government can directly participate in the project investment, it can effectively remove the obstacles to the development of distributed energy. Local governments can also supervise infrastructure operators and distributed energy suppliers to negotiate contracts on their own terms.

China's traditional utilities are the main stakeholders of energy efficiency obligation or emissions reduction obligation. They have the incentive to work with third-party distributed energy providers to achieve clean and efficient transformation of energy products and services. In PPP models, the traditional utilities and distributed energy suppliers need to negotiate through the agreement. The key is how to divide costs and benefits.

Given various factors, distributed energy investors may face financing pressures in the long payback period. In PPP mode, the government may provide guarantee funds or risk-sharing facilities, allowing the project company to access low-interest commercial loans. In addition, the government can support the project with fiscal measures, such as value-added tax rebates. Some incentive programmes such as emissions allowances and renewables certificates can also work as collateral to reduce the lender's risk and facilitate access to finance.

Depending on which partner is responsible for owning and maintaining assets at different stages of the project, PPP agreements could take many forms, such as Build-Own-Operate (BOO), Build-Operate-Transfer (BOT), DBFO and Build-Lease-Operate-Transfer. The BOO and BOT are the most common models. With the BOO model, the private-sector partner finances, builds, owns and operates a utility project in perpetuity, while under the BOT, the private-sector partner is granted authorisation to finance, design, build and operate a utility project for a specific period of time, after which ownership is transferred back to the public-sector partner.

Source: Wadedwer and Patil (2015), "Comparative study between PPP mode of contracts and EPC mode of contracts".

Digitally enabled connectivity-based models

Adding digital technology into the distributed energy picture allows for innovations in both of the models discussed above. To understand the impact of digital, it is useful to consider an analogy with business models used in the Internet economy.

Links to the Internet economy

Digitally enabled connectivity has a number of similarities with the properties of the Internet. These similarities can enable new business models that rely on principles also employed in Internet services.

- **Peer to peer:** DES, as well as the Internet itself, have multi-source and multi-terminal characteristics. These allow for direct peer-to-peer connections. With the Internet, these allow two-way communication of information. By adopting a similar multi-source, multi-terminal approach in energy, DES can take advantage of peer-to-peer exchanges not only of data, but of energy. This opens the opportunity for prosumers to trade directly with each other.
- **Centrally optimised services:** A number of highly successful business models in the Internet are based on a centralised platform optimising the use of assets by integrating information across a vast number of users. For example, platforms such as Airbnb and Uber create value by using assets more efficiently, thanks to linking supply and demand in innovative ways. Similarly, navigation systems such as Waze integrate data from their users in real time to optimise traffic flows. This principle can be applied to energy, enhancing the value of services an ESCO can provide to consumers.

It is possible to combine aspects of both of these, for example where a central optimisation takes place in a smaller DES and these systems then exchange data and energy in a peer-to-peer fashion.

While the analogy between Internet applications and modern DES is often made, it should also not be overstretched due to clear differences between the two.

- **Different interaction mechanisms:** In daily activities, information is exchanged between people, between machines, between people and machines, and across different systems. Information is the starting point of this interaction, but also the result of this interaction, thus generating strong information demand. Put differently: information supply not only meets, but **creates** information demand. The exuberant vitality of the Internet economy indeed stems from this interaction. By contrast, energy exchanges are derived from surplus energy in different time and space dimensions. Therefore, the magnitude and quantity of energy exchanges are relatively limited compared with information exchanges.
- **Different marginal costs:** Once information is generated, it can be infinitely copied, thus the marginal cost of sharing can be zero, and the benefit is determined by the intellectual property and information value. However, energy does not have the same basic properties. Energy can be transformed, but cannot be copied. The marginal cost of energy is clearly greater than for information, which poses a challenge for energy sharing.
- **Different storage costs:** With the continuous improvement of computer hardware and software technologies, the storage cost of information is greatly reduced, and its marginal cost is near zero, which drives the surging development of big data and cloud computing technologies. By contrast, the cost of electricity storage is and will likely remain a barrier to its widespread adoption.

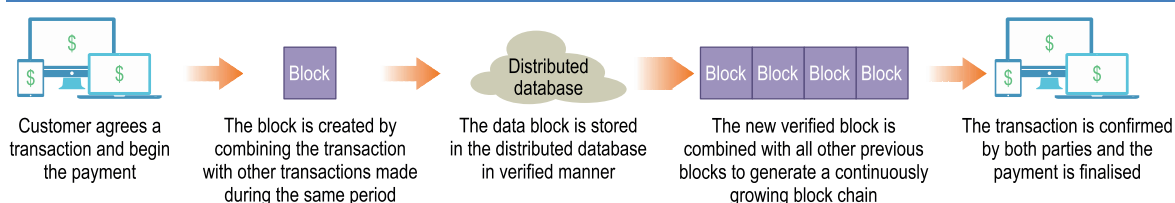
These differences notwithstanding, there are interesting parallels as the following discussion highlights. They include peer-to-peer transactions between individual devices and digitally enabled local optimisation of systems all the way to fully integrated, centrally optimised platforms.

Peer-to-peer energy and blockchain

The blockchain is essentially a distributed database. In real time, all transaction records are distributed to and shared by each client. Traditional centralised databases store data in a central server and only authorised users can access the server. Unlike these systems, the data in a blockchain system is replicated and distributed in a peer-to-peer network. All transaction participants can have a backup of the data blockchain and capture the information on current transactions. Moreover, modification of data needs to be verified by other users in the network, and the dataset is managed jointly by the parties involved in the transaction (Crosby et al., 2016).

Thus decentralisation is a basic characteristic of the blockchain. The market participants can carry out peer-to-peer transactions, and verify and save data through the blockchain without involvement of third-party credit institutions or intermediary structures. This not only simplifies the transaction process but also protects the security of transactions from malicious attacks. Moreover, the blockchain is built on one-way hash functions, meaning that each block in the blockchain contains the hash value of the previous time zone block, and all blocks are connected as chains. New blocks will only strengthen the previous blocks. The irreversibility of time ensures that any data modification is traceable. Any unilateral modification will be rejected because the dataset is shared in real time with all other end users. This improves the security of transactions. Based on these characteristics, various registration systems on monetary flows, financial assets and ownership certificates can be managed with blockchain technologies. This can enhance trust among the market participants, simplify the transaction process, reduce transaction costs and improve transaction efficiency.

Figure 2.10 • Illustration of blockchain trading system



Key point • Blockchain technologies allow transactions to be carried out securely in a distributed manner.

The future energy industry will face an increasing number of prosumers as a result of continuous expansion of DES, and they may desire to trade with other end users. Such transactions would be characterised by small size, high frequency and diversity of participants. Consequently, it is important to build a platform to facilitate and secure this large number of small transactions in a low-cost manner, which will be able to effectively improve the efficiency of distributed clean energy. For this, blockchain-based platforms are gaining increasing importance. The network structure of the blockchain is in line with the physical structure of DES. Meanwhile, its characteristics of decentralisation, transparency and security against modification can meet the requirements of distributed energy transactions, which are real-time, dynamic and dispersed. These automatic and peer-to-peer transactions need not rely on centralised power companies and other third-party intermediaries.

Box 2.6 • LO3's trading platform for distributed energy based on blockchain technology

In order to enhance the emergency preparedness to address large-scale power outages caused by natural disasters such as Hurricane Sandy, the state of New York launched a strategy called Reforming the Energy Vision (REV), which aims to address economic, environmental and security concerns of the power system through innovation. The main objective of the REV is to reduce greenhouse gas emissions by 40% by 2030 compared with 1990 levels, increase the share of renewables to 50% in New York, and reduce building energy consumption by 23% compared with 2012 levels. In order to achieve these targets, REV has proposed regulatory reforms including support for the clean energy market, launched the Clean Energy Fund to energise the market, and encouraged cutting-edge pilot projects through innovative technologies. The main solutions comprise increasing the use of renewables in the central system, improving energy efficiency and constructing DES to improve energy reliability.

Against this background, LO3 Energy has partnered with Siemens to present a microgrid solution and a blockchain trading platform for providing energy services in the Brooklyn borough of New York City, in the areas of Boerum Hill, Park Slope and Gowanus. End users in the microgrid can sell

electricity to the neighbourhood when their rooftop solar PV produces more electricity than they need. The transactions are settled with virtual currency using the blockchain. LO3 Energy completed its first peer-to-peer automatic transaction in April 2016.

The smart meter installed on the customer site can automatically record relevant data. Each transaction, enabled by the blockchain platform, is registered as a block and registered in the energy blockchain. The system uses the pre-defined intelligent contract and peer-to-peer transaction to realise automatic management and transaction recording at a lower cost. Energy pricing is determined by the highest price that consumers are willing to pay through an automatic auction. Moreover, the microgrid and blockchain trading platform in Brooklyn go beyond distributed energy transactions. In view of the damage caused by Hurricane Sandy in 2012, the project plans to install battery storage units in the grid in order to achieve the best allocation of power resources through automatic trading and management and ensure energy supply in the case of outage caused by natural disasters. The project is still in an early stage, involving about 50 end users with smart meters installed. The objective is to extend to 1 000 end users by 2018 and to gradually expand the coverage of the microgrid and blockchain trading platform to become part of more widely deployed smart city solutions.

Sources: NYS (2017), "Reforming the Energy Vision", website; Siemens (2017), "A microgrid grows in Brooklyn".

A number of blockchain projects have emerged over the past few years, such as the Brooklyn LO3 Energy microgrid project in the United States; the Adaptive Virtual Power Plant project developed by StromDAO, a German venture company (StromDAO, 2017); and an EV charging management system developed by Innogy SE, a subsidiary of German power group RWE (Lielacher, 2017). These projects have also received increasing attention from traditional power companies. For example, Conjoule GmbH, a start-up developing peer-to-peer energy markets powered by blockchain technology, recently got 4.5 million euros in a Series A funding round from Tokyo Electric Power Company Holdings and Innogy SE (Econotimes, 2017). However, a number of challenges exist with the application of existing blockchain implementations in the energy system (IEA, 2017f).

Centrally optimised systems

A principal advantage of digitally enabled connectivity-based business models is the ability to collect and analyse large amounts of data and to optimise the use of a vast number of assets accordingly. China is already seeing practical applications of this model; two examples are presented in more detail (Box 2.7, 3.1).

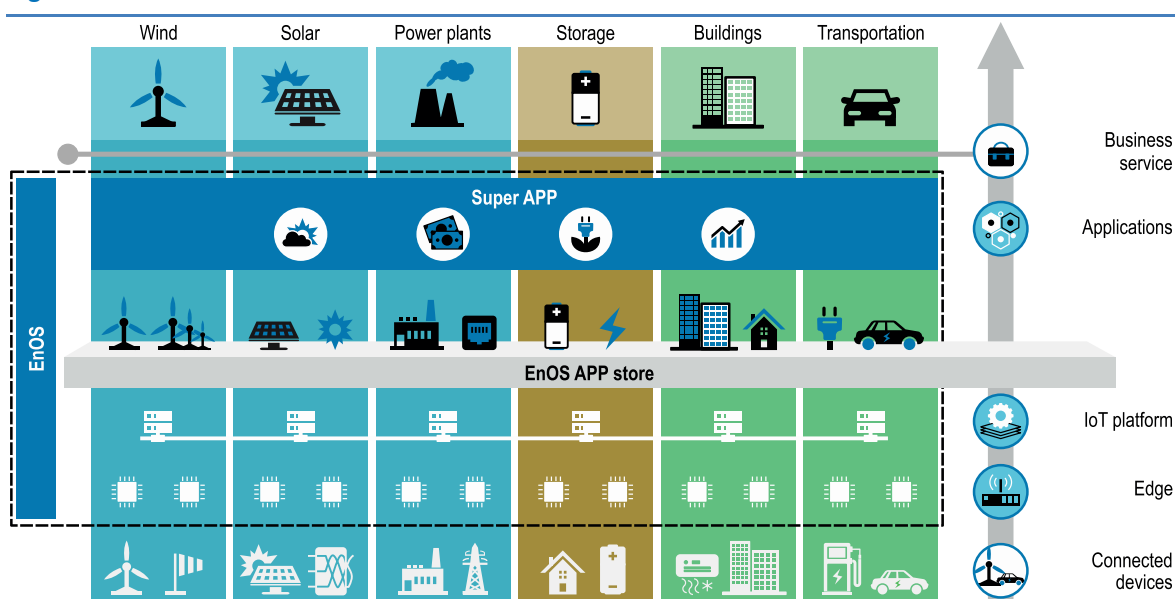
Box 2.7 • Envision's platform for Internet of things: EnOS™

Envision Energy is a large Chinese wind turbine manufacturer that has launched a data platform based on the Internet of things called EnOS in September 2016. It connects and manages various devices related to energy generation, consumption, storage, transmission and distribution through cloud computing and big data analytics. The objective is to make energy devices operate collaboratively at the level of each household, each community and even each city. Such optimisation can reduce power generation investments, monitor and manage load, and achieve supply-demand balance in response to the market dynamics.

The main benefit of this platform is its close integration and optimisation among different components of the entire energy system. It thus allows for the concrete application of the principles of smart DES. The platform has already been commercially implemented by utilities and other energy companies.

Source: Envision 2017, EnOS™ platform for Internet of Things.

Figure 2.11 • Illustration of EnOS



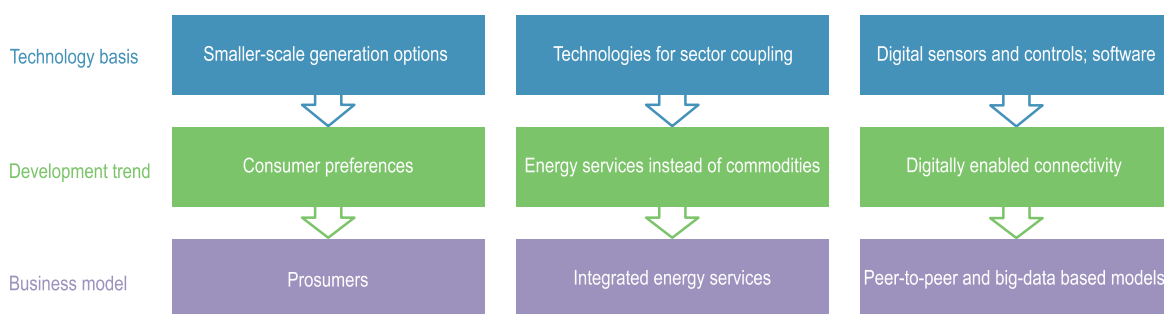
Source: Envision 2017, EnOS™ platform for Internet of Things.

Key point • The EnOS system connects and manages a wide range of both generation and end-use technologies in order to enable collaboration at the level of households, communities and cities.

Summary

This chapter has linked the three development trends outlined in Chapter 1 with the technological and economic building blocks to realise DES in practice. Three distinct technology aspects of modern DES underpin the different development trends. In turn, these lead to different opportunities for business models (Figure 2.12).

Figure 2.12 • Links between the technology basis, development trends and business models of DES



Key point • Technologies form the basis of DES, and these can be linked through development trends to the business models that can enable their deployment.

So far, the discussion has focused on analysing DES more generally. In order to derive analytical conclusions for the case of China, the situation of DER in China must be discussed more in-depth. This is the focus of the next chapter.

References

- Balmert, D. and K. Petrov (2010), "Regulatory aspects of smart metering", http://erranet.org/wp-content/uploads/2016/03/KEMA_Issue_Paper_Smart_Metering_FINAL_eng.pdf.
- BNEF (Bloomberg New Energy Finance) (2016), "Digital energy market outlook", www.bnef.com/core/insights/15297.
- BRE (2017), "The Edge, Amsterdam", www.breeam.com/index.jsp?id=804.
- Broad (2017), 远大 EMC 案例 [Energy Management Contract Case Study of Broad Group], www.broad.com/ProductShow-14.aspx.
- BSRIA (Building Services Research and Information Association) (2017), *World Renewables – Heat Pump Market*, BSRIA, Bracknell, England.
- BWE (Bundesverband WindEnergie [German Wind Energy Association]) (2012), "Community wind power", www.wind-energie.de/sites/default/files/download/publication/community-wind-power/bwe_broschuere_buergerwindparks_engl_10-2012.pdf.
- Crosby, M. et al. (2016), "Blockchain technology: Beyond bitcoin", *Applied Innovation Review*, No. 2.
- EC (European Commission) (2012), *Reduction of Legal-Administrative Barriers for PV System Installations in Europe*, <https://ec.europa.eu/energy/intelligent/projects/en/projects/pv-legal>.
- EC (2011), *Set of Common Functional Requirements for the Smart Meter*, https://ec.europa.eu/energy/sites/ener/files/documents/2011_10_smart_meter_functional_requirements_report_full.pdf.
- Econotimes (2017), "Japan's largest utility TEPCO invests in blockchain energy startup Conjoule", www.econotimes.com/Japans-largest-utility-TEPCO-invests-in-blockchain-energy-startup-Conjoule-796070.
- Encraft (2009), *Warwick Wind Trials Project Report*, www.microwindturbine.be/Rapportering_files/Warwick+Wind+Trials+Final+Report+%281%29.pdf.
- Envision (2017), EnOS™ platform for Internet of Things, www.envision-energy.com/energy-os.
- Euroheat&Power (2017a), "Country by country 2017: China", www.euroheat.org/publications/country-country-2017/.
- Euroheat&Power (2017b), "Country by country 2017: Executive summary", www.euroheat.org/publications/country-country-2017/.
- Farrell, J. (2014), "Minnesota's value of solar: Can a northern state's new solar policy defuse distributed generation battles?" Institute for Local Self-Reliance, Minneapolis, MN, <https://ilsr.org/wp-content/uploads/2014/04/MN-Value-of-Solar-from-ILSR.pdf>.
- GIZ (2016), *Cogeneration & Trigeneration – How to Produce Energy Efficiently: A Practical Guide for Experts in Emerging and Developing Economies*, www.giz.de/fachexpertise/downloads/2016-en-energy-cogeneration-trigeneration-guide.pdf.
- Gsänger, S. and J. Pitteloud (2015), "Small wind world report 2015", http://small-wind.org/wp-content/uploads/2014/12/Summary_SWWR2015_online.pdf.
- GWEC (Global Wind Energy Council) (2017), "Global wind statistics 2016", www.gwec.net/wp-content/uploads/vip/GWEC_PRstats2016_EN_WEB.pdf.

- Hui, J. et al. (2017), “Analyzing the penetration barriers of clean generation technologies in China’s power sector using a multi-region optimization model”, *Applied Energy*, Vol. 185/2, pp. 1809-1820, <https://doi.org/10.1016/j.apenergy.2016.02.034>.
- IEA (International Energy Agency) (2017a), *Market Report Series: Renewables 2017*, OECD/IEA, Paris.
- IEA (2017b), *World Energy Investment 2017*, OECD/IEA, Paris.
- IEA (2017c), *Status of Power System Transformation 2017*, OECD/IEA, Paris.
- IEA (2017d), *Energy Technology Perspectives 2017*, OECD/IEA, Paris.
- IEA (2017e), *Global EV Outlook 2017*, OECD/IEA, Paris.
- IEA (2017f), *Digitalization & Energy*, OECD/IEA, Paris.
- IEA (2016a), *World Energy Outlook 2016*, OECD/IEA, Paris.
- IEA (2016b), *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems*, OECD/IEA, Paris.
- IEA (2016c), *Medium-Term Renewable Energy Market Report 2016*, OECD/IEA, Paris.
- IEA (2016d), *World Energy Investment 2016*, OECD/IEA, Paris.
- IEA (2016e), *Re-powering Markets: Market Design and Regulation during the Transition to Low-Carbon Power Systems*, www.iea.org/publications/freepublications/publication/REPOWERINGMARKETS.pdf.
- IEA (2014a), *Linking Heat and Electricity Systems Co-generation and District Heating and Cooling Solutions for a Clean Energy Future*, OECD/IEA, Paris.
- IEA (2014b), *Heating without Global: Warming Market Developments and Policy Considerations for Renewable Heat*, OECD/IEA, Paris.
- IEA (2014c), *Technology Roadmap: Energy Storage*, OECD/IEA, Paris.
- IEA (2011), *Renewable Energy Markets and Prospects by Technology*, OECD/IEA, Paris.
- IEA (2008), *Combined Heat and Power: Evaluating the Benefits of Greater Global Investment*, OECD/IEA, Paris.
- IEA (2007), *Biomass for Power Generation and CHP*, OECD/IEA, Paris.
- IEA and Tsinghua University (2015), *Building Energy Use in China: Transforming Construction and Influencing Consumption to 2050*, OECD/IEA, Paris.
- IEA ETSAP (Energy Technology Systems Analysis Program) (2013), “District heating”, https://iea-etsap.org/E-TechDS/PDF/E16_DistrHeat_EA_Final_Jan2013_GSOK.pdf.
- IRENA (International Renewable Energy Agency) (2017), *Costing Alliance*, dataset provided to the IEA, IRENA, Abu Dhabi.
- IRENA (2012), *Renewable Energy Cost Analysis: Biomass for Power Generation*, www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf.
- Kelly, M. and R. Elberg, (2016), *Executive Summary: Global AMI Tracker 4Q16 Section 1, Research Report*, Navigant Research.
- LBNL (Lawrence Berkeley National Laboratory) (2017), “Putting the potential rate impacts of distributed solar into context”, LBNL, Berkeley.
- Lielacher, A. (2017), “Innogy charges new electric car fleet using Ethereum blockchain”, *Bitcoin Magazine*, 5 May, <https://bitcoinmagazine.com/articles/innogy-charges-new-electric-car-fleet-using-ethereum-blockchain/>.

- Moussawi, H., F. Fardoun and H. Louahlia (2017), "Selection based on differences between cogeneration and trigeneration in various prime mover technologies" *Renewable and Sustainable Energy Reviews*, Vol. 74, pp. 491-511, <https://doi.org/10.1016/j.rser.2017.02.077>.
- Moussawi, H., F. Fardoun and H. Louahlia-Gualous (2016), "Review of tri-generation technologies: Design evaluation, optimization, decision-making, and selection approach", *Energy Conversion and Management*, Vol. 120, pp. 157-196, <https://doi.org/10.1016/j.enconman.2016.04.085>.
- Moya, J.A. (2013), "Impact of support schemes and barriers in Europe on the evolution of cogeneration", *Energy Policy*, Vol. 60, pp. 345-355, <https://doi.org/10.1016/j.enpol.2013.05.048>.
- NBSC (National Bureau of Statistics of China) (2016), *China Statistical Yearbook 2016*, www.stats.gov.cn/tjsj/ndsj/2016/indexeh.htm.
- NEA (2016), 推进能源清洁高效利用, 促进热电联产健康有序发展-解读 (关于印发<热电联产管理办法>的通知) [Interpretation of Administrative Measures of Combined Heat and Power] http://www.nea.gov.cn/2016-04/18/c_135289349.htm
- NYS (New York State), (2017), Reforming the Energy Vision website, <https://rev.ny.gov/>.
- Olivares-Galvan J.C., E. Campero-Littlewood and S. Magdaleno-Adame (2016), "Review paper on wireless power transmission", *International Journal of Science and Research*, Vol. 5/2, <http://ieeexplore.ieee.org/document/6702725/>.
- Pitteloud J. and S. Gsänger, (2017), *Small Wind World Report 2017*, http://small-wind.org/wp-content/uploads/2014/12/Summary_SWWR2015_online.pdf.
- Randall, T. (2015), "The Smartest Building in the World", www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building.
- RenSMART (2017), "Solar PV comparison table", www.rensmart.com/Products/SolarPV.
- SEPA (Smart Electric Power Alliance) and Black & Veatch (2017a), *Beyond the Meter: Planning the Distributed Energy Future, Volume I*, <https://sepapower.org/resource/beyond-the-meter-planning-the-distributed-energy-future-volume-i/>.
- SEPA and Black & Veatch (2017b), *Beyond the Meter: Planning the Distributed Energy Future, Volume II*, <https://sepapower.org/resource/beyond-meter-planning-distributed-energy-future-volume-ii/>.
- Shaw, S. et al. (2008), "Status report on small wind energy projects supported by the Massachusetts Renewable Energy Trust", <http://archives.lib.state.ma.us/handle/2452/335409>.
- Siemens (2017), "A microgrid grows in Brooklyn", www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/smart-grids-and-energy-storage-microgrid-in-brooklyn.html.
- StromDAO (2017), website, <https://stromdao.de/innovation/start>.
- US DOE (United States Department of Energy) (2017), "Cost and price metrics for automotive lithium-ion batteries", US DOE, <https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf>.
- Wadedwer, A. and S. Patil (2015), "Comparative study between PPP mode of contracts and EPC mode of contracts", *International Journal on Recent and Innovation Trends in Computing and Communication*, Vol. 3/12.

- Weiss, W., M. Spörk-Dür, and F. Mauthner, (2017) *Solar Heat Worldwide*, www.solarthermalworld.org/sites/gstec/files/news/file/2017-06-02/solar-heat-worldwide-2017.pdf.
- Yan, B. et al. (2016), “Gas-fired combined cooling, heating and power (CCHP) in Beijing: A techno-economic analysis”, *Renewable and Sustainable Energy Reviews*, Vol. 63, pp. 118-131, <https://doi.org/10.1016/j.rser.2016.05.036>.
- Yaqoot, M., P. Diwan and T.C. Kandpal (2016), “Review of barriers to the dissemination of decentralized renewable energy systems”, *Renewable and Sustainable Energy Reviews*, Vol. 58, pp. 477-490, <https://doi.org/10.1016/j.rser.2015.12.224>.

Chapter 3. Development of distributed energy systems in China

The previous chapters introduce modern distributed energy systems (DES), describe their technical building blocks and give examples of business models for their commercialisation. In order to understand the prospects for modern, clean and efficient DES in the People's Republic of China (hereafter, "China"), a deeper look at the history of distributed energy in China is required. This chapter provides such more detailed background. Because the traditional approach to distributed energy has been different for natural gas-based systems and renewable energy, their histories are discussed separately. In a second step, the prospects of these technologies are highlighted. This is complemented by the status and prospects of related smart enabling technologies. The chapter concludes with an assessment of barriers to the adoption of modern, integrated DES.

History and status quo

The concept of DES in China

In the 1980s, combined heat and power (CHP), also called co-generation, was introduced into China as a prototype of distributed energy. With the government's policy support, CHP made great progress. But because of the higher price for natural gas and supply constraints, most CHP projects in China are coal-fired. Modern, clean distributed energy projects in China only emerged after 2000. The distributed energy stations in the Beijing Gas Control Centre and Guangzhou University City were the first typical gas DES. But there was no specific industrial policy on distributed energy in China before 2010.

After 2010, distributed energy, especially distributed gas and solar energy, grew much faster within the period of the 12th Five-Year Plan (FYP) (2011-15), and during this period a series of industrial policies on distributed energy was released. In October 2011, the National Development and Reform Commission (NDRC), the National Energy Administration (NEA), the Ministry of Housing and Urban-Rural Development (MOHURD) and the Ministry of Finance (MOF) jointly issued the Instructions on the Development of Distributed Natural Gas (DNG) (NDRC et al., 2011), which clarified the goals and supporting policies for DNG in China for the first time. In July 2013, the NDRC issued the Interim Measures for the Management of Distributed Power Generation (NDRC, 2013), in which the definition of distributed power generation was first established, and set out requirements on the construction, integration, operation, management, etc. of distributed power generation projects. In addition, the NDRC and other governmental departments have issued policies on distributed solar energy, dispersed wind energy, new energy microgrids, etc. Some local governments have also issued relevant supporting documents. During this period, although the term "distributed energy" had not been used directly, a series of concepts for energy supply and utilisation were developed that could be considered "distributed", including:

- **Distributed power generation.** An energy facility employing cascading energy use with power output that is installed at the user's site or nearby with most of the power that is generated consumed by the user, with the excess power being sold to the grid and balanced in a nearby distributed grid.
- **DNG.** A modern energy supply source that uses natural gas as fuel and is located near the demand centre. Its energy efficiency is above 70% due to heat-electricity-cold co-generation or other means.

- **Distributed solar photovoltaic (PV).** Solar PV that is located at the user's site or nearby with most of the power generated consumed by the user, with the excess power sold to the grid and balanced in a nearby distributed grid.
- **Dispersed wind power.** Wind power generated close to demand centres, connected to the local power grid rather than being transmitted over a long distance.
- **New energy microgrid.** This intelligent integrated energy utilisation network is based on a local distributed grid, uses multiple energy resources such as wind, solar and natural gas and has high new energy power penetration. It balances local supply and demand needs through energy storage (ES) and system optimisation and is able to interact with the public grid or run relatively independently as needed.
- **Hybrid energy system.** In China, two definitions of hybrid energy system are used now. One relates to an integrated energy supply system, which is based on the local environment and utilises various available traditional and new energy resources to satisfy the demand for electricity, heating, cooling and gas. At the same time it operates at a high level of efficiency. Typical technologies used include gas combined cooling, heat and power (CCHP), distributed renewable energy (DRE) systems and intelligent energy microgrids. The second type of hybrid system is located in areas with rich energy resources and a high demand. This system integrates the use of different resources such as wind, solar, hydro, coal and gas.

The introduction of these schemes and policies demonstrates the close attention China's energy sector has paid to distributed energy. They also reflect the flexibility of distributed energy and the various forms it can take. The advance of technology and innovative business models have given rise to a new concept of modern DES which emphasises the integration of diverse, clean supply options that can meet the demand for energy services in an efficient and innovative way.

Table 3.1 • Distributed energy-related policies in China

Title	Theme	Published by	Time
13th FYP on Energy	DP	The State Council	Dec. 2016
Energy Production and Consumption Revolution Strategy (2016-30)	DP	NDRC	Dec. 2016
13th FYP on Power, Natural Gas, etc.	DP	NDRC, NEA	2016
Some Opinions on Further Deepening Reform of Electricity Sector, and its supporting documents	R	The CPC Central Committee, the State Council	Mar. 2015
Some Opinions on Deepening Reform of Oil and Gas Sector	R	The CPC Central Committee, the State Council	May 2017
Interim Measures for the Management of Distributed Power Generation	IP	NDRC	Jul. 2013
Instructions on the Development of Distributed Natural Gas	IP	NDRC, NEA, MOHURD, MOF	Oct. 2011
Notification on Releasing the List of First-Round National Distributed Natural Gas Demonstration Projects	IP	NDRC, NEA, MOHURD, MOF	Jun. 2012
Implementing Rules on Distributed Natural Gas Demonstration Projects	IP	NDRC, NEA, MOHURD	Nov. 2014
Notification on Regulating the Management of Natural Gas Power Feed-in Tariff	IP	NDRC	Dec. 2014
Interim Measures on Distributed Solar Power Management	IP	NEA	Nov. 2013

Notification on Issues such as Giving Distributed Solar Power Subsidy Accordance to Power Generation	IP	MOF	Jul. 2013
Notification on Further Implementation of Distributed Solar Power Policies	IP	NEA	Sep. 2014
Notification on Promoting the Construction of Distributed Solar Power Demonstration Area	IP	NEA	Nov. 2014
Instructions on the Development and Construction of Dispersed-Connection Wind Power Projects	O	NEA	Nov. 2011
Guideline on Promoting the Construction of New Energy Microgrid Demonstration Projects	O	NEA	Jul. 2015
Trial Measures on Promoting the Construction of Grid-Connected Microgrid	O	NDRC, NEA	Jul. 2017
Notification on Releasing the List of New Energy Microgrid Demonstration Projects	O	NDRC, NEA	Mar. 2017
Instructions on Promoting the Construction of Hybrid Energy System Demonstration Projects	O	NDRC, NEA	Jul. 2016
Guideline on Promoting the Development of Internet-Plus Smart Energy System	O	NDRC, NEA, MIIT	Feb. 2016
Notification on Promoting Energy Storage Participating in Electricity Ancillary Services Market in the Three North Areas	O	NEA	Jun. 2016
Guideline on the Development of Electrical Vehicle Charging Infrastructure (2015-20)	O	NDRC, NEA, MIIT, MOHURD	Nov. 2015
Notification on Releasing the List of First-Round Hybrid Energy Demonstration Projects	O	NEA	Jan. 2017
Instructions on Promoting the Utilisation of Natural Gas	O	13 departments including NDRC, NEA, etc.	Jun. 2017

Notes: DP = development plan; R = reform; IP = industrial policy; O = other; CPC = Communist Party of China; MIIT=Ministry of Industry and Information Technology.

History and status quo of DNG

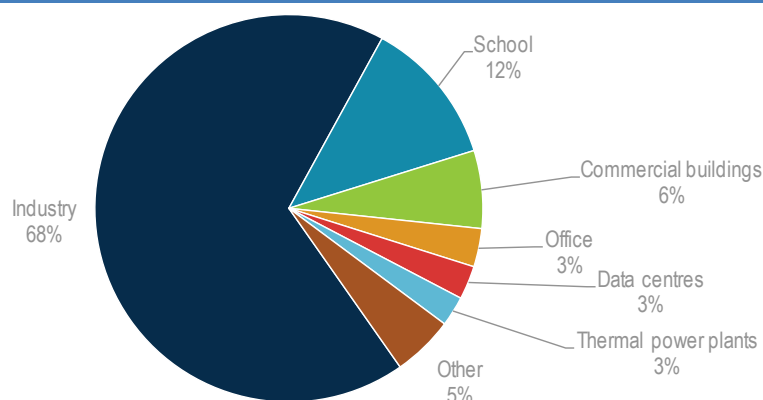
China's DNG development dates back to the late 1990s. Since 2003, when mainland China began to build distributed energy stations, it has constructed several DNG projects including the Dispatching Centre of the Beijing Gas building, Shanghai Pudong International Airport and the Central Hospital in Shanghai's Huangpu district. Over the past ten years, the Chinese government has continued to promote the development of DES with roughly 120 completed DNG projects in China at the end of 2015, having an installed capacity of about 1.4 gigawatts (GW). This figure is according to (incomplete) statistics of the NEA.

China's reform of its power system, the division of its government and corporate functions, the unbundling of power generation ownership from transmission and distribution (T&D) network companies, and the establishment of a power trading market platform, have all contributed to the development of DNG in China. The Chinese government has issued a series of policies to support the development of DNG. According to the 13th FYP for Energy Development (NDRC and NEA, 2016a), China will implement the Plan for Boosting Natural Gas Consumption. Sectors such as the residential use, power generation, transport and industry are the focus for raising the proportion of natural gas consumption; during the 13th FYP, it is expected to grow by 13%

annually, reaching 350 billion cubic metres (bcm) by 2020. According to the National Bureau of Statistics, national consumption of natural gas totalled 116 bcm in the first half of 2017, an increase of 13.5% year-on-year.

China's main users of DNG include industrial parks, commercial complexes, data centres, schools, office buildings, integrated parks and thermal power plants. These users are relatively large and have a continuous demand for cooling, heating and power. Projects that supply energy for these users account for 97% of total installed capacity in scale and 72.5% in number. Industrial parks have a relatively high installed capacity, taking up 67.7% of the total, with schools contributing 12.2% and commercial building complexes 6.5% (Figure 3.1). In China, projects for building cooling, heating and power as well as district cooling, heating and power each make up approximately half of the DNG projects. Because parks of various kinds and commercial complexes have a stable demand for electricity, cooling and steam, power is mainly provided by gas turbines or by combined cycle gas turbines. Hospitals, schools, hotels and office buildings have a smaller and less stable demand, so power is mainly supplied by gas turbines and gas micro-turbines.

Figure 3.1 • Proportion of installed capacity of types of DNG projects in 2015



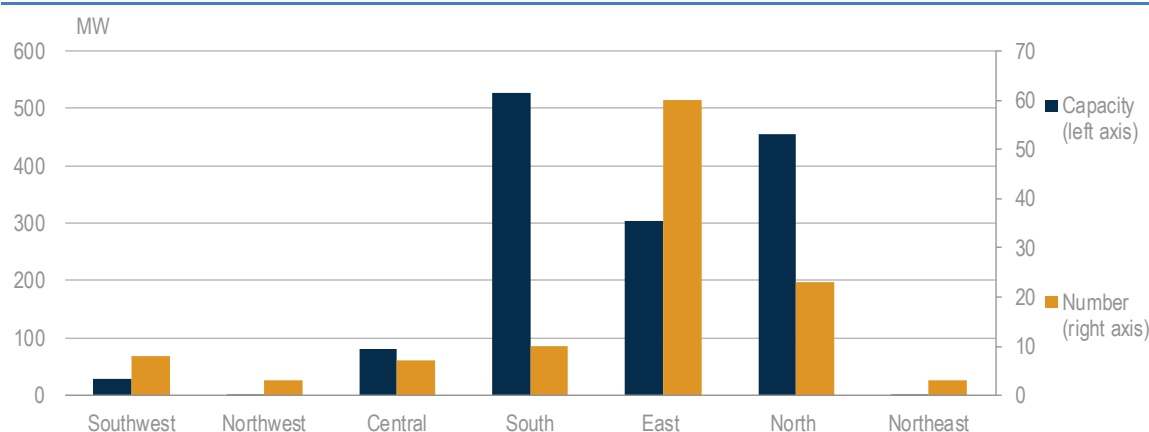
Source: Based on internal NEA data.

Key point • Industry accounts for the largest share of DNG projects.

Nationwide, at the end of 2015, South China, North China and East China took up the largest proportion of total installed capacity, roughly 92% altogether. While DNG projects in Central China, Northwest China and Southwest China were also gradually increasing, their proportion of the total remained relatively stable. Development among the regions was fairly unbalanced.

Compared to the total number of projects in China, DNG is relatively well developed in East China, North China and South China. Generating sets in these three areas account for 82% of the total number (Figure 3.2). DNG projects that are up and running are mainly located in large and medium-sized cities such as Shanghai, Beijing, Changsha and Guangzhou.

So far, China's DNG development has faced many problems, such as low profitability, problematic energy pricing mechanisms, incomplete supporting policies, difficulties in grid connection and grid access, and a lack of key technological breakthroughs. However, on-grid tariff policies and subsidy mechanisms are improving, and grid connection services are delivering, which will help to resolve the problems hindering DNG grid connection. Energy companies are now actively expanding the market for DNG.

Figure 3.2 • Installed capacity of DNG projects by region, 2015

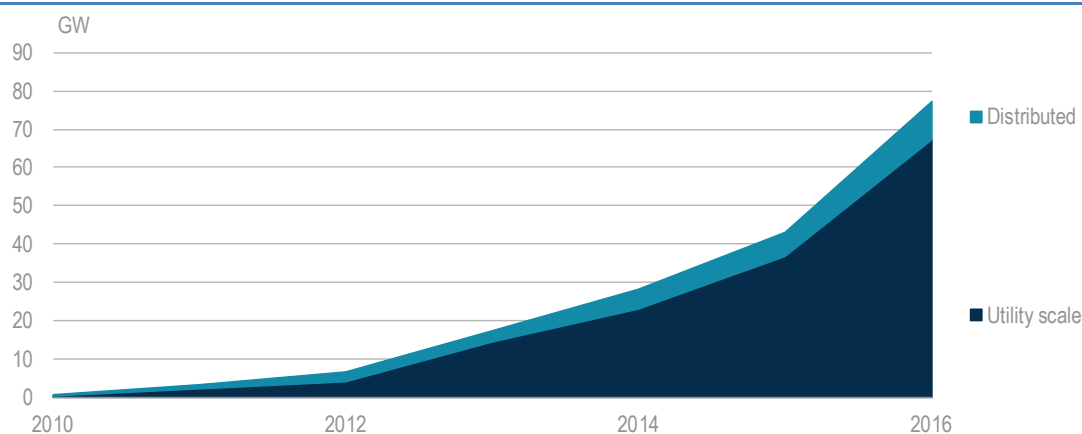
Source: Analysis based on NEA data.

Key point • The South China region has the largest amount of DNG capacity, while East China has the largest number of individual projects.

The status quo of DRE

Distributed PV

At the end of 2016, China's newly installed PV capacity reached 34.22 gigawatts (GW), ranking first worldwide for the fourth consecutive year. That same year, additional large-scale centralised power stations had a capacity of 30.48 GW and distributed power stations a capacity of 3.73 GW. The cumulative installed capacity was 77.42 GW, also the largest globally. Utility PV power stations had a cumulative installed capacity of 67.1 GW and distributed power stations 10.32 GW (Figure 3.3). The total annual generation was 66.2 terawatt hours (TWh), accounting for 1% of China's annual gross generation (IEA, 2017).

Figure 3.3 • Cumulative installed PV capacity, China, 2010-16

Source: IEA (2017), *Market Report Series: Renewables 2017*.

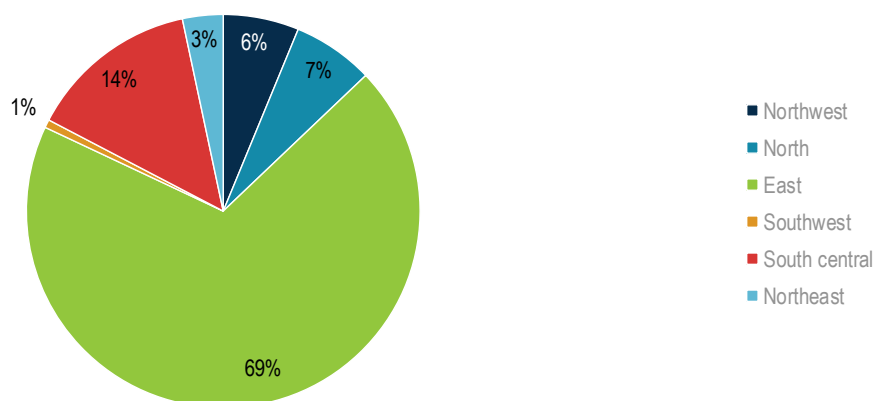
Key point • To date, utility-scale installations dominate Chinese PV.

Geographically, PV generation is shifting to the Central and Eastern regions. In regard to new PV capacity nationwide, 9.74 GW comes from the Northwest region, making up 28% of the total; the

capacity in other regions is 24.8 GW, accounting for 72% of the total. Nine provinces have increased their installed capacity by over 1 GW.⁷

In terms of scale, distributed PV (DPV) capacity is increasing at a faster pace than utility-scale PV. In 2016, newly installed capacity increased by 200% year-on-year. DPV power generation enjoyed very strong growth in the Central and East regions (Figure 3.4). Provinces that topped the list were Zhejiang, Shandong, Jiangsu, Anhui and Jiangxi.

Figure 3.4 • New DPV installations, 2016



Source: NEA (2017a), 2016 年光伏发电统计信息 [Solar Power Generation 2016 Statistics].

Key point • DPV projects are concentrated in the east of China.

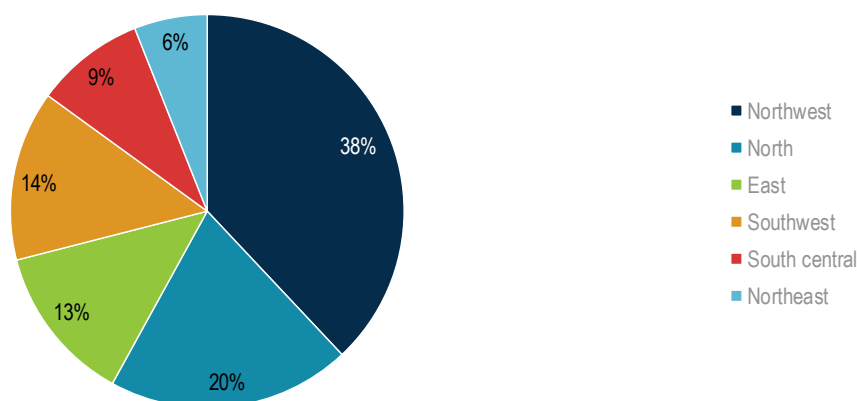
Wind power

Traditionally, wind power is used predominantly in very large-scale plants. However, efforts are under way to incentivise deployment on a smaller scale. The example of wind power is provided to highlight some of the challenges associated with a focus on highly centralised supply options and how a move towards more distributed solutions can help address the challenges of this technology. For wind power in the Chinese context, “distributed” refers to deployment patterns of smaller-scale groups of turbines, in contrast to large parks of several hundred megawatts (MW).

In 2016, China's newly installed onshore wind capacity was 18.71 GW, down by 42% year-on-year. The cumulative installed capacity reached 147 GW (IEA, 2017). After years of rapid growth, China's wind power market is entering a period of more steady development, maintaining its first place worldwide in installed wind power capacity. At the end of 2016, 30 provinces, municipalities, autonomous regions and territories (excluding Hong Kong, China; Macau, China; and Chinese Taipei) had established their own wind farms. There were 11 provinces or territories with a cumulative installed capacity between 1 GW and 5 GW and 12 provinces or territories with more than 5 GW (NEA, 2017b). Although wind power grid connection is becoming increasingly faster, problems still exist. Total capacity is concentrated in particular areas (Figure 3.5), resulting in the need to curtail wind generation at times of high production and reducing the incentive for further wind power development.

Since China entered its 13th FYP period, the national energy authorities have proposed synchronising centralised and distributed development and put forward relevant management methods. Some inland regions have begun to utilise local resources to plan for wind power developments, bringing new opportunities for small and medium-sized wind power investment enterprises.

⁷ Specifically, capacity in Shandong has increased by 3.22 GW, Henan by 2.44 GW, Anhui by 2.25 GW, Hebei by 2.03 GW, Jiangxi by 1.85 GW, Shanxi by 1.83 GW, Zhejiang by 1.75 GW, Hubei by 1.38 GW and Jiangsu by 1.23 GW.

Figure 3.5 • Total wind capacity in China by region, 2016

Source: NEA (2017b), 2016 年风电并网运行情况 [Wind Power Generation 2016 Statistics].

Key point • Total wind capacity in China is concentrated in the North and Northwest regions.

Solar water heater and heat pump systems

In recent years, China's solar water heater utilisation has been increasing in scale and has seen an expanding range of applications. This industry has created an entire supply chain consisting of material, product, craft, equipment and manufacturing. At the end of 2015, the collection area of solar thermal energy in China reached 440 million square metres (m²), and its annual production capacity as well as its end-use market each, on their own, made up more than 70% of global use. For many years, China has maintained its leading position in manufacturing of water heating systems as well as their utilisation in a wide range of end-use applications. There have also been technological breakthroughs in solar energy-based heating and cooling, as well as industrial and agricultural applications. The range of applications is expanding from domestic hot water to new diversified applications, including higher temperature heat applications.

China has significant potential for increasing the use of solar energy in cooling and heating during the 13th FYP. The Outlook for Solar Energy Development in the 13th FYP (NEA, 2016a) has clarified China's resolve to promote the extended use of solar hot water.

As one of the applications of DER, the development of solar water heaters and heat pump (HP) systems has gained increasing attention and support. In the future, industrial and agricultural demonstration projects will be carried out, such as solar drying, industrial hot water, aquaculture, greenhouse cultivation and greenhouse heating. This will accompany the construction of new energy demonstration cities and new energy industry complexes, as well as green energy demonstration counties and districts. Solar water heater and HP system utilisation thus have significant potential for further development.

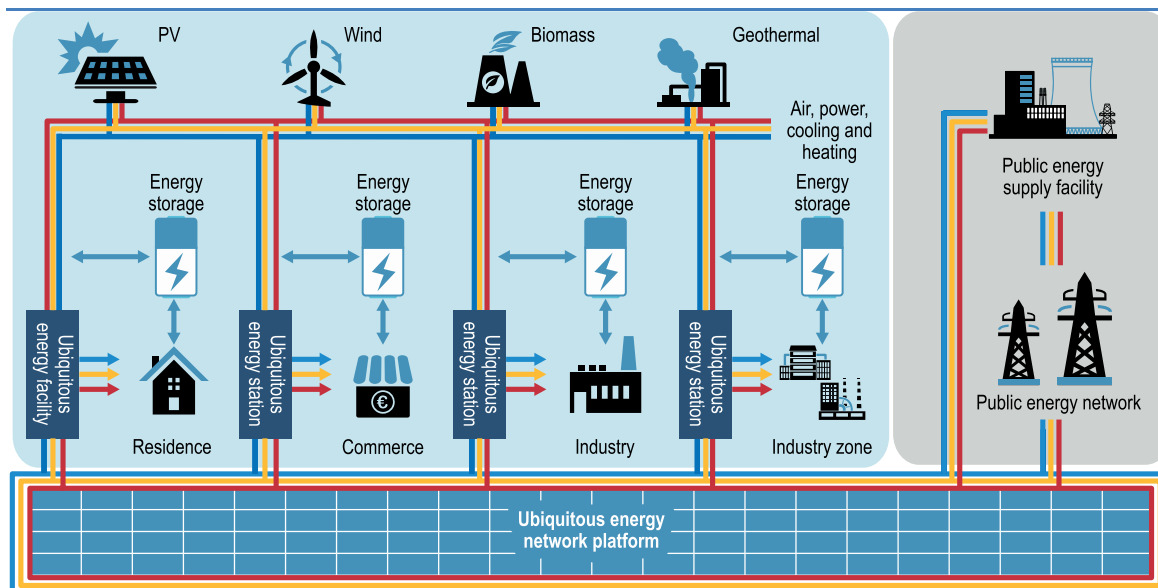
Biomass and waste

China covers a vast area with a large population, and its bioenergy resources are widespread. However, the availability of biomass varies across the nation. Almost half of the biomass resource is concentrated in provinces such as Sichuan, Henan, Shandong, Anhui, Hebei, Jiangsu, Hunan, Hubei and Zhejiang. By contrast, the vast northwestern regions and other provinces and territories have smaller shares. A forthcoming International Energy Agency (IEA) report, *District Energy Systems in China: Assessment Methodology and Business Models*, will examine the potential for solid biomass use in district heating in China.

At present, the development, technology and use of biomass energy in China still lags behind developed countries. However, according to the Outlook for Biomass Development in the

13th FYP (NEA, 2016b), the NEA plans to complete the commercialisation and large-scale use of bioenergy by 2020. The annual use of bioenergy reaches approximately 58 million tonnes of coal equivalent in the 13th FYP. The overall installed capacity of biomass electricity generation was 12 GW in 2016, and the total energy output was 64 TWh (IEA, 2017). Most of the total capacity is divided relatively evenly between agriculture and forestry biomass combustion and municipal solid waste, with a smaller contribution of around 0.5 GW from biogas power generation. The annual consumption of biogas will be 8 billion cubic metres (bcm), of liquid biofuels 6 million tonnes (Mt), and of biomass briquettes 30 Mt.

Figure 3.6 • Illustration of the Ubiquitous Energy Network



Source: ENN (2017), "Ubiquitous Energy Network"

Key point • The Ubiquitous Energy Network integrates an information network with physical energy facilities and loads, using big data and intelligent controls to enhance efficiency and facilitate system optimisation.

Box 3.1 • Energy optimisation and planning: Sino-German Eco-park project, Qingdao city, Shandong province

The Sino-German Eco-park project, located in Qingdao city, Shandong province, is a national demonstration project for multiple, complementary energy source systems in China. It also demonstrates a national renewable-based microgrid. The project covers a planned area of 11.59 square kilometres, incorporating industrial, commercial and residential facilities.

Rather than applying a traditional isolated planning method, the private energy company ENN has adopted an integrated approach to its planning, linking it closely with urban planning. The system layout is based on a centrally optimised energy system integration platform (referred to as an Ubiquitous Energy Network by ENN). The platform uses big-data analytics to explore the synergies of various energy end-users to integrate a variety of energy sources and thus include a set of complementary energy facilities. This approach enhances the overall value of the energy system by enabling the most effective configuration of loads, sources, networks and storage (Figure 3.6).

In the Sino-German Eco-park project, first, the demand side is optimised to reduce energy consumption and promote green buildings which integrate innovative ventilation and energy-saving technologies. Second, the project makes full use of local solar, geothermal and biomass resources, combined with ES technology to support the transition towards a low-carbon and efficient energy system. Third, the project ensures a dynamic balancing between supply and demand by considering the evolution of loads in the near, medium and long term.

In the short and medium term, ENN will construct pan-energy stations with the appropriate dimensions. In the long term, the project aims to connect various energy facilities and improve their interoperability to set up a pan-energy network. This will optimise overall operations and reduce investment and energy costs. At present, two pan-energy stations are in operation and are connected with each other. Upon completion of the project, the overall energy efficiency is expected to reach more than 80%, the renewable energy utilisation rate more than 20%, energy intensity 0.23 tonnes of coal equivalent per 1 500 United States dollars (USD), and a carbon intensity of 220 tonnes of carbon dioxide (CO₂) per million USD.

Source: ENN (2017), “Ubiquitous Energy Network”

Development potential

The development potential of DNG

Demand for DNG

In recent years, especially after the decrease of the natural gas gate station prices set by the government in 2015, DNG has seen more positive development. Though China’s economy has stepped into a “new normal” (a popular Chinese economic phrase referring to a slower pace of structural change), it still maintains relatively rapid growth, with growing energy consumption.

Users now demand a better quality of energy and have greater environmental awareness. This is an advantage for DNG. Newly developed projects apply DNG in industrial complexes, data centres, office buildings, hotels, airports and schools. Currently, China is still undergoing new urbanisation, with increased cooling and heating demand from consumers. For example, residents’ heating demand in the south during the winter months is gaining more attention. This growing demand could be satisfied by DNG in the future. In general, with the development of China’s economy and society, growing purchasing power and increased environmental awareness, DNG is expected to see further accelerated growth.

Summer cooling demand in the south can benefit the development of natural gas more broadly: increased summertime demand can help smooth seasonal demand variations. This benefit is particularly relevant because demand for heating peaks in winter in the north, with a lower demand in the summer months. Because of these weather extremes, the seasonal difference in gas demand in China is relatively significant.

According to the China Natural Gas Development Report 2017 (NEA et al., 2017), in 2016 the average demand in winter is 1.7 times the demand in summer. At present, gas storage in China is not sufficient to smooth this large demand difference, resulting in restrictions on gas field production in the summer. Since the demand for cooling peaks in summer, development of gas-based cooling has the potential to complement the demand for heating in the northern area. This could allow more consistent year-round gas demand and thus reduce the need for investment in storage facilities.

Natural gas resources and supply

China has both conventional and unconventional natural gas resources. According to IEA data, proven technically recoverable reserves in China at the end of 2016 totalled 5.44 trillion cubic metres (tcm). China also has diversified import channels, including the continental China-Central Asia natural gas pipeline (the overall transport capacity of its A, B and C branches reaches 55 bcm

per year), the China-Myanmar natural gas pipeline (transport capacity is 12 bcm per year), and the eastern coastal liquefied natural gas (LNG) receiving station. (In 2016, the LNG receiving station had an accumulated receiving capacity of 46.8 Mt per year, equivalent to 64.6 bcm per year.) The east line of the China-Russian Federation natural gas pipeline is also under construction. Assuming that current pipeline projects are completed on time, import infrastructure can thus support the increase of DNG consumption in the next few years.

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According to the Outlook for Natural Gas Development in the 13th FYP (NDRC and NEA, 2016b), the total supply of natural gas in China will reach over 360 bcm (domestic and imported). Storage and infrastructure can also contribute to the realisation of this goal. According to the plan, by 2020 the accumulated proven geological reserves of conventional natural gas will reach 16 tcm, shale gas over 1.5 tcm, and coalbed gas more than 1 tcm. The transportation infrastructure of main and supporting pipelines will amount to 104 000 kilometres, the mainline gas transportation capacity will exceed 400 bcm per year, and the accumulated working gas volume from underground gas storage will reach 14.8 bcm.

DNG technology and cost trends

Though China has had a relatively late start in manufacturing its own equipment, it has made much progress. Although domestic manufacturing is not a benefit per se, it can contribute to cost reductions, which are important for the future uptake of DNG technology. Chinese companies have begun to produce aero-derivative gas turbines and have been reducing production costs steadily over the years. The Chinese Academy of Sciences has also developed proprietary gas turbine technology in its Suzhou Jinji Lake programme (Yang, 2016).

The improving commercial model of DNG

After almost two decades of development, DNG has gradually created a diversified commercial model. First, many enterprises adopt a series of measures to mitigate the high price of gas and equipment. For example, measures such as selective optimisation, design optimisation and equipment-integrated optimisation can be applied to achieve a reasonable match between cooling, heating and power. Second, more enterprises choose joint participation with stakeholders to reduce the costs of gas supply and land usage, thereby improving the long-term stability of programmes. Third, many programmes provide networked energy supply by reaching out to local users, and maximising the efficiency of energy usage through digitalization. In this way, users can enjoy better energy quality, and the project's economic efficiency is increased. Improved business models are thus an important driver of DNG development.

Government support for DNG

The government's goal to raise the proportion of natural gas in total energy consumption creates a favourable environment for the development of DNG. The Outlook for Natural Gas Development in the 13th FYP (NDRC and NEA, 2016b) proposes four major projects, namely "Natural gas power generation and DER projects", "Gasification engineering of key regions in air pollution management", "Gasification engineering in transport" and "Increasing gas utilisation efficiency". During the 13th FYP period, the government "proposes to develop DNG and other highly efficient programmes, gradually build natural gas peaking power plants and promote CHP generation according to local conditions." At the end of the 13th FYP, in 2020, the installed capacity of natural gas electricity generation will reach over 110 GW, taking up more than 5% of the total installed capacity of all other energy sources. Many local governments have also issued supporting policies in order to reduce air pollution and increase energy efficiency.

Future DNG potential

The Guidance on the Development of Distributed Natural Gas published in 2011 by four ministries including the NDRC stated, “In 2020, China will promote the utilisation of DER in cities above the designated size, with an installed capacity of 50 GW, and preliminarily achieve DER equipment industrialisation.” Given the current installed capacity of DNG and the project pipeline, it is difficult to reach an installed capacity of 50 GW by 2020.

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By contrast, the 13th FYP on Electricity Power Development issued in 2016 (NDRC and NEA, 2016a) stated that China will promote the development of DNG, reaching an installed capacity of 15 GW by 2020.

The annual growth rate of natural gas consumption during the 12th FYP period was 12.4%. If natural gas consumption is estimated to reach 360 bcm at the end of the 13th FYP, the annual growth rate during these five years needs to reach at least 13%. It is expected that the targeted 15 GW capacity for 2020 will be achieved, since FYP targets are usually met.

However, the prospect of DNG development critically depends on achieving a smart, efficient and integrated deployment path. This means that better integration with other resources in modern DES may emerge as an avenue by which not only the target of DNG can be achieved, but the development of the energy system as a whole can be improved.

Box 3.2 • Development of residential fuel cell-based CHP business in Japan

In Japan, as of May 2017, more than 200 000 units of fuel cell-based micro-CHP systems, with the standard name ENE-FARM, have been installed for residential use. ENE-FARM consumes city gas or propane gas as fuel to produce around 700 watts of electricity and heat at the same time. ENE-FARM generates electricity by using electrochemical reactions of fuel cells. There are two types: the polymer electrolyte fuel cell (PEFC) and the solid oxide fuel cell (SOFC). Both types need hydrogen as a fuel, and hydrogen is reformed from city gas by the reformer in the fuel cell system unit. Household users can consume the electricity generated by fuel cells and exhaust heat is recovered as hot water, which is stored in the water tank and used for the kitchen and bathroom as well as floor heating.

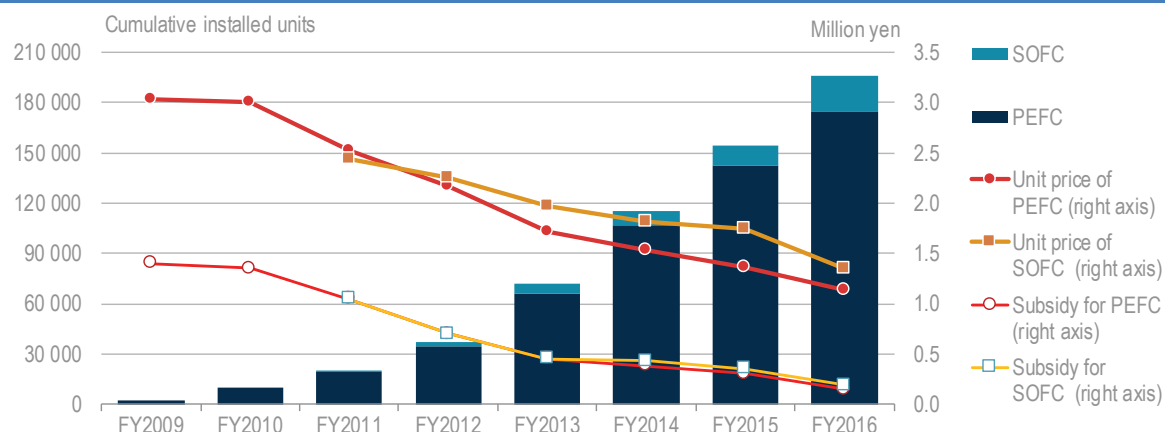
By generating electricity and heat in the same place for final consumption, energy losses such as grid loss and heat loss are much lower than for centralised systems, and total energy efficiency reaches more than 80% (of the higher heating value). This highly efficient energy usage results in lower CO₂ emissions and primary energy consumption than the combination of centralised gas-fired power generation and on-site hot water production using a gas boiler.

In 2009, ENE-FARM was commercialised as the first fuel cell-based micro-CHP system in the world. PEFC type ENE-FARM came onto the market from 2009 and increased rapidly to almost 180 000 units by the end of 2016. In 2012, the SOFC type ENE-FARM became available. The SOFC type generates electricity more efficiently than PEFC, with the latest model reaching around 50% efficiency, and the installed units have increased to around 20 000 units. As the production number has increased, the unit price has decreased dramatically from around USD 32 000 (JPY 3 million) in 2009 per unit to almost USD 9 000 (JPY 1 million) per unit in 2016. To promote ENE-FARM, the Japanese government offered a subsidy to reduce the customer's initial investment. As the market matured, the subsidy was decreased gradually, starting from almost USD 16 000 (JPY 1.5 million) per unit in 2009 and reaching around USD 140 (JPY 150 000) per unit in 2016. To make ENE-FARM a self-sustaining product without subsidy, further price reduction is required.

Hydrogen fuel cells generate zero emissions as a pollution-free and highly efficient energy source. However, the industry that is producing, storing and transporting hydrogen is still in the early stages of development. Thus, large-scale deployment of hydrogen fuel cell systems faces many challenges. At present, ENE-FARM relies on the existing urban gas system. The urban gas supplier

collaborates closely with equipment manufacturers in order to introduce hydrogen products and stimulate market growth. The gas utility is shifting away from serving as a single energy supplier to being a comprehensive energy products and services provider.

Figure 3.7 • Cumulative installed units, unit prices and subsidy, 2009-16



Source: METI (2017), *Current State of the Strategic Roadmap for Hydrogen and Fuel Cells*.

Key point • ENE-FARM fuel cells have seen rapid market development in recent years.

The development potential of DRE

DRE is seeing rapidly increasing demand and decreasing cost

In today's China, the benefits of using renewable energy are widely understood and embraced. Apart from industries and businesses, more and more households now consider DPV systems as a good option. With the implementation of the "PV poverty alleviation" project, PV systems are now also seeing deployment in rural areas (NDRC, 2016).

With the scale of development of PV and related technological advances, costs are dropping accordingly. China has been transforming from a major PV-manufacturing country into a country that drives global demand for PV. To some extent this is also true for wind power.

The development of renewable energy is strongly supported by the government

The Outlook for Solar Energy Development in the 13th FYP (NEA, 2016a) proposes that by the end of 2020, installed solar power capacity is set to exceed 110 GW. Of this, PV will make up over 105 GW (up from 43.18 GW at the end of 2015) and solar thermal power will contribute 5 GW. The collector area of solar thermal power utilisation will reach 800 million square metres (m²) of surface area. A recent reduced emphasis on solar thermal has resulted in a significant drop in demand growth in the last two years.

The Outlook for Wind Power Development in the 13th FYP (NEA, 2016c) proposes that by the end of 2020, the installed capacity of wind power grid connection is set to exceed 210 GW (in 2015, the number was 129 GW), of which offshore capacity will constitute over 5 GW. While typically installed at very large scale, the deployment of wind turbines in smaller groups and closer to load is gaining momentum in China.

Apart from wind power and solar energy, biomass energy and other renewable energy sources also fall within the range of DRE. However, considering its extensiveness, convenience and flexibility, DPV is currently the major part of DRE programmes and is well positioned to remain so in future.

Systems for carbon emissions trading and green certificates can promote the development of renewable energy

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In recent years, China has started pilot projects of carbon emissions trading and is planning to open a national carbon emissions trading market in 2017-18. China will “give priority to projects that are easier to start and successively open a carbon emissions trading market covering eight major industries, so as to guarantee a national carbon emissions trading market with well-established institutions, active trading, strict monitoring and high transparency” (YICAI, 2017).

In February 2017, three ministries, including the NDRC, published the Notice on the Trial Implementation of Renewable Energy Green Power Certificate Issuance and Voluntary Trading System (NDRC, MOF and NEA, 2017) establishing a voluntary subscription system of renewable energy green electricity certificates, and the trial issuance of green electricity certificates to wind power and PV enterprises. Voluntary subscription started on 1 July 2017.

The opening of the national carbon emissions trading market and the issuance of green electricity certificates can promote the development of renewable energy. Even though DPV generation is not currently included in the green electricity certificate system, overall improvements in the general environment for renewable energy are important to promoting a DPV system expansion.

Increasing DRE can help reduce the challenges of centralised renewable energy deployment

Despite the fast growth of China’s wind power and installed PV capacity, severe wind and solar energy curtailment still exists. In particular the “Three North Areas” (Northeast, North and Northwest China) are faced with the most severe wind and solar curtailment, where most capacity is in centralised installations. According to the NEA, in 2016 the amount of power loss caused by wind curtailment was 49.7 TWh, representing a rate of 17%; the overall solar curtailment volume in the first half of 2016 was 3.28 TWh, representing a rate of 19.7% in the Northwest area (i.e. Xinjiang, Gansu, Qinghai, Shannxi, Ningxia) (NEA, 2017c).

Against this backdrop, China is actively advancing DRE (mainly DPV systems), and has set itself ambitious goals. The Outlook for Energy Development in the 13th FYP (NDRC and NEA, 2016c) proposes that “DPV generation should serve as a priority. PV should develop in scale through enlarging diversified use of ‘PV plus’” (different PV utilisations). A key measure here is to promote rooftop DPV generation.

The government also encourages innovative DPV models. The Outlook for Solar Energy Development in the 13th FYP (NEA, 2016a) proposes that “DPV generation trading should be combined with electricity system reform. It is encouraged to construct PV power programmes in consideration of electricity power load.”

Predicting the potential of DRE

DPV will be the backbone of DRE during the 13th FYP Plan, and related documents have clearly stated its development goals in this area.

The Energy Development Outlook in the 13th FYP (NDRC and NEA, 2016c) places a strong emphasis on DPV, with 60 GW of the 110 GW goal for PV power generation in 2020 supplied from DPV. The Outlook for Solar Energy Development in the 13th FYP (NEA, 2016a) proposes to “establish 100 DPV application demonstration zones by 2020, in which 80% of newly built rooftops and 50% of existing

rooftops will be equipped with PV power generation facilities.” The DPV power generation target is thus more ambitious than the 45 GW target for centralised power plants.

According to the NEA, in June 2017, the total solar capacity in China reached 102 GW, including 84 GW of large-scale PV plants and 17 GW of DPV. Compared with large-scale PV, DPV lags behind in total capacity, but in the first half of 2017 new DPV installations were at 290% compared to the previous six months, while large-scale installations decreased by 16%. This illustrates that the potential of DPV has gained recognition across the industry.

By integrating DPV with other resources, including highly efficient co-generation facilities, it is possible to meet customer demand at very low levels of carbon emissions and at a competitive cost. Hence, the deployment of DPV could benefit from a more integrated approach as part of modern DES.

Status and potential of other aspects of DES

As highlighted in Chapter 2, modern DES rely on technologies that go beyond the generation options discussed so far but also include approaches to combine different energy resources into integrated solutions. They also feature components such as electric vehicles (EVs), batteries and other innovative technologies such as fuel cells. This section briefly reviews the status and potential of these options.

Battery electricity storage

ES is by far the world’s fastest-growing new energy industry. After more than a decade of development, China’s ES industry has stepped into an important phase of transitioning from demonstration applications to early commercialisation.

At the end of 2016, the installed capacity of China’s ES projects in operation totalled 24.3 GW, of which battery ES made up only 243 MW, with the vast majority coming from pumped storage hydro. Among battery ES, lithium-ion and lead-acid batteries dominated the picture. Lithium-ion batteries made up the biggest share at 59%, increasing by 78% compared with the previous year. In 2016, the installed capacity of newly built battery ES projects in operation was 101.4 MW, with a year-on-year rise of 299%. The installed capacity of new emerging battery ES projects in planning and under construction in 2016 was approximately 845.6 MW. It is also predicted that battery ES will maintain a high level of growth in the short term (CNESA, 2017).

Lithium battery technology is mainly applied to grid ES (e.g. electric support service, renewable energy grid connection, peak load shifting), base station backup, family solar storage systems and solar-powered EV charging stations.

In terms of the key applications in the ES market, the new increased ES installed capacity in the field of DES registered the highest year-on-year increase of 727%, followed by the 523% growth in renewable energy grid connection (CNESA, 2017). In terms of regional distribution, new battery ES projects are mostly located in Northwest and East China, and the main storage application is for microgrids.

On 22 September 2017, the NDRC, NEA and three other ministries issued Guidelines for Promoting the Development of Energy Storage Technology and Industry. The document stated that “user-side distributed energy storage systems should be encouraged. Entry criteria for deploying user-side energy storage systems should be laid down so as to guide and regulate the establishment of the system. Power companies with rights to manage distribution network and eligible residential users should be encouraged to install energy storage. Local consumption

ratios of DER and demand response should be improved so as to lower energy consumption cost. Exploration of relevant business models should be encouraged.”

EVs

In 2012, China published Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012-20), proposing that by 2020, China’s annual EV and plug-in hybrid EV production capacity would reach 2 million, with an accumulated production and sales volume over 5 million (SC, 2012). Transport electrification is featured as a key development strategy in China’s 2030 energy strategic planning.

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Currently, China is faced with an urgent situation in environmental and pollution management, as well as growing energy security challenges. As a result, both central and local governments have published a series of regulations and policies on EV technology development. With the government’s support, businesses are also vigorously advancing EV and ES technology, increasing the share of China’s EVs in the global market.

In the long run, EVs are enabling technologies for the substitution of petroleum demand. Although EVs have not yet been significant in the replacement of petroleum, with their rapid advance they will play an increasingly vital part in reducing China’s dependence on oil imports, thus improving energy security. At the same time, smart charging of EVs can improve the match between electricity demand and the availability of wind and solar power, absorbing potential production surpluses during particularly windy and sunny periods. The batteries inside the EVs are the main enabler for this. It is therefore very likely that China will play a critical role in the world’s fast-emerging field of EV and ES technology.

Hydrogen and fuel cells

In recent years, hydrogen-powered fuel cells have received increased attention from both the government and enterprises. For example, hydrogen-powered fuel cell technology has begun to be applied in the field of automobiles. Currently, there are four 35-megapascal hydrogen refuelling stations in operation in China, situated in Beijing, Shanghai, Zhengzhou and Guangzhou.

Currently, hydrogen is produced primarily from coal, coke-oven gas byproducts and natural gas. With the development of distributed systems and the fuel-cell vehicle industry, it could be produced mainly using renewable-based distributed energy (Box 3.3).

Box 3.3 • Challenges and opportunities of power-to-gas in Germany

Germany's renewable resources and energy consumption are unequally distributed over its regions. For instance, whereas Germany's wind capacity is mainly located in the north and northeast, electricity consumption is mostly in the south. Electricity generated by wind energy in the north has to be transmitted over long distances to the south (e.g. to the Rhein-Ruhr and Rhein-Main area), which causes bottlenecks in the grid.

Uniper, an international energy company based in Düsseldorf, is developing power-to-gas projects to test innovative approaches to using electricity, which may be supplied from renewable energy sources. Currently, Uniper has two power-to-gas pilot projects: WindGas Falkenhagen and WindGas Hamburg. Both projects generate hydrogen by means of electrolysis. In general, the hydrogen can be either directly used for industrial uses and transport or combined with CO₂ to produce methane, a fuel for power generation, heat supply and mobility (Figure 3.8). In addition to the two pilot projects, Uniper has a co-operation agreement with BP to examine the technical and economic feasibility of power-to-gas processes in refinery processes.

WindGas Falkenhagen

The plant is able to produce up to 360 m³ per hour of hydrogen from wind power (2 MW) through alkaline electrolysis. The hydrogen is fed into the natural gas pipeline. When renewable energy drives electrolysis, this is effectively storing and transporting renewable energy. According to Uniper, "WindGas Falkenhagen will enable the company to gain a greater understanding of the technical and regulatory challenges involved in the set-up and operation of such storage plants, and to acquire valuable practical experience for application in future multiple or larger installations." Within the framework of the European STORE&GO project, WindGas Falkenhagen will be extended by a methanation plant, which is expected to be ready in early 2018. This will demonstrate that "synthetic methane" can be also be injected into the existing gas pipeline network.

WindGas Falkenhagen demonstrates that renewable energy could be stored within the natural gas grid as the generated hydrogen is transported via pipeline to a connection point of the grid, where it is injected into a high-pressure transmission pipeline. This project shows that power generation can be decoupled from consumption to make it available as hydrogen or methane to other sectors including transport, industry and heat.

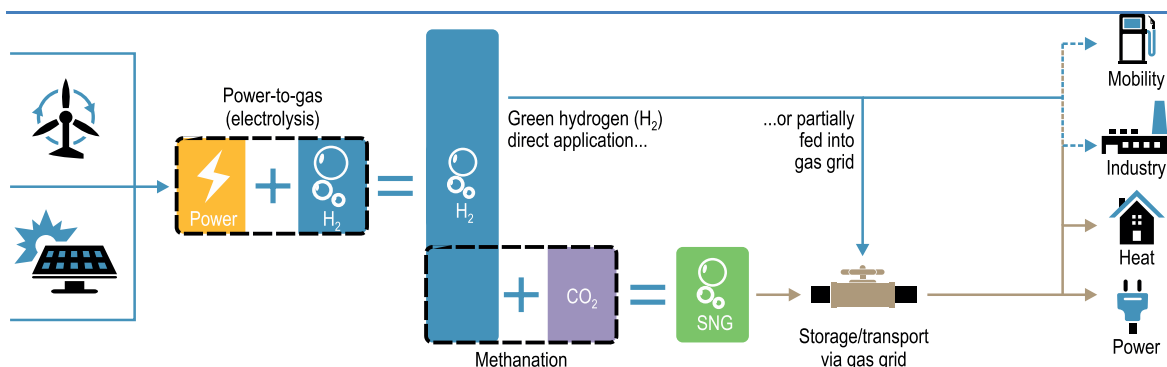
WindGas Hamburg

In October 2015, the WindGas Hamburg project was commissioned using a more efficient proton exchange membrane (PEM) electrolyser in comparison with alkaline electrolysis. PEM units are characterised by faster load dynamics and the capacity for temporary overload operation. Both these properties are advantages in power-to-gas applications.

Currently, PEM electrolyser units are commercially available only in the power input range of up to 100 kilowatts – the development of larger PEM electrolysers of 1.5 MW would be the next step, offering more efficient and economic power-to-gas solutions. Uniper is co-operating with SolviCore (development of the membrane electrode assembly) and Hydrogenics (constructing and packaging the complete electrolyser) to develop the larger electrolyser. Uniper Energy Storage is operating the prototype as part of the hydrogen injection plant and is responsible for the field trial. The project contributors also include the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt [DLR]) and Fraunhofer Institute for Solar Energy Systems ISE for scientific monitoring.

Although power-to-gas technology is available and usable and provides the option of structuring variable renewable energy, a legal framework should be developed to create a level playing field among the different clean technologies.

Source : Uniper (2016a), "BP and Uniper aim to harness 'green hydrogen' to produce fuels"; Uniper (2016b), "Power to gas"; Uniper (2016c), "Converting electricity from renewables to hydrogen"; Uniper (2016d), "Membrane electrolysis for power to gas plants".

Figure 3.8 • Main applications for the conversion from electricity to gas

Notes: H₂O = water; H₂ = hydrogen; CO₂ = carbon dioxide; SNG = synthetic natural gas.

Source: Uniper (2017), *Applications for the Conversion from Electricity to Gas*.

Key point • Production of hydrogen via electrolysis can be a way to generate synthetic fuels from renewables.

Integration of different energy sources

Recent years have seen the development of China's industrial parks, the popularisation of microgrids and new energy power generation, as well as the constant upgrading of investment models. While initial efforts focussed on technology, more recently finding suitable economic arrangements and business models is receiving equal attention. In 2016 the NEA started the construction of integrated projects that combine multiple complementary energy sources, as one of the key measures of establishing "Internet plus" smart energy systems. In late 2016, the NEA announced the first batch of 23 demonstration projects using multiple complementary energy sources and integrated optimisation, located in 13 provinces and territories. An example of such an integrated project is the Demonstration Projects on Multi-energy Complement and Integrated Optimization, in the Lize financial business district of Beijing.

Most of the demonstration projects are integrated energy supply systems for end users. Their designs and planning processes are now completed. However, because of programme complexity and other reasons, some are not yet in operation. In addition, demonstration programmes such as large-scale comprehensive energy stations in cities had appeared even before the concept of integration of different energy sources was put forward. These projects are also good examples of distributed gas turbine and energy cascade utilisation.

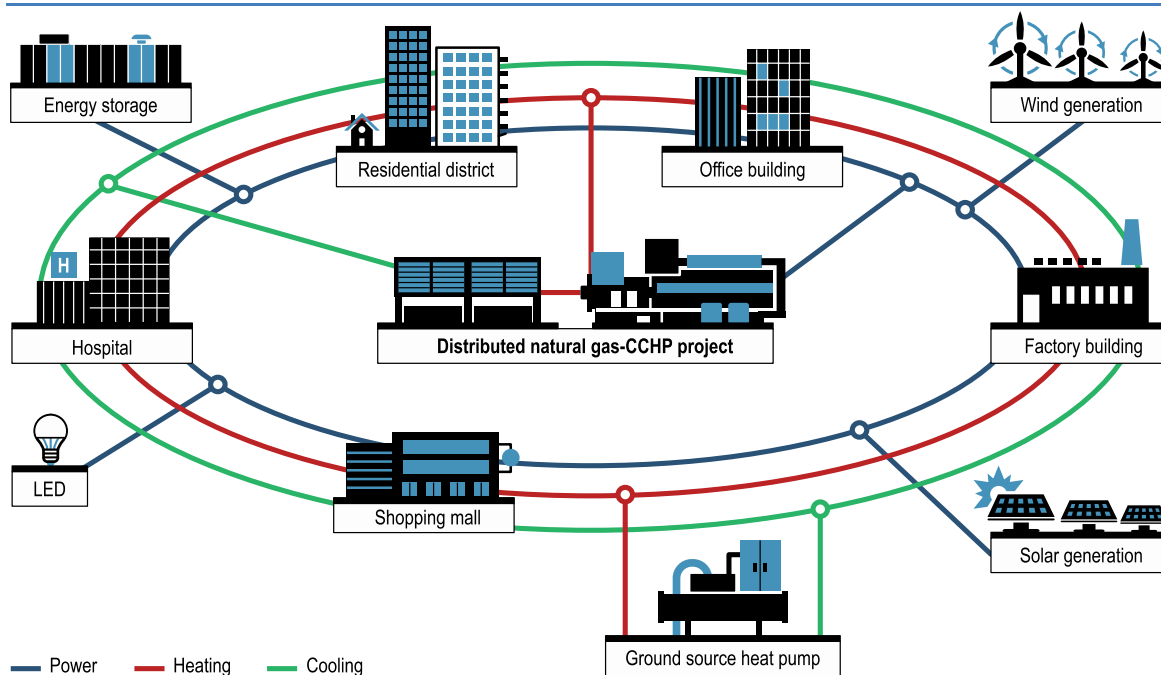
The integration of different energy sources can provide a flexible solution for meeting the energy needs of commercial and industrial complexes. While flexibility within an industrial complex is profitable for enterprises, this flexibility also improves the security and stability of China's energy supply for the larger grid. With the prospect of extensive new energy consumption, this flexibility can decrease the peak load requirements and support the frequency regulation of power grids (Zheng and Wenlin, 2017).

With the ongoing energy system reform in China, the power industry of the future is likely to embrace more ambitious electricity generating plans, accompanied by the emergence of a spot market and adjusted end-user electricity prices. Thus energy integration projects will play a greater role even beyond commercial and industrial complexes – in the field of large-scale energy supply. In line with other energy system reforms, the operational model based on siloed consideration of grid networks, heating networks and gas networks will increasingly be overcome. The expectation is that difficulties in collaborating among multiple sectors, unifying plans and improving efficiency will also be resolved.

Box 3.4 • Golden Concord Group Limited's (GCL) microgrid project in Suzhou Institute of Technology

The microgrid project, developed by GCL in Suzhou city, Jiangsu province, is a national renewable-based microgrid demonstration project in China. The microgrid aims to integrate six energy systems based on solar PV, gas-fuelled CCHP, wind energy, low-grade heat supplied by ground source HPs and solar thermal, light-emitting diodes (LEDs), as well as ES. The area of construction of the first phase was 19 515 m². The energy load of office buildings from electricity, air conditioning and hot water is estimated to total 1 000 kilowatts (kW), about half that of traditional centralised energy systems. The rooftop solar PV can provide 350 kW of installed electricity capacity, and natural gas 400 kW for electricity and 400 kW for heating and cooling services. The project is also integrated with multiple technologies including a 100 kW ES system, wind and solar combined system, EVs, microgrid and LEDs. The buildings can achieve more than 50% energy self-sufficiency with more than 30% energy savings. Primary energy is converted in a cost-effective and efficient way to meet end-use needs from lighting, motors, appliances, air conditioners, heating, hot water and steam. This leads to savings in energy investments of 30%, a reduction of energy consumption by 40%, improvement of energy efficiency by 40% and reduction of emissions by more than 50%.

The core benefit of GCL's microgrid offerings comes from integrating a variety of energy sources with various characteristics to construct a microgrid system, which allows an optimal use of these various energy sources by meeting end-use needs with electricity, cooling, heating, steam and other energy products. This helps improve overall energy efficiency, reduces the total cost of energy consumption, achieves emissions reduction and protects the environment.

Figure 3.9 • Illustration of GCL's microgrid

Note: LED = light-emitting diode.

Source: GCL (2017), "Intelligent energy project of golden concord group limited", <http://en.gcl-power.com/site/case>.

Key point • The microgrid enables the integration of multiple energy sources and loads to maximise efficiency and reduce the cost of energy consumption.

Challenges

China's transition to low-carbon energy brings both opportunities and challenges to the development of DES. At present, China's DER options are expected to enjoy rapid growth judging from market demand, relevant policies, technologies and costs. However, based on traditional ways of deployment, they also face economic, system, policy and market challenges to achieve stable development. These challenges should be carefully analysed and tackled, so as to create a sound market and policy environment for modern DES to scale up.

Economic challenges

Internalisation of system benefits

As discussed in Chapter 1, DES have multiple societal benefits including clean, low-carbon and user-friendly attributes, but under the existing pricing mechanisms, these are not reflected in the prices of cooling, heating and power products. As a result, these wider benefits of DES do not translate into economic competitiveness for DER. In addition, prices of most energy products are still under some control by governments, which may not fully reflect the supply-demand situation. As a result, the existing pricing mechanism does not provide a price signal that is an accurate reflection of the full value of DES.

The major barrier to the development of DNG in China is the lack of an efficient pricing mechanism, leading to operating losses for projects outside areas with very high demand for cooling and heating. This can be attributed to the fact that the cost of fuel takes up a large portion of the total cost and has a decisive impact on the economic performance of the DNG system. Compared with coal and other energy sources, natural gas in China is priced high yet enjoys no subsidies as does new energy, so it is not competitive. In addition, the on-grid tariff for most natural gas power is decided by the NDRC by way of a benchmarked tariff or case-by-case approval. One feature of such a pricing method is that the on-grid tariff, once decided, will remain unchanged for a long time, so the variations of the fuel prices upstream will not be transmitted effectively and in a timely way to the electricity price downstream.

DRE such as PV and biomass currently rely on government subsidies and show good economic performance only when governments provide supplementary support. This poses challenges to sustaining growth rates. In the context of gradually decreasing subsidies for renewable energy, it also prevents investors from foreseeing the expected project returns.

Economic problems caused by poorly matched systems

As highlighted already, a modern approach to DES starts with a detailed understanding of demand patterns. Historically, demand for heating, cooling and electricity has been misjudged for some DNG projects, leading to economic challenges. In the early stages of design, larger size is prioritised in both load analysis and unit type selection, without sufficient consideration of whether capacity matches the load. As a result, when projects are put into operation, power plants have a low loading rate and a poor economic performance.

What is of equal importance to DRE is system matching, including the matching between the load and the power distribution network and the matching between different sources of energy such as PV and wind power. If the grid cannot absorb all the power and no proper energy storage facilities are built, problems such as wind curtailment and PV curtailment emerge.

Competition among different energy types and lack of pricing of externalities

In the whole energy system, distributed energy and concentrated fossil energy such as coal can serve as alternatives and thus they compete with each other. When external environmental factors such as climate change and particulate pollution are ignored or the external benefits are not fully reflected in the prices of energy products, distributed energy is usually at a disadvantage. For instance, the on-grid tariff for DNG is too high compared with that of coal power, so there will be an insufficient incentive for DNG to replace coal power.

The Chinese government has made major efforts to develop renewable energy. For instance, the bidding price for electricity has decreased to under RMB 0.6 per kilowatt hour among enterprises on the PV Top Runner base. In Notices on Adjusting the Benchmark On-Grid Tariff for Onshore Wind Power and Photovoltaics issued by the NDRC at the end of 2016, the on-grid tariff for PV power stations and onshore wind power was lowered on the basis of resource areas. According to the Notice on Demonstration Projects of Achieving Grid Parity in the On-Grid Tariff for Wind Power issued by the NEA recently, the on-grid tariff of demonstration projects should be the same as the locally benchmarked on-grid tariff for coal power (NEA, 2017d). Given this context, comparisons will also be made concerning the economic return between distributed and centralised development.

System and policy challenges

Restrictions on third-party access to energy infrastructure

Grid access is relevant for DES from two perspectives: first, as a way to obtain input fuel and second, as a way to sell power and services to the central electricity grid. China's natural gas pipeline network is composed of long-distance pipelines and distribution networks. The long-distance pipelines are mainly invested in, built and operated by state-owned companies such as China National Petroleum Corporation (CNPC) and Sinopec. The main pipeline networks are mainly built by CNPC and Sinopec, and the provincial pipeline networks are built by China National Offshore Oil Corporation (CNOOC) and natural gas pipeline companies at the provincial level. For a long time, the pipeline networks have been exclusively used by these companies and have seldom been opened for third-party access. The NDRC and the NEA have sought to promote fair access to natural gas pipeline facilities, promulgating the Administrative Measures on the Construction and Operation of Natural Gas Infrastructure (NDRC and NEA, 2014a) and the Supervision Measures on Fair Access to Oil and Gas Pipeline Network Facilities (for Trial Implementation) (NDRC and NEA, 2014b). However, it is still difficult for third-party enterprises to gain access to the existing natural gas networks. Since the end of 2014, gas companies such as ENN, Guanghai Energy and Beijing Gas have started to attempt third-party access to LNG imports by using the receiving terminals of CNPC and have successfully imported spot LNG. However, LNG is generally transported in liquid form because of access barriers to transferring LNG into gas pipelines. At the end of 2015, Beijing Gas started to import spot LNG from Algeria and direct it into the fourth Shanxi-Beijing gas pipeline after turning the liquid into gas. This was the first time a gas company imported LNG through pipelines. Yet at this stage, it is still difficult for small-scale DNG projects to get spot natural gas at a low price via third-party access to pipeline infrastructure. In addition, urban gas distribution pipeline companies usually hold the franchise, which hinders DNG projects from gaining access to the distribution pipeline.

Currently, China's electrical grids and distribution networks are managed by grid companies under natural monopolies. Although policies have been introduced to support the direct power purchase of big users and cost-reflective transmission and distribution pricing, there are still issues such as high barriers to direct power purchase and opaque grid capacity. For grid

connection of DES projects, the existing policies are difficult to implement in practice. Thus, in the event that duties and obligations after grid connection are not defined, the actual operation of grid connection may not be entirely smooth.

Downstream urban heating networks are mainly controlled by enterprises owned by local government. The surplus cooling or heating power is often sold to these power enterprises, instead of downstream users via the cooling or heating network. In such cases, there is a sharp decrease in revenue.

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Co-ordination barriers among cooling, heating and power

Facilities of DES are mainly gas pipeline networks, heat pipeline networks, and refrigeration and heat exchanging stations. In China, cooling, heating and power have been supplied and managed separately. Cooling and heating systems are managed by the department of housing and construction under city administration, while power is managed by the energy sector. On the other hand, cooling and heating systems are constructed and operated by heating companies, while power is operated by power supply companies. DES integrate the overall power supply and remove the traditional barriers between cooling, heating and power supply. Yet their need for development cannot be fulfilled under the current construction and management model. Gas pipeline networks and heat pipeline networks are often managed by city administrations and their developers, which may not be the same team as investors and developers of distributed energy projects. Thus, it is difficult to co-ordinate all these players.

In addition, distributed energy projects demand more accurate prediction of the load of cooling, heating and power. Thus the project's operation and efficiency are affected by large changes in demand. For users, if the cooling, heating and power prices of distributed energy are not more competitive than the prices of power supplied by the city administration, users are not motivated to use alternative forms of service provision, based on considerations including safety, stability and habit.

Aligning incentives

Co-ordination of DER and the grid is the prerequisite of DER development. DER are produced and consumed locally. To a certain extent this presents challenges to grid companies because it compromises their profits, which are gained from the difference between purchase and sale price as well as sales volume. Aside from this, because grid companies are required to provide free grid connection for DER generation projects with an installed capacity below 6 MW and regulate variable DER (YICAI, 2016), they are burdened with increased operating and scheduling costs. These differing interests are not well managed on the basis of the system and environmental value of DER, which limits grid companies' incentive to facilitate DER grid connection.

The new round of power system reform encourages DER development and supports enterprises with DER generation participating in the competitive electricity market, allowing them to set up power companies. These will compete with grid companies to some extent. At present, the detailed implementation rules for distributed power sales have not yet been determined, and the operation and profit models of power companies are not clear. Although these companies have mushroomed, specific business scopes and models need to be further explored. China's first DER project to incorporate power distribution and sale – Beijing Energy Investment Holding Company Ltd.'s project in Shenzhen International Low Carbon City – was approved in June 2016 by the NEA. This project is the first in China to integrate generation, distribution and sale, and it will establish an "Internet plus" platform based on the smart grid, creating an innovative energy supply model.

Market challenges

Need for cost reduction for DNG

To sustain development of DNG, apart from appropriate pricing mechanisms, lower technology costs as well as improved optimisation of systems are critical. First, the cost of DNG can be reduced through more competitively priced core components. At present, most domestic DNG projects use imported core equipment produced by GE, Siemens and others. Investment in equipment has accounted for a relatively large proportion of the total investment, and the operation and maintenance are costly. Thus increasing availability of competitively priced technology is of central importance. This can be achieved through either more competitively priced imported technology or – if the required factors are in place – the establishment of a local manufacturing capability in core technologies such as gas turbine hot section components and combined-cycle operation control technologies.

Second, the concept of the energy Internet, or an increasingly networked system of energy supply and demand enabled by digitalization, is gaining in popularity. The DNG system is a key part of this, characterised by the integration of different energy sources, integrated optimisation and interconnected information. In co-ordination with other energy resources, DNG can benefit from further progress in key technologies, such as microgrid self-healing control, DER generation and microgrid, smart use of electricity, and demand response technologies.

DRE has great potential for cost reduction. Greater efforts would result in giving full play to its advantage of integration and reducing system costs.

Market development's heavy dependence on policies

In view of the above-mentioned economic, system and market challenges, investors' confidence in DES largely comes from the government's support and encouragement, as well as being a sign of future development indicated by policies. With the increasing demand for energy conservation, emissions reduction and environmental protection, local governments are paying more and more attention to the development of clean energy. However, the huge discrepancy among regions in understanding DES projects and their related policies has a great impact on market development.

In Shandong province, due to concerns about the economic efficiency of DNG at the early stages, a batch of projects dragged on, and enterprises and the government were not motivated to proceed. In 2015, Shandong province issued the Guidance on Accelerating Ultra-low Emissions from Coal-Fired Units (Boilers), which mapped out the overall thinking, work principles and key tasks (DEP-SD, 2015). The goal was to convert coal-fired generating sets with a capacity of 100 000 kW and above, and coal-fired boilers with a capacity of more than 10 steam tonnes per hour, to ultra-low emissions ones, thus meeting the natural gas turbine generating set (boiler) emissions standards before the end of 2018. Units (boilers) that fail to meet the standards in due time will be discontinued and renovated. In February 2017, Shandong Development and Reform Commission issued the Guidance on Accelerating the Promotion of Natural Gas Use (DRC-SD, 2017). It put forward that development of DNG and DER should be promoted; co-generation projects should be developed appropriately in major air pollution prevention and abatement cities; natural gas CCHP projects should be vigorously advanced; and projects that integrate natural gas with wind power, PV and other renewable energy should be encouraged. The goals are to install the first DNG generating set in Shandong in 2018, and increase the installed capacity to about 4 GW with natural gas consumption reaching about 4 bcm by 2020. As these policies are formulated and gradually implemented, the DNG development market in Shandong has become

increasingly active, and the previous wait-and-see attitude is becoming more positive. Many projects have made substantial progress, and some are already under construction.

These changes in market development show that the development of DES is greatly influenced by policies, the local government's determination to reduce emissions and its constantly improved understanding of DES. Policies serve as great incentives for development. In the important period of opportunities for DES development, the challenges confronting many local governments are how to better guide and support the scaling up and healthy development of the industry, and formulate appropriate supportive policies.

The problems of lack of data and information

China has not attached particular importance to the improvement of risk management and the construction of quality monitoring systems. Domestic DES projects generally face problems such as opaque information and difficulty in assessing the risks of construction and operation. These challenges not only increase the investment risk and the cost of capital for DRE projects, but also reduce their attractiveness to investors. This restricts the development of domestic DES projects, especially the financing channels and the scale of DPV.

Several aspects trouble investors – the complex relations among stakeholders of DPV generation, the difficulty in co-ordinating and sharing information about construction and operation, and insufficient disclosure of information about DPV power plants, developers and generating capacity. As a result, investors cannot measure project quality, and find it difficult to form a mature asset assessment system, which blocks substantial intervention by insurance companies and reduces risk-sharing mechanisms. The lack of certainty regarding the expected profitability of DPV projects also reduces the investment inclination of commercial lenders, institutional investors, financing institutions and policy banks.

Information technologies are needed to make information about the construction, operation and risks of DES accessible and transparent. To promote the marketisation of DES, it is necessary to standardise every aspect of the construction of a power plant and make it transparent. It also requires improvements in management efficiency and the timeliness of construction, financing, operation, maintenance and transaction of DRE projects, thus ensuring that decision-making is based on timely, accurate and reliable data.

Addressing the different challenges for DES will require a systemic approach, involving different levels of government and a diverse range of industry stakeholders. In the absence of such measures, the uptake of DES will remain challenging in China. Possible measures will be discussed in Chapter 4.

References

- CNESA (China Energy Storage Alliance) (2017), 储能产业研究白皮书 [Energy Storage White Paper 2017], <http://ex.bjx.com.cn/html/20170531/22003.shtml>.
- DEP-SD (Department of Environmental Protection, Shandong Province) (2015), 关于加快推进燃煤机组（锅炉）超低排放的指导意见 [Guidance on Accelerating Ultra-Low Emissions from Coal-Fired Units (Boilers)], http://xxgk.sdein.gov.cn/zfwj/lhf/201508/t20150824_283642.html.
- DRC-SD (Development and Reform Commission, Shandong Province) (2017), 关于推进天然气利用发展的指导意见 [Guidance on Accelerating the Promotion of Natural Gas Use], www.sdfgw.gov.cn/art/2017/2/6/art_216_232697.html.

Source: ENN (2017), “Ubiquitous energy network”,
www.enn.cn/wps/portal/enn/en/jsmcst/lut/p/b1/04_Sj9Q1M7lwMDUxNjLQj9CPykssy0xPLMnMz0vMAfGjzOLNgpzcHZ0MHQ3cXXydDBYD3d3MLYOcDI0cDfRzoxwVAUgzQKM!/?pageid=jsmcst

GCL (2017), “Intelligent energy project of golden concord group limited”, <http://en.gcl-power.com/site/case>.

IEA (2017), *Renewable Energy Market Report 2017*, OECD/IEA, Paris.

METI (Ministry of Economy, Trade and Industry) (2017), *Current State of the Strategic Roadmap for Hydrogen and Fuel Cells*, Tokyo,
www.meti.go.jp/committee/kenkyukai/energy/suiso_nenryodenchi/pdf/008_01_00.pdf.

NDRC (National Development and Reform Commission) (2016), 关于实施光伏发电扶贫工作的意见 [Opinion on PV Poverty Alleviation], www.nea.gov.cn/2016-04/05/c_135250679.htm.

NDRC (2013), 分布式发电管理暂行办法 [Interim Measures for the Management of Distributed Power Generation], www.gov.cn/gongbao/content/2013/content_2515010.htm.

NDRC et al. (2011), 关于发展天然气分布式能源的指导意见 [Instructions on the Development of Distributed Natural Gas], www.ndrc.gov.cn/zcfb/zcfbtz/201110/t20111013_438374.html.

NDRC and NEA (National Energy Administration) (2016a), 电力发展 “十三五” 规划 [The 13th Five-Year Plan on Electricity Power Development].

NDRC and NEA (2016b), 天然气发展 “十三五” 规划 [The 13th Five-Year Plan on Natural Gas Development].

NDRC and NEA (2016c), 能源发展 “十三五” 规划 [13th Five-Year Plan on Energy],
www.ndrc.gov.cn/zcfb/zcfbtz/201701/t20170117_835278.html.

NDRC and NEA (2014a), 天然气基础设施建设和运营管理办法 [Administrative Measures on the Construction and Operation of Natural Gas Infrastructure],
www.ndrc.gov.cn/zcfb/zcfbl/201403/t20140320_603521.html.

NDRC and NEA (2014b), 油气管网设施公平开发监管办法 (试行) [Supervision Measures on Fair Access to Oil and Gas Pipeline Network Facilities (for Trial Implementation)],
http://zfxgk.nea.gov.cn/auto92/201402/t20140224_1768.htm.

NDRC, MOF (Ministry of Finance) and NEA (2017), 关于试行可再生能源绿色电力证书核发及自愿认购交易制度的通知 [Notice on the Trial Implementation of Renewable Energy Green Power Certificate Issuance and Voluntary Trading System], www.nea.gov.cn/2017-02/06/c_136035626.htm.

NEA (Nuclear Energy Agency) (2017a), 2016 年光伏发电统计信息 [Solar Power Generation 2016 Statistics].

NEA (2017b), 2016 年风电并网运行情况 [Wind Power Generation 2016 Statistics],
www.nea.gov.cn/2017-01/26/c_136014615.htm.

NEA (2017c), 2017 年上半年光伏发电建设运行信息简况 [Brief Introduction on the Solar Power Construction and Operation for the First Half of 2017], www.nea.gov.cn/2017-08/04/c_136499745.htm.

- NEA (2017d), 关于开展风电平价上网示范工作的通知 [Notice on Demonstration Projects of Achieving Grid Parity in the On-Grid Tariff for Wind Power], http://zfxgk.nea.gov.cn/auto87/201705/t20170524_2794.htm.
- NEA (2016a), 太阳能发展 “十三五” 规划 [The 13th Five-Year Plan on Solar Energy Development], http://zfxgk.nea.gov.cn/auto87/201612/t20161216_2358.htm.
- NEA (2016b), 生物质能发展 “十三五” 规划 [13th Five-Year Plan on Bioenergy Development], http://zfxgk.nea.gov.cn/auto87/201612/t20161205_2328.htm?keywords=.
- NEA (2016c), 风电发展 “十三五” 规划 [13th Five-Year Plan on Wind Power Development], www.nea.gov.cn/2016-11/29/c_135867633.htm.
- NEA et al. (2017), 中国天然气发展报告 [China Natural Gas Development Report], www.sohu.com/a/165814907_468637.
- SC (State Council of China) (2012), 节能与新能源汽车产业发展规划 (2012-20) [Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012-20)], www.gov.cn/jwqk/2012-07/09/content_2179032.htm.
- Uniper (2017), *Application for the conversion from electricity to gas*, updated from *Sektorenkopplung als Teil der Energieversorgung von morgen*, http://www.fze.uni-saarland.de/AKE_Archiv/DPG2017-AKE_Muenster/Vortraege/DPG2017_AKE8.2_Schoof_Sektorkopplung.pdf.
- Uniper (2016a), “BP and Uniper aim to harness ‘green hydrogen’ to produce fuels”, www.uniper.energy/content/dam/uniper-corporate/documents/en/press/20161006_PM_BP-Uniper_Kooperation_en.pdf.
- Uniper (2016b), “Power to gas”, www.uniper.energy/content/dam/uniper-energy-storage/documents/broschures/en/KT_Power_to_Gas_EN_160922.pdf.
- Uniper (2016c), “Converting electricity from renewables to hydrogen”, www.uniper.energy/content/dam/uniper-energy-storage/documents/broschures/en/PP_WindGas_Falkenhagen_EN_160922.pdf.
- Uniper (2016d), “Membrane electrolysis for power to gas plants”, www.uniper.energy/content/dam/uniper-energy-storage/documents/broschures/en/PP_WindGas_Hamburg_EN_160922.pdf.
- Yang, Y. (2016), 实现能源梯级利用 国内首个自主研发分布式燃机项目成功投运, [The First Distributed Energy Project Using Gas Turbine with China’s Own Intellectual Property Commissioned], <http://news.bjx.com.cn/html/20160510/731570.shtml>.
- YICAI (2017), 解振华：今年将启动全国碳排放权交易市场 [Xie Zhenhua: The National Carbon Emissions Trading Market Will Start This Year], www.yicai.com/news/5249313.html.
- YICAI (2016), 分布式天然气与可再生能源协调发展 [Research on Co-ordinated Development Of Distributed Natural Gas and Renewable Energy], www.sohu.com/a/121566210_481842.
- Zheng, F. and G. Wenlin (2017), 多能互补助力未来能源网络经营 [Multi-power Complement Helping Power Network Operation in the Future], State Grid Corporation of China News, www.qh.sgcc.com.cn/html/main/col12/2017-04/25/20170425152230502967272_1.html.

Chapter 4. Policy analysis and suggestions

In China, establishing a clean, low-carbon, secure and highly efficient energy system has become the principal direction of the energy industry. Balancing the roles of government and the market is vital for success. With the reform of the government, China's energy governance system is undergoing a fundamental transformation from a planned approach to a more market-oriented system. The market is increasingly playing a leading role in energy development, and the government is gradually reducing the traditional administrative approval, production instructions and other rigid management methods, and relying more and more on development planning and industrial policies to guide the the energy industry.

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The characteristics of distributed energy systems (DES) – for example, clean, low-carbon, highly efficient - are fully consistent with China's energy development targets. The energy management requirements of DES also align with the current change in China's energy management approach. To support the development of distributed energy, the important areas of focus are now service provision and creating a suitable market environment (Shi and Wang, 2017). In this regard, on the one hand, the government can provide clear signals to the market through energy plans and guide the direction of energy investment; on the other hand, it is essential to create a fair market for distributed energy, including market and grid access, as well as allowing innovative arrangements for electricity transactions, to enable distributed energy to compete fairly.

Such an improved overall framework requires a concerted, systemic approach. Hence, this final chapter includes suggestions directed at a diverse range of government entities. Rather than providing a definitive solution, the suggestions are intended to guide further discussion and aim to underline the need for a systems approach.

Development plans and policy

Distributed energy is different from traditional more centralised energy systems in its technology, scale, business model and operation. Thus the most important policy measures for distributed energy are also different. Since by their nature DES are well suited to the participation of diverse market players, key supportive measures for DES revolve around creating the market environment for effective competition to provide services through distributed energy resources (DER). This includes providing clear and stable policy signals, opening the way for competition by ensuring access, and minimising regulatory hurdles to participation.

Development plans

An energy development plan guides energy development and investment, leading energy technology innovation and promoting energy policy improvement. The five-year plan on energy and its sub-plans for specific areas such as power, gas and coal are the most important guidelines in China's energy sector. The evolving role of distributed energy in these plans illustrates the development of distributed energy in China.

In the 11th Five-Year Plan (FYP) on Energy published in 2007 (NDRC, 2007), DES were recognised as one of the cutting-edge technologies and strategic areas. In the following 12th FYP on Energy and its sub-plans (SC, 2013), for the first time clear requirements and targets were set for distributed energy in China. In the latest 13th FYP on Energy (NDRC and NEA, 2016), more ambitious targets were set for distributed energy: in 2020 the installed capacity for distributed gas power should reach 15 gigawatts (GW) and distributed solar power should reach 60 GW.

Table 4.1 • Distributed energy in the energy development plans

Development plan	Requirement	Target
11th FYP on Energy	Distributed energy technology was outlined as one of the cutting-edge technologies and strategic areas.	
12th FYP on Energy	Develop distributed energy actively on the principle of electricity generation mainly for self-use with surplus sold to the grid, and achieve the co-ordinated development of centralised and distributed energy.	By 2015, build 1 000 gas distributed energy projects; the distributed solar capacity should reach 10 GW; build 100 renewable distributed energy-based new energy demonstration cities.
13th FYP on Energy	Use centralised and distributed energy simultaneously, and pay high attention to the development of distributed energy; accelerate the construction of distributed energy projects and gas peak power plants; optimise the development of solar energy, give priority to distributed solar.	By 2020, the capacity of distributed natural gas power should reach 15 GW and distributed solar 60 GW.
13th FYP on Natural Gas	Encourage the development of distributed gas energy; develop gas peak power plants in a co-ordinated manner; develop gas combined heat and power (CHP) station under suitable conditions.	By 2020, gas power installed capacity should reach 110 GW, accounting for more than 5% of the total capacity.
13th FYP on Wind Power	Push forward the development and employment of distributed wind power; explore the construction of wind power with microgrid; promote the construction of new energy microgrid with wind-solar-storage.	
13th FYP on Solar Energy	Promote distributed solar power in the Central and East regions comprehensively; give priority to the development of distributed solar power, especially those connected to the low-voltage distribution network and consumed nearby.	
13th FYP on Bioenergy	Develop distributed bioenergy; collecting, transforming and consuming bioenergy locally. Actively develop distributed biomass CHP. Prioritise use of biomass for distributed CHP applications.	
Energy Production and Consumption, Revolution Strategy (2016-30)	Promote the development of centralised and distributed energy system simultaneously; give priority to distributed energy when developing renewable energy.	

However, the anticipated dramatic increase in distributed energy did not take place in the past 12th Five-Year Period (2011-15). Instead, distributed energy, in particular distributed natural gas (DNG), has struggled in China. The goal for distributed energy in the 12th FYP on Energy was not achieved (Lyu, 2016), which is unusual in China. The reasons for this failure in the past five years are multiple (see details in Chapter 3); however, there is great potential for increased clarity in the policy guidelines for distributed energy to help address this in the future.

DES not only cover different areas of the energy sector such as power, renewable, gas, bioenergy, etc., but are also linked with several departments including those responsible for power, heating and gas. In order to prompt the development of DES in the 13th FYP period and beyond, an integrated approach is of central importance. The following provides a summary of the key factors to consider in achieving this.

Clarifying the role of distributed energy in the future energy system and energy transition

The changing and evolving role of distributed energy in China in the past - from a “cutting-edge technology and strategic area” in the 11th FYP to definite development goals in the 12th and 13th FYPs - reflects the deepening understanding of distributed energy. Nowadays, China is experiencing a fundamental energy transition, not only regarding the energy consumed (i.e. from mainly relying on fossil fuel to using renewables) but also the configuration of the energy system and the way energy is utilised (i.e. a focus on improving energy efficiency and lowering emissions

as well as a move from heavy industry to an increasing demand for services). As a continuation of this process, DES can be further integrated into China's energy transition strategy as the key to promoting clean energy use and reform of the supply side of energy. DES can also be recognised as an important part of China's energy transition and future energy system, as well as a pathway to addressing pollution issues and increasing the use of renewable energy.

Setting out detailed development goals for distributed energy at different government levels

The central government provides an important framework for DES development by setting overall goals for distributed energy, such as the amount of total installed capacity and the extent of distributed energy deployment and use. It also establishes the main technical requirements including energy efficiency standards, environmental regulations and safety requirements. Guidance from the local provincial and municipal governments is equally important, setting out detailed subregional plans in harmony with the overall plan and local conditions such as resource endowments, grid structure and demand characteristics.

Co-ordinating the development of energy infrastructure

To achieve optimal outcomes for DES, the scale and layout of DES should be co-ordinated with the development of gas supply and renewables energy resources. At the same time, efficient DES development needs to take into account the development of relevant infrastructure such as the electricity distribution grid, gas pipeline network, heating and cooling networks (SGERI, 2012), and the development of new technologies such as smart grids and the energy Internet.

Industrial policy on distributed energy in China

As highlighted at the beginning of Chapter 3, DES have seen a diverse range of policy approaches over the past decades. The future evolution of DES could benefit from assessing the impact of these policies and the possibility of developing them further, reflecting the innovation in DES and the new role they can play in China's energy transition.

Distributed energy integration policies

Connecting with the distribution grid is a prerequisite to improving the reliability and efficiency of DES. At the same time, the integration of DES could provide the valuable flexibility the system needs (Nyeng and Østergaard, 2010; Purchala et al., 2006). There is little disagreement between the grid company and the distributed energy operator on whether a distributed energy station should be integrated with the grid; the dispute is often more focused on how to connect with the grid, and the responsibilities and obligations of each party. This is one of the main obstacles hindering the integration of distributed energy (as discussed in Chapter 3).

Therefore, as required in the 13th FYP on Energy, the development of distributed energy will be greatly promoted by introducing standards on integration and operation to clarify the technical demand, procedures for integration, and the obligations and responsibilities of each stakeholder (ERI, 2013; SGERI, 2012). The following principles can help to guide the development of standards in accordance with the characteristics and requirements of distributed energy.

- Make it fair and open. This would include clearly defining the obligation of the grid company to provide grid access and integration services for all distributed energy stations, and disclosing necessary information on the distribution network including the total capacity, spare capacity, development plans, etc. Meanwhile, basic requirements on distributed energy could be set out to ensure the distributed energy project is integrated into the grid without compromising the operation of the main grid.

- Simplify integration procedures. Nowadays, distributed energy projects are generally small in size and more and more often owned by individuals or small and medium-sized enterprises (SMEs). Long and complicated integration procedures may prevent them from investing in distributed energy. The government and grid companies could resolve this by providing a targeted integrating service to small distributed power projects, including simplifying the integration procedure, lowering technology requirements, and reducing connection charges to eliminate integrating barriers and reduce costs (Hu, 2016).
- Strengthen regulation. Effective regulation is critical to guarantee full compliance with standards and ensure the fulfilment of rights and obligations. In this regard, the designation of responsible authorities in central and local government can strengthen regulation of integration activities and the operation of distributed energy projects.

Distributed natural gas pricing scheme

DNG can be of great value in terms of energy savings, emissions reduction, etc. compared with traditional centralised fossil fuel power generation based on coal. However, the ongoing prices received by DNG generators for the electricity and heat they provide are set by the pricing department of the government based on the coal power plant and coal-fired heating boiler price. The clear environmental and system benefit of DNG projects is not fully reflected in this pricing scheme (Liu, 2016), resulting in weak market competitiveness and low attractiveness to investors. At the same time, the government has to provide large subsidies to sustain existing DNG projects. Furthermore, the gas price has fluctuated frequently in recent years but the electricity feed-in tariff and heat price of DNG remained unchanged or lagged far behind. The National Development and Reform Commission (NDRC) proposed that “the feed-in tariff for gas power should adjust when the gas price changes significantly”, but in practice this price linkage mechanism was not implemented fully and gave no clear interpretation of when and how much the price should be adjusted, leaving DNG projects facing increased economic pressure when the gas price increases (Shi and Wang, 2017).

In order to relieve economic pressure on DNG projects, a key solution is first, to improve the price linkage mechanism between gas and the electricity, heat and cooling supplied (Shi, 2011; Ben, 2010), and set out detailed linkage conditions and time limits, to allow competition among DNG projects. Second, for the long term the DNG pricing scheme can be improved in the context of reform of energy pricing and the electricity system. In this way pricing can fully reflect the system-wide benefit of DNG in the electricity and heat price, improving the economy and competitiveness of DNG projects in China, and relieving the government’s subsidy burden.

Reforms in related areas

The market environment plays a decisive role in the development of distributed energy: an open and fair market can effectively stimulate a large number of SMEs and individuals to take part, while a rigid market will stop them from entering. In this respect, a mature power and gas market, stable and anticipated returns, and a fair competition environment are critical. Hence, ongoing reforms in related areas – in particular in the electricity and oil and gas sectors, and to construct a carbon trading market – can have a relevant impact on DES.

Electricity system reform

Despite much progress since the last electricity system reform started in 2002, a number of problems persist, including the lack of electricity market trading and a distorted electricity price, which affect the further development of renewables and distributed energy. In these

circumstances, in 2015 the Chinese government started a new round of market-oriented electricity system reform. This included reform in the electricity pricing scheme and electricity trading mechanism and the opening of the electricity retail market, which are all closely related to the development of distributed energy (Box 4.1). The guideline document of this reform – *Some Opinions on Further Deepening the Reform of Electricity Sector* (SC, 2015) – stressed the need to “ensure fair access of the grid and establish a new mechanism for the development of distributed energy” and “fully open the development of distributed energy in the user side”. All those measures would encourage and promote the development of distributed energy in China. In the process of reform, the following more detailed measures could be considered to further promote the development of distributed energy.

- Support distributed energy’s participation in electricity trading (Song, 2017). Detailed trading rules could be set to allow distributed energy to sell spare power to nearby consumers in a simplified way: distributed energy projects and power consumers could sign transaction contracts after registering with the provincial electricity trading centre, and the contract could be carried out after being checked for safety issues by the trading centre. The grid company could charge for services such as power transmission and electricity measurement, but waive the trading fee for distributed energy. For distributed energy companies that do not trade in the market, the grid company could fully acquire surplus DES power generation.
- Explore establishing a distributed energy electricity trading centre. With the development of distributed energy and accumulation of its electricity trading experience carried out through the provincial trading centres, the government could take steps to establish specialised municipal and country-level distributed energy power trading platforms. This kind of platform would be located closer to the distributed energy projects and their customers, making transactions easier and promoting distributed energy’s development. These platforms could be hosted in the grid company’s dispatching centre in order to reduce costs and increase efficiency.
- Support the development of distributed energy in the construction of new distribution networks. New distributed networks could be established as pilot areas for the use of distributed energy. The development and impact of distributed energy in the network planning and construction process could be considered in advance. Enterprises in this area could be encouraged to give priority to the use of distributed energy and set up retailing companies or sell spare power directly to customers nearby.
- Establish a scientific and reasonable pricing scheme. Accurate price signals are the precondition for the development of distributed energy. China’s power price has been set by the government for a long time, and could fail to fully reflect the changes taking place. It is important to form a new energy pricing scheme that could fully reflect the DER’s system value and environmental benefit, and allocate the grid cost fairly and reasonably between DES and normal customers.

Box 4.1 • New round of electricity system reform

In March 2015, the Communist Party of China (CPC) Central Committee and the State Council jointly issued *Some Opinions on Further Deepening Reform of Electricity Sector*, and later the NDRC and the National Energy Administration (NEA) issued another six supporting documents, starting a round of electricity system reform in China. The main contents of this reform include:

- Pushing forward reform of the electricity pricing scheme in a co-ordinated manner and straighten out the electricity price formation mechanism.
- Pushing forward reform of the electricity trading system and improve the market-oriented trading mechanism.

- Establishing relatively independent electricity trading centres and form a fair market trading platform.
- Pushing forward reform on the electricity generation and consumption planning scheme and let the market play a more important role.
- Steadily pushing forward retail-side reform and open the electricity retail business to social capital in a co-ordinated manner.
- Ensuring fair access to the grid and establish new mechanisms for the development of distributed energy.
- Strengthening electricity planning and regulation and improve the safety and reliability of the electricity supply.

As of May 2017, the reform had been carried out as planned and had made progress in several areas. First, the integrated pilot of different aspects of electricity system reform has taken place at the provincial level. Although the Tibetan Autonomous Region was still working on its pilot reform plan, all other provinces and territories have started pilot reform, including 21 provinces and/or territories that carried out integrated pilots of electricity system reform; 9 provinces and the Xinjiang Production and Construction Corps carried out retail pilot reform; and 3 provinces carried out renewable energy consumption pilot reform. Second, progress has been made on reform on prices for electricity transmission and distribution (T&D). Setting separate T&D prices is the prerequisite and key point of electricity pricing reform. As of July 2017, the NDRC had already approved 18 provincial and Shenzhen grid T&D price standards, and the remaining 14 provinces had almost finished and were awaiting approval. Third, national electricity trading centres to carry out electricity trade have been established in Beijing and Guangzhou, as well as 31 provincial trading centres and corresponding electricity market management commissions. More than 37 769 market entities have already registered in the State Grid's operating area, including 26 628 power generation enterprises, 10 181 power consumers and 1 182 electricity retail companies. In the first four months of 2017, the traded power generation reached 1 235.6 terawatt hours (TWh) in the State Grid's operating area, an increase of 6.9% compared with the same period in 2016. This figure included 1 013.4 TWh in the form of long-term contracts and 222.2 TWh in the form of market trade. In addition, reforms of power retail and new distribution grid construction are steadily being carried out.

Source: SC (2015), 关于进一步深化电力体制改革的若干意见 [Some Opinions on Further Deepening the Reform of Electricity Sector]; NEA (2017), 两部门召开电力体制改革吹风会 交易量将翻番 [Two Departments Hold Press Conference Jointly Introducing Progress of Electricity System Reform].

Reform in the oil and gas sector

DNG energy is an important form of distributed energy and also one of the main uses of gas. Its development thus could contribute greatly to improving air quality and reducing carbon emissions in China. For a long time, China's gas market has been dominated by three big state-owned enterprises (SOEs) (i.e. China National Petroleum Corporation [CNPC], Sinopec and China National Offshore Oil Corporation [CNOOC], called the Big Three). The low level of marketisation and a lack of competition have long hampered the development of the gas industry and gas infrastructure (Wang and Zhang, 2015). Fully formed market mechanisms and timely, accurate price signals are key to stabilising the natural gas market and improving the profitability of distributed gas energy projects. At present, China is carrying out a fundamental market-oriented reform in the oil and gas sector in an attempt to increase competition in the gas sector. Reform in the following areas could greatly encourage the development of DNG.

- Establish a natural gas trading market with a competitive natural gas trading centre and platform that allows all kinds of suppliers and consumers of different sizes and with different

ownership to participate in and make deals in a market-oriented way. The natural gas downstream sector could be opened to all participants to increase competition in the retail market, so that distributed energy projects can choose their gas supplier and path freely. Control of the gas retail price could be steadily loosened to achieve market pricing at last, so that distributed gas projects can optimise their gas supply packages based on the market price.

- Push forward third-party access to natural gas infrastructure. Fair and open access to the existing gas infrastructure is the precondition for the construction of a natural gas market. The government could further push forward third-party access of gas infrastructure such as pipelines and liquefied natural gas regasification facilities. These should not only be limited to spare capacity. The gas infrastructure operators should publish standards on technology requirements, access procedures, etc. and disclose relevant operational information periodically and in a timely manner. Clear charging standards for infrastructure access will allow the operators of distributed gas energy projects to forecast gas purchase cost and decrease operational risk.
- Strengthen natural gas market regulation. Effective regulation is also an indispensable part of a sound market. The government can strengthen regulation on natural gas trading and third-party access to natural gas infrastructure, and penalise activities such as discrimination against small customers and monopoly pricing, to ensure the full functioning of the market.

Box 4.2 • Reform in the oil and gas sector

On May 2017, the Central Committee of the CPC and the State Council released the long-awaited oil and gas reform plan, which highlighted eight reform areas, including:

- Open upstream exploration and mining in a co-ordinated manner: enforce a bidding mechanism on oil and gas exploration, allowing eligible companies to take part in conventional oil and gas exploration and mining; and establish an exploration and mining system led by big SOEs.
- Improve the crude oil import and export management system, focused on qualification management.
- Improve the oil and gas pipeline operation mechanism: unbundle retail and pipeline activities; open major pipelines (inter- and intra-provincial) to third parties.
- Deepen reform in the already competitive downstream segment; increase the supply capability of high-quality oil and gas products. Draft and implement higher standards on quality, safety, environment and efficiency, and eliminate outdated capacity.
- Reform the pricing system for oil and gas products: the pricing mechanism of refined petroleum products should be more market-oriented, while government should step in when abnormal price fluctuations occur; encourage marketisation of the non-residential gas price, and improve the pricing system of residential gas; establish an oil and gas trading hub, and encourage qualified market entities to participate.
- Deepen reform of oil and gas SOEs: encourage qualified SOEs to open to diversified ownership, develop the supply chain by encouraging the creation of new independent companies in engineering and equipment manufacturing, and remove long-criticised social functions of SOEs (e.g. schools, hospitals owned by SOEs).
- Improve the oil and gas stockpiling system. Establish and improve the stockpiling system consisting of government reserves, corporate social responsibility reserves and commercial reserves; encourage private capital to take part in investment and operation of stockpiling facilities. Establish gas peak-shaving policy and reserves.
- Establish and improve safety and environmental regulations across the oil and gas industry.

Carbon trading market and renewable quota and green certification mechanism

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Carbon emissions trading schemes and renewable energy quota/green certification systems have been long used in the United States and European Union (EU) to constrain carbon emissions and promote the development of renewable energy. These schemes could give clean energy economic compensation in a market-oriented way. In October 2011, China started carrying out a carbon emissions trading pilot in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen. The traded products include an emissions quota (granted by the government), Chinese Certified Emissions Reduction (CCER) and their financial derivatives. China plans to expand this carbon emissions trading system to cover the whole country later in 2017. In addition, China sold its first renewable energy green certification in June 2017, and is considering introducing the renewable energy quota in the near future.

Like renewable energy such as wind and solar, natural gas, especially distributed gas, has the advantage of clean, lower-carbon emissions (compared with other fossil fuels) and higher efficiency, which could contribute towards the decarbonisation of China's energy sector and improving the environment. For this reason, in the next step it would be advantageous to consider a mechanism similar to the renewable energy quota/green certification system to apply to DES that meet particularly high efficiency standards. Furthermore, distributed energy could be allowed to participate in national carbon emissions trading through CCER, and measures could be taken to streamline filing and certification processes for DER.

Box 4.3 • The EU Emissions Trading Scheme

The EU Emissions Trading Scheme (EU ETS) is the world's first and so far the largest installation-level "cap-and-trade" system for cutting greenhouse gas emissions. The system works by putting a limit on overall emissions from covered installations that is reduced each year. Within this limit, companies can buy and sell emissions allowances as needed. This cap-and-trade approach gives companies the flexibility they need to cut their emissions in the most cost-effective way. The EU ETS covers approximately 11 000 power stations and manufacturing plants in the 28 EU member states plus Iceland, Liechtenstein and Norway, as well as aviation activities in these countries. In total, around 45% of total EU greenhouse gas emissions are regulated by the EU ETS. The EU ETS remains the world's biggest emissions trading market, accounting for over three-quarters of international carbon trading.

The first trading period (2005-07) was a process of "learning by doing". The EU ETS was successfully established as the world's biggest carbon market. However, the number of allowances, based on estimated needs, turned out to be excessive; consequently the price of first-period allowances fell to zero in 2007. The covered areas were mainly power and manufacturing.

Second trading period (2008-12). Iceland, Norway and Liechtenstein joined. The number of allowances for the period was reduced by 6.5%, but the economic downturn depressed emissions, and thus the demand by even more. This led to a surplus of unused allowances and credits, which continued to suppress the carbon price. Aviation was brought into the system in this period.

Third trading period (2013-20). The biggest changes have been the introduction of an EU-wide cap on emissions (reduced by 1.74% each year) and a progressive shift towards auctioning of allowances in place of cost-free allocation. Croatia joined the ETS.

Fourth trading period (2021-30). The European Commission presented in July 2015 a legislative proposal to revise the EU ETS for the period after 2020, including: a decline in the overall number of allowances at an annual rate of 2.2% from 2021 onwards, compared with 1.74% currently; better targeted and more dynamic allocation of free allowances; and several support mechanisms to help the industry and the power sectors meet the innovation and investment challenges of the transition to a low-carbon economy.

Source: EC (2017), The EU Emissions Trading System (EU ETS).

The role of local government

Local government could play a vital role in the development of distributed energy. With the reform of the functioning of government in China, the role of central government in the energy arena is increasingly focused on planning, policies and regulation; local governments now are granted more and more freedom in implementing the plans and policies, and exert greater influence. In practice, local governments could promote the development of distributed energy, by implementing a consistent approach towards the different roles it plays for DES.

City planner

The local government is the planner and constructor of the city and its energy infrastructure. The development of distributed energy is heavily reliant on and closely related to the city and its infrastructure in many ways: distributed gas projects need an appropriate electricity, heating, cooling and gas infrastructure; distributed energy could contribute to the fulfilment of a city's energy saving and environmental goals; distributed solar power also influences the city's landscape directly. In this respect, it is optimal for the city government to consider the development of distributed energy when planning the development of the city and its associated infrastructure.

- Urban development planning. In the planning process for city development, especially when planning new areas such as Xiong'an (a new city planned to the southwest of Beijing) or other local economic development areas, the interaction between energy supply and urban development can be considered, such as planning the supply of water, electricity, gas, heating and cooling in a co-ordinated way.
- Urban energy planning. Urban energy demand can be analysed and forecast to determine key channels and modes of energy supply in the long and short term. Low carbon emissions, energy savings and protection of the environment would be the key principles of energy supply. Appropriate measures would be to integrate distributed energy into energy development planning and to identify the most suitable areas for distributed energy systems such as shopping malls, central business districts, stadiums, etc.

Energy development promoter

China as a country covers a large area with different physical environments and with different levels of economic development. Normally, the central government will consider the general condition of the whole country when making energy policy, which may not fully reflect the characteristics and advantages/disadvantages of a certain province or city. Therefore, there is an important opportunity for local governments to introduce specific supporting policies based on central government policy and their own local circumstances. For example, in provinces where the supply of natural gas is abundant and cheap such as Sichuan (unlike most other areas in China), the government could provide preferential policies in gas supply for distributed gas energy, whereas in the coastal areas where imported gas is more expensive but with a higher level of economic development, the local government could provide an appropriate financial incentive alongside an improved feed-in tariff to support the development of distributed gas energy (Niu, 2014). In doing so, it would be important to ensure that incentive policies do not diminish the importance of market reform to create a healthy market environment for distributed energy and do not create market distortions.

Box 4.4 • Case study: Shanghai's supporting policies on DNG

Shanghai has long led China in the development of DNG, with total installed capacity exceeding 150 MW. DNG is used in different areas ranging from hospitals, hotels and traffic hubs to business centres and exhibition centres. According to the Shanghai 13th FYP on Energy, DNG installed capacity will reach 200 MW in 2020. Early in 2004, Shanghai published for the first time the Notification on Encouraging and Supporting Gas Air Conditioning and Distributed Energy in Shanghai, which was much earlier than the first national policy on distributed energy and later updated in 2008, 2013 and 2017. The main supporting policies introduced in Shanghai are as follows:

- **Finance subsidy.** Provides an initial installed subsidy to distributed gas projects during construction and an additional subsidy after commission according to their energy efficiency and capacity factor. The total subsidy increased substantially from USD 85/kW (RMB 700/kW) in 2004 to USD 520/kW (RMB 3 500/kW) in 2017.
- **Integration policy.** Requires the grid company to speed up the construction of the distribution grid and consider the requirements of distributed energy in the designing and planning process; streamlines the integration process, which is required to be finished in 20 working days for qualified distributed gas projects. Waive the system spare capacity fee for distributed gas projects with capacity below 500 kW; for those exceeding 500 kW, the fee is also waived if the customer has already paid for the consumed power according to its transformer capacity or highest demand.
- **Favourable gas price.** The gas suppliers are obligated to fulfil the demand of distributed gas and gas air-conditioning projects as a priority. The gas price is also adjusted according to the upstream station price, and a favourable discount is given to the distributed gas and gas air-conditioning projects. In September 2015, the non-resident gas price was decreased by RMB 0.42 per cubic metre.
- **Feed-in tariff.** Introduces a specific feed-in tariff policy for distributed gas energy with timely adjustment when the gas price changes to support the economic competitiveness of distributed gas projects. The latest adjustment took place in December 2015 when the temporary feed-in tariff of distributed gas energy was increased to USD 0.108/kWh (RMB 0.726/kWh).
- In addition, to reduce the burden for enterprises the Shanghai government has also set out detailed procedures for activities such as approving distributed gas projects, application for subsidies and responsibility of relative governmental departments.

Sources: Ren, Ban and Zhou (2015), "Current status and future prospect of gas distributed generation in Shanghai"; thede.cn (2017), 上海市最新天然气分布式能源补贴政策发布, [Shanghai Published the Newest Subsidy Policy for Distributed Natural Gas Project].

Energy regulator

Heating and gas utility companies in China are SOEs belonging to the local government which is the regulator of the operation of the energy industry, and also the supplier of heating and gas. Nowadays, the power, heating and gas supply are operated by different utility companies and regulated by different government departments. This could hamper co-operation and communication among different industries, and possibly have a negative effect on the improvement of operational and energy efficiency because of the mutual constraints between the upstream and downstream industries. Taking Beijing as an example, the municipal government is pushing forward coal-to-gas transfer in the area of power and heating in an attempt to alleviate local air pollution; most of the locally produced electricity and heat are from natural gas now, and power and heating are also the two biggest customers of gas in Beijing. There is plenty of synergy among electricity, heating and gas supply companies in optimising

dispatch, demand control and emergency response (Li, Zhang and Xu, 2017). To fully exploit this synergy, the following measures could be considered.

- Improve co-ordination between energy supply industries. Encourage electricity, heating and gas companies to carry out cross-border operations and co-operation. Private investors entering the energy sector can be encouraged to develop modern DES themselves or to participate in mixed-ownership reforms of state-owned energy enterprises.
- Encourage local governments. Local government could be encouraged to innovate in the energy regulation mechanism and where appropriate consolidate regulatory functions for different industries such as electricity, gas and heating, to build integrated regulation systems, continuously improve government management efficiency and reduce the regulatory burden for distributed energy enterprises.

Public procurement

Local governments are not only the city's energy provider but also one of the main energy consumers. Government departments and public institutions such as hospitals, schools and gymnasiums consume a large amount of energy every year, and their energy choices are a source of guidance to the whole society. Local governments could exert a direct influence with their energy supply choices and by promoting distributed energy in these areas. By demonstrating the utilisation of distributed energy in the public sector, the private sector may have a better case for investment in DES and come to follow the public sector. As a recent example, the Beijing government built a gas distribution energy station and associated gas and heating infrastructure in Tongzhou subcentre, which could provide electricity, heating, cooling and hot water simultaneously.

Market development

With the development of a market economy and reform in the energy field, the role of government in energy development is gradually changing: government's management of and constraint on microbusiness activities is decreasing, and more resources are concentrated on regulation and providing an enabling environment. The development of regulatory rules and their implementation are important steps to creating a favourable environment for enterprises. In the development of distributed energy, the government can play a significant role in this regard, providing support and services for project development, technical research, international co-operation, etc., while maintaining energy security and environmental protection at the same time.

Improving the financing and investment and approval system

Some of the main barriers to the development of distributed energy in China are the difficulty of raising capital, the high cost of capital and lengthy approval procedures. As an accompaniment in the important journey of China's energy transition to clean and highly efficient energy utilisation, improving the financing and investment and the approval system can not only promote the development of distributed energy but also move forward the modernisation of China's energy management system and energy market. Some measures to be considered are:

- Diversify distributed energy investment entities. Public-private partnership (PPP) and SOE mixed-ownership reform are two important elements of reform, and could be used in the development of distributed energy to broaden the source of investment and improve enterprise management. The government could identify a batch of distributed energy projects as PPP pilot projects and provide favourable terms such as financial subsidies to attract private investment. It could also select existing state-owned distributed energy projects to

carry out mixed-ownership reform pilots and attract the projects' existing customers or neighbouring stakeholders to invest, thus improving the projects' ownership structure and management mechanism.

- Diversify financing channels for distributed energy projects. Targeted policies could support distributed energy projects' financing activity and decrease their financing cost. The encouragement of all types of financial institutions including banks, funds, securities and insurance companies to give priority to distributed energy projects and developing and piloting new financial products such as small loans, project mortgages and equity investment would also be a positive contribution. Government could encourage financial institutions to co-operate with local governments to establish distributed energy project investment and financing platforms, which provide financial support to SMEs.
- Professionalise distributed energy operation. Most of the distributed energy projects in China today are invested in and operated directly by energy consumers, and due to limited technology capability, experience, capital and other factors, some of these projects are not well maintained or operated. The government could encourage the public utility companies (i.e. power, gas, heating suppliers) and private companies to set up specialised energy service companies to maintain and operate distributed energy projects. Different business models could be promoted for the construction and operation of distributed energy projects, such as Build-Operate-Transfer, Build-Operate-Own and energy management contracts.
- Improve the approving efficiency of distributed energy projects (China.com, 2017). This includes the further streamlining of government administration and further delegation of power to lower levels, as well as a further transfer of the right of approval for distributed gas projects within the energy development plan to the municipal government level. For all distributed renewable projects including wind and solar, a filing mechanism could be used instead of approvals. A pilot to implement the approval/filing of distributed energy projects in a "one-stop" management system could be a means of implementing this. All the dispersed regulation responsibilities, including safety, environment, health, etc., could be integrated into one or two departments to relieve the regulatory burden and increase efficiency. Full use could be made of the national investment project online approval and regulatory platform, and information on project approval and regulation could be disclosed in a timely manner.

Access to basic energy data

Basic energy data such as customer demand, spare grid capacity and gas supply are a prerequisite for developing distributed energy projects. The flexibility and small-scale features of distributed energy make it a perfect match for investment by SMEs and individuals. Such distributed energy projects could give small investors the freedom to fully exert their advantages in creativity and activity compared with large-scale enterprises. However, a disadvantage of SMEs and individuals is their limited ability to conduct basic investigations and obtain the data needed for investment (Yang, 2017). In addition, repeated basic investigation by different entities is also inefficient and could increase the cost and development period of distributed energy projects, ultimately affecting their competitiveness and profitability.

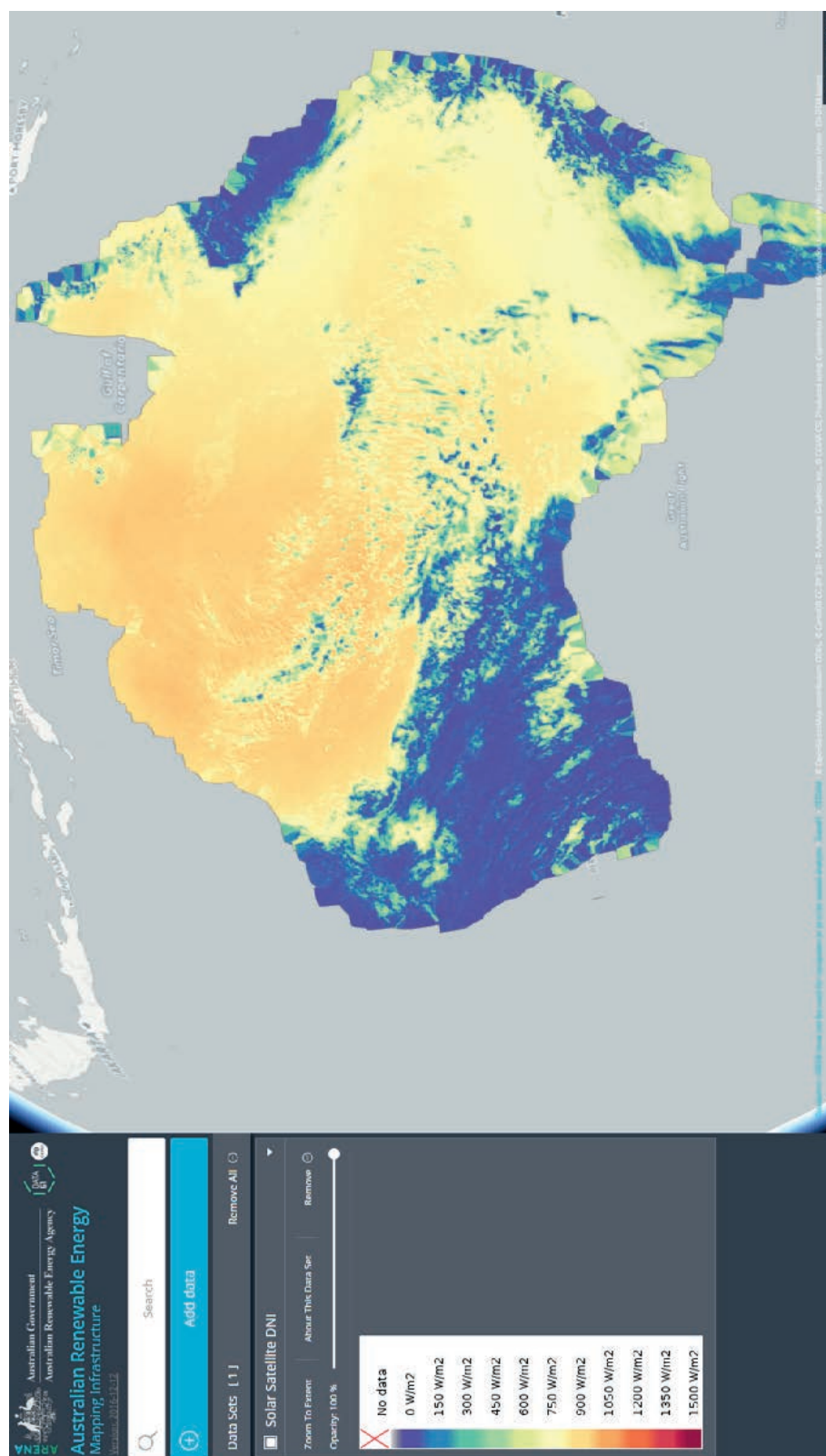
As a public service provider, the government could play a role by providing basic energy data. The government could collect and integrate data that is dispersed in different departments and utilities and make it accessible to the public for free use, reducing the "threshold" for energy project development. In practice, the government could do this in different ways, such as establishing energy data platforms as seen in Amsterdam or the Australian Renewable Energy Mapping Infrastructure (AREMI) energy map (Box 4.5).

Box 4.5 • International experience on basic energy data sharing

The Australian government has developed a fully public mapping tool, AREMI, that is connected directly with government department databases such as the Australian Energy Market Operator, the Bureau of Meteorology and Geoscience, all in Australia. The main purpose of AREMI is to provide basic data for energy investors (Figure 4.1). Energy investors can obtain information on the distribution of power infrastructure, energy demand forecasts, grid investment plan, etc. through the platform, which also provides other basic data such as population, weather and geography. The platform is easy to use with all the data shown on a map that the user can download as needed. The data from the platform can be used to inform investment decisions without large pre-construction costs.

The city of Amsterdam has developed an Energy Atlas system for the energy sector to publish basic local energy information. The content of the system includes basic data, energy data, energy potential and other aspects. The basic data include information on the city's population distribution, building stock (size, construction date, density, etc.) and social indicators such as ownership of property, disposable income and consumption patterns, and even a map that shows the level of insulation of each roof. The energy data include two categories: energy consumption, displaying information on gas, power, heating and cooling demand, and existing wind power and rooftop PV distribution. The energy potential shows the potential of Amsterdam's local energy resources, from solar, wind, geothermal and waste to energy storage and waste heat. The user can freely query the relevant information and analyse the data to select the most appropriate locations and the best technology choices for facilities such as heating, cooling and power supply.

Figure 4.1 • AREMI showing direct normal irradiance levels



Source: AREMI (2016), *Australian Renewable Energy Mapping Infrastructure*.

Key point • Geospatial data on resources and electricity infrastructure help inform investment decisions.

Distributed energy technical standards system

Distributed energy covers multiple areas, from power and heating to gas. They have features that are different from traditional energy systems, particularly concerning their business model, technology, operation, etc. As a result, most existing technology standards are not suitable for distributed energy. At the same time, there are no technology standards for DES design and operation owing to its relatively short history in China. This has a negative influence on the construction of distributed energy projects. For example, some distributed gas projects choose equipment with reference to traditional thermal power plant design standards. When coupled with overestimated heating and cooling demand, this results in overcapacity of equipment, low load factors, and low operating efficiency, which can influence the economic competitiveness of the project. Thus, there is a key opportunity to establish a suitable and scientific standards system to support the development of distributed energy. The system could include standards on the following aspects:

- Distributed energy project design and construction codes. A full use of all kinds of available primary energy, with a focus on the principle of maximising the overall energy efficiency would involve balancing heating, electricity and cooling demand, setting out requirements for technical route selection, demand forecast, equipment choice, construction, etc.
- Grid connection standards for distributed energy. This would require drafting specific grid connection standards for DES of different types and different capacity in accordance with the aforementioned principles discussed in integration policies.
- Distributed energy station operation codes. Technological demands for distributed energy operation, safety regulation, emergency response, etc. could be outlined.
- Codes on related areas. New technologies such as smart grids, modern distribution grids, microgrids and energy storage are closely linked with the development of distributed energy. It is therefore better to consider the interactions between distributed energy and these new technologies when developing standards for them.

Dealing effectively with the safety risks associated with distributed energy

Safety is the baseline for any energy system. Distributed energy brings fundamental change to the traditional energy system, not only concerning issues such as efficiency and environment, but also safety risks. The main safety risks associated with distributed energy are as follows:

- Operational safety risk of DES. With more and more new SMEs and individuals with little experience in electrical equipment operation entering the distributed energy area, there are increasing personal and equipment safety risks. These can be addressed by appropriate standards.
- Safety impact on the distribution network. With the increase of distributed energy penetration, especially variable distributed renewables, there is also increasing impact on the operation of the distribution grid. Appropriate technical standards for islanding detection can effectively avoid such security risks.
- Cybersecurity risk to the energy system. With the rapidly growing digitalization of the energy industry, cybersecurity risk is becoming one of the main risks facing the the energy system, especially the electricity system. For a cyberattacker targeting the main power system, the presence of grid-connected DER could provide an ideal “entrance”, since these resources are small scale, without the level of cybersecurity risk prevention measures taken by large-scale centralised energy systems. These could be easy to access and used to further enter the grid system if there is no isolation between them.

In order to minimise such cyber-safety risks, first the government could strengthen safety regulations on distributed energy, periodically carry out safety analyses and set out targeted measures, such as training, improving distributed networks and establishing “cyber safe areas” for distributed energy connection. However, what is even more important is to take these safety risks into consideration when planning and designing DES, and control and decrease the risk effectively through technology measures taken in advance. Establishing professional DES operating enterprises could compensate for the lack of technological capabilities of SMEs and individuals.

Encouraging distributed energy technology innovation

Accelerating the energy technology revolution is one of China’s main energy development strategies (i.e. energy production, consumption, technology and system revolution, and international energy co-operation). It is also the key solution for the multiple challenges that China faces today (as discussed in Chapter 3).

To further this strategy, the government could work in different ways to support distributed energy technology research, development and deployment (RD&D). This would include: increasing funding support for relevant RD&D activities, especially for critical technologies such as large-scale storage and energy internet; establishing distributed energy technology research centres in co-operation with big utility enterprises, universities, research institutions and energy customers; providing support to enterprises’ RD&D activities through tax incentives, financial subsidies, etc.

International co-operation

Energy is an international issue, and developing clean energy and distributed energy is the choice of many countries in the context of the global energy transition. As outlined in the Chapter 1, the development of distributed energy throughout the world has been taking place for decades. Countries such as Germany and Denmark have made great progress in this area and have accumulated valuable experience.

As the world’s largest energy consumer and greenhouse gas emitter, China is closely linked to the world’s energy development and international co-operation on energy will play a more and more important role in accelerating its own energy revolution. China is now increasingly involved in global energy governance and could further strengthen its relevant global work by establishing and maintaining broad dialogue, developing communication and co-operation mechanisms with other governments, international energy organisations, enterprises and research institutions, and encouraging co-operation in areas such as distributed energy, which could be beneficial to all parties. Meanwhile, China’s success and experience in distributed energy, especially in improving energy access using distributed energy, its business model innovation and decreasing costs can be of great value to other developing countries.

In this context, this publication is already a concrete step in this direction, being the latest outcome of the co-operation between China and the International Energy Agency, integrating the contributions of both.

References

AREMI (Australian Renewable Energy Mapping Infrastructure) (2016), Australian Renewable Energy Mapping Infrastructure, <http://nationalmap.gov.au/renewables/>.

- Ben, H. (2010), *Looking at Distributed Energy System from a Strategic Perspective: A Solution to China's Low-Carbon Development Strategy for Next 20 Years*, www.zshg.com/zwny/10-11-21.htm.
- China.com (2017), 广州建成南方五省区内首个四网融合智能小区项目 [The First "Smart Energy" Demonstration Project of Southern China Completed in Guangzhou] <http://news.china.com/finance/11155042/20170329/30370819.html>.
- EC (European Commission) (2017), *The EU Emissions Trading System (EU ETS)*, https://ec.europa.eu/clima/policies/ets_en.
- ERI (Energy Research Institute of National Development and Reform Commission) (2013), 分布式发电发展模式和经营管理方式研究 [Distributed Power Generation – A Study on Development Modes and Management Methods], <http://www.efchina.org/Reports-zh/reports-20130909-zh>.
- Hu, X.J. (2016), 中国天然气分布式能源发展现状与前景展望 [Development and Prospect of Distributed Gas Energy in China], www.qianzhan.com/analyst/detail/220/161109-610cf187.html.
- Li, L.C., Y.J. Zhang and M. Xu (2017), 我国能源系统形态演变及分布式能源发展 [The Change of Energy System and Development of Distributed Energy in China], *Distributed Energy*, Vol. 2/1.
- Liu, M.P. (2016), 我国天然气分布式能源发展的制约因素及政策建议 [Constraints for Distributed Gas in China and Policy Suggestions], www.sohu.com/a/106512391_131990.
- Lyu, M. (2016), 天然气分布式：问题与“十三五”建议 [Distributed Gas Energy: Problems and Suggestions for the 13th Five-Year Plan], www.jiemian.com/article/984557.html.
- NDRC (National Development and Reform Commission) (2007), 能源发展“十一五”规划 [11th Five-Year Plan on Energy Development], http://law.chinalawinfo.com/fulltext_form.aspx?Db=chl&Gid=89987.
- NDRC and NEA (National Energy Administration) (2016), 能源发展“十三五”规划 [13th Five-Year Plan on Energy], www.ndrc.gov.cn/zcfb/zcfbtz/201701/t20170117_835278.html.
- NEA (2017), 两部门召开电力体制改革吹风会 交易量将翻番 [Two Departments Hold Press Conference Jointly Introducing Progress of Electricity System Reform], www.nea.gov.cn/2017-07/26/c_136474425.htm.
- Niu, G. (2014), 分布式发电政策综述 [Policy Review of Distributed Power Generation], www.mat-test.com/ViewFullPDF.htm?aid=OJ150803000316fiPIRo.
- Nyeng, P. and J. Østergaard (2010), *System Integration of Distributed Energy Resources*, Technical University of Denmark, Department of Electrical Engineering, Copenhagen.
- Purchala, P. et al. (2006), "Distributed generation and the grid integration issues", https://eusustel.be/public/documents_public/WP/WP3/WP%203.4.1%20Distributed%20generation%20and%20grid%20integration%20issues.pdf.
- Ren, H., Y. Ban and W. Zhou (2015), "Current Status and future prospect of gas distributed generation in Shanghai", *Journal of Policy Science*, Vol. 9, pp.51-63, <http://r-cube.ritsumei.ac.jp/bitstream/10367/6559/2/jsp-09-03.pdf>.

SC (State Council of China), (2015), 关于进一步 深化电力体制改革的若干意见 [Some Opinions on Further Deepening the Reform of Electricity Sector], www.ne21.com/news/show-64828.html.

SC (2013), 能源发展“十二五”规划 [12th Five-Year Plan on Energy Development], www.gov.cn/zwggk/2013-01/23/content_2318554.htm.

SGERI (State Grid Energy Research Institute), (2012), 分布式能源的政策法规关键问题研究 [Research on Key Policy and Regulatory Issues of Distributed Energy], www.nea.gov.cn/2012-02/10/c_131402694.htm.

Shi, M.Y. (2011), 发展分布式能源的政策诉求 [Policy Demand of Distributed Energy], www.csee.org.cn/home.aspx?PageId=e9ee7a95-621c-4620-8553-4207956c6bdf&ArticleId=f0830521-fb82-4339-a28f-b78d119cdd4f.

Shi, D. and L. Wang (2017), 中国天然气发电发展现状及国际经验借鉴 [Development of Distributed Gas Power Generation in China and International Experience], <http://news.bjx.com.cn/html/20170527/828032.shtml>.

Song, W.M. (2017), 我国天然气分布式能源的发展现状及趋势 [Development and Tendency of Distributed Energy in China], <http://news.bjx.com.cn/html/20170206/806567.shtml>.

thede.cn (2017), 上海市最新天然气分布式能源补贴政策发布, [Shanghai Published the Newest Subsidy Policy for Distributed Natural Gas Project], www.thede.cn/index.php?c=article&id=1516.

Wang, X.J. and Q. Zhang (2015), 天然气分布式能源面临三大挑战 [Natural Gas Energy Distribution is Facing Three Major Challenges], www.china5e.com/news/news-924613-1.html.

Yang, L. (2017), 阿姆斯特丹的能源地图 [Amsterdam's Energy Map], <http://yuanchuang.caijing.com.cn/2017/0223/4238123.shtml>.

Acronyms and abbreviations

AMI	Advanced metering infrastructure
AREMI	Australian Renewable Energy Mapping Infrastructure
BEV	Battery-electric vehicles
BOO	Build-Own-Operate
BOT	Build-Operate-Transfer
CCER	Chinese Certified Emissions Reduction
CCHP	Combined cooling, heat and power
CHP	Combined heat and power
CNESA	China Energy Storage Alliance
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO ₂	carbon dioxide
CPC	Communist Party of China
DBFO	Design-Build-Finance-Operate
DEP-SD	Department of Environmental Protection, Shandong Province
DER	Distributed Energy Resource
DES	Distributed energy systems
DG	Distributed generation
DH	District heating
DH&C	District heating and cooling
DLR	<i>Deutsches Zentrum für Luft- und Raumfahrt</i> [German Aerospace Centre]
DNG	Distributed natural gas
DPV	distributed photovoltaic
DR	Demand response
DRC-SD	Development and Reform Commission, Shandong Province
DRE	Distributed renewable energy
DS	Distributed storage
EfW	Energy from waste
EMS	Energy management systems
EPC	Energy performance contract
ERCOT	Electric Reliability Council of Texas
ERI	Energy Research Institute of National development and Reform Commission
ES	Energy storage
ESCO	Energy service companies
EU	European Union
EU ETS	EU Emissions Trading Scheme
EV	Electric vehicles
FYP	Five-Year Plan
HP	Heat pump
ICE	Internal combustion engine
ICT	Information and communication technology
IEA	International Energy Agency
LED	Light-emitting diodes
LNG	Liquefied natural gas
METI	Ministry of Economy Trade and Industry
MOF	Ministry of Finance
MOHURD	Ministry of Housing and Urban-Rural Development
NDRC	National Development and Reform Commission

NEA	National Energy Administration
NERC	North American Electric Reliability Corporation
NYISO	New York Independent System Operator
PEFC	Polymer electrolyte fuel cell
PEM	Proton exchange membrane
PHEV	Plug-in hybrid electric vehicles
PPP	Public-private partnership
RD&D	Research, development and deployment
REV	Reforming the Energy Vision
RMB	Chinese Renminbi
SEPA	Smart Electric Power Alliance
SGERI	State Grid Energy Research Institute
SME	Small and medium-sized enterprises
SMUD	Sacramento Municipal Utility District
SOE	Stated-own enterprises
SOFC	Solid oxide fuel cell
T&D	Transmission and distribution
USD	United States dollars
VoS	Value of solar
VRE	Variable renewable energy
WPT	Wireless power transfer

Units of measure

Bcm	billion cubic metre
GW	gigawatt
kW	kilowatt
kWh	kilowatt hour
MW	megawatt
MWh	megawatt hour
tcm	trillion cubic metre
TWh	terawatt hour

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