International Renewable Energy Agency

MARKET INTEGRATION OF DISTRIBUTED ENERGY RESOURCES

INNOVATION LANDSCAPE BRIEF

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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1 HOW IT WORKS

DER participation in

Electricity wholesale markets	Ancillary service markets	Capacity markets
↓	↓	↓

Power system benefits

Load shifting & peak shaving	• Provision of ancillary services • Network congestions management	Improved generation capacity planning

Integrated DER in the grid and increased flexibility in the power system

3 SNAPSHOT

- In EU, DERs can offer 100 GW of demand response potential.
- New York's ISO (NYISO) is planning to enable DER participation in Day-Ahead Demand Response Program and Demand Side Ancillary Services Program.
- By 2050, DERs would supply 30–45 % of Australia's electricity needs

2 KEY ENABLING FACTORS

- Aggregators enable DER to bundle and behave like a traditional power plant in the market
- DSO becomes market facilitator or market maker for DERs
- Enhanced co-ordination between DSO and TSO
- Advanced metering infrastructure

WHAT ARE DERs?

Distributed energy resources (DERs) are small and medium-sized power sources connected to the distribution network, that can potentially provide services to the power system

MARKET INTEGRATION OF DERs

Participation in wholesale and ancillary service markets exposes DERs to **market prices** and enable **demand-side flexibility**

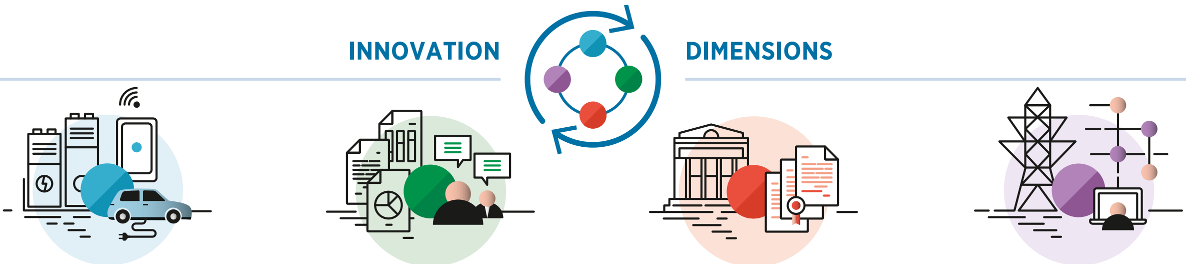
ABOUT THIS BRIEF

This innovation landscape brief is part of the project "Innovation landscape for a renewable-powered future", which maps innovations, identifies synergies and formulates solutions for integrating high shares of variable renewable energy (VRE) into power systems.

A synthesis report, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (IRENA, 2019a), details the need for synergies between different innovations to create actual flexibility solutions for power systems. Solutions to drive the uptake of solar and wind power span four broad dimensions of innovation: enabling technologies, business models, market design and system operation.

Along with the synthesis report, the project includes a series of innovation landscape briefs, each covering one of 30 key innovations identified across those four dimensions. The 30 innovations are listed in the figure below.

INNOVATION DIMENSIONS



ENABLING TECHNOLOGIES

1 Utility-scale batteries
2 Behind-the-meter batteries

3 Electric-vehicle smart charging
4 Renewable power-to-heat
5 Renewable power-to-hydrogen

6 Internet of things
7 Artificial intelligence and big data
8 Blockchain

9 Renewable mini-grids
10 Supergrids

11 Flexibility in conventional power plants

BUSINESS MODELS

12 Aggregators
13 Peer-to-peer electricity trading
14 Energy-as-a-service

15 Community-ownership models
16 Pay-as-you-go models

MARKET DESIGN

17 Increasing time granularity in electricity markets
18 Increasing space granularity in electricity markets
19 Innovative ancillary services
20 Re-designing capacity markets
21 Regional markets

22 Time-of-use tariffs
23 Market integration of distributed energy resources
24 Net billing schemes

SYSTEM OPERATION

25 Future role of distribution system operators
26 Co-operation between transmission and distribution system operators

27 Advanced forecasting of variable renewable power generation
28 Innovative operation of pumped hydropower storage

29 Virtual power lines
30 Dynamic line rating

This innovation landscape brief provides an overview of a market design innovation that allows distributed energy resources (DERs) to provide grid services, by participating in wholesale and ancillary service markets and being exposed to market prices (also referred to as explicit or incentive-driven demand response, as opposed to implicit or price-based demand response in which end-consumers react to price signals). The objective of the market integration of DERs is to achieve better integration of these resources into the grid and to use them to increase grid flexibility.

The brief is structured as follows:

I. DESCRIPTION

Distributed energy resources (DERs) are small or medium-sized resources that can potentially provide services to the power system, directly connected to the distribution network or near the end-user (European Commission, 2015). DERs include distributed generation, behind-the-meter batteries and controllable loads that can be used for demand response, *e.g.* household appliances, smart charging electric vehicles (EVs), power-to-heat (heat pumps, electric boilers, enabled by smart meters and data services) (ARENA, 2018).

The following figure shows the different types of DERs.

Figure 1: Types of distributed energy resources

BEHIND-THE-METER BATTERY

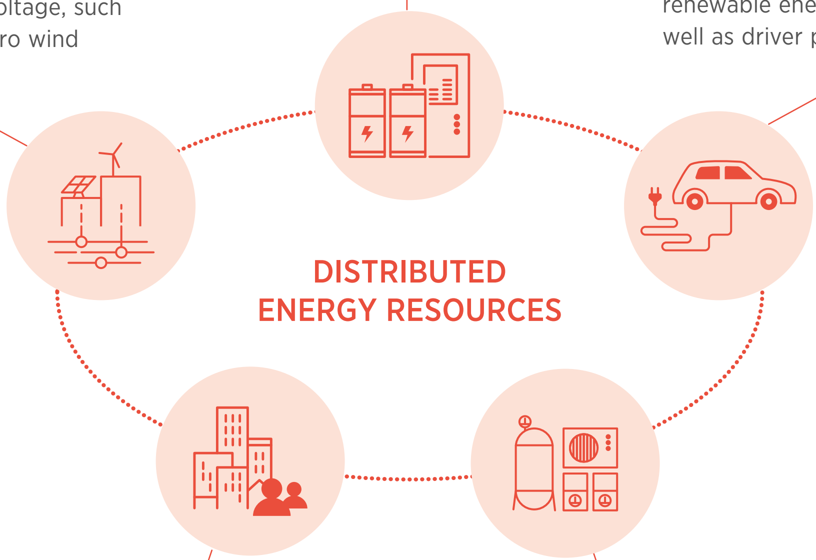
Small batteries that are connected at the consumer end and store electrical energy during periods of surplus generation.

SMART CHARGING ELECTRIC VEHICLES

Optimising the charging cycle of the EVs according to distribution grid constraints and local renewable energy availability, as well as driver preferences.

DISTRIBUTED GENERATION

Generation from plants connected at low and medium voltage, such as solar rooftops, micro wind turbines, etc.



DEMAND RESPONSE

Process that enebles consumers to alter their electricity consumption patterns and provide grid services, individually or through an aggregator.

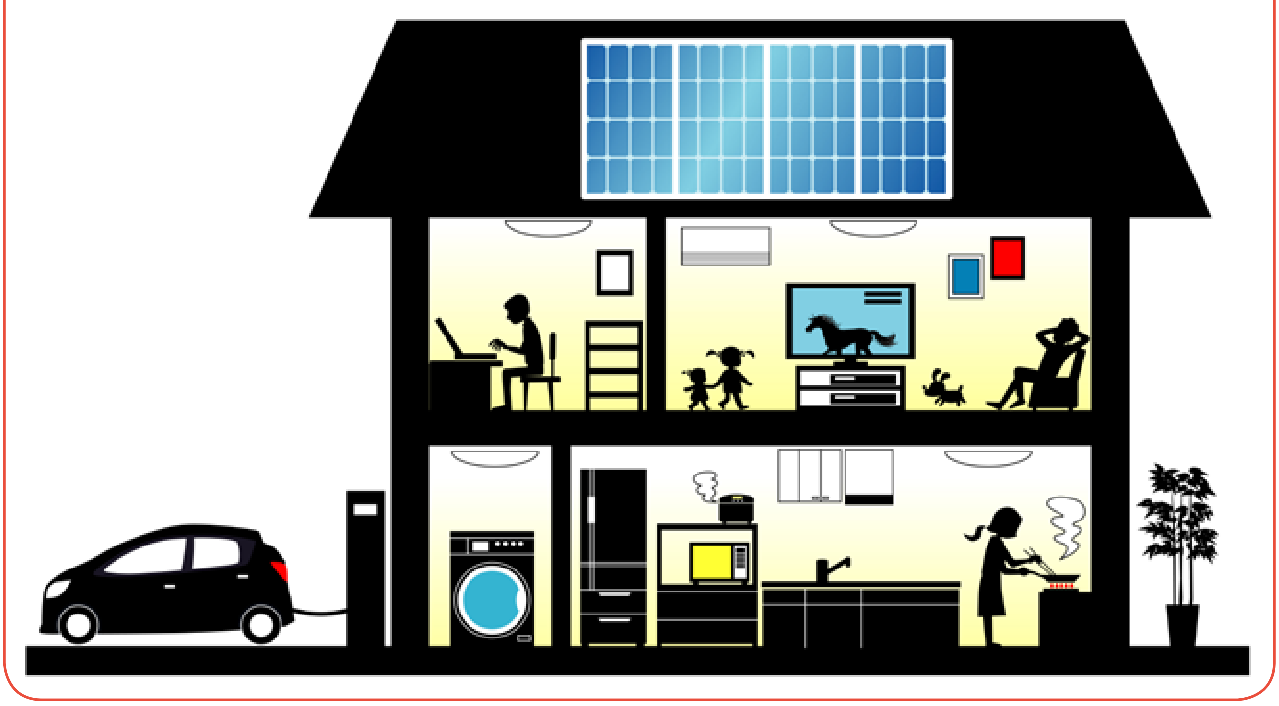
POWER-TO-HEAT

Thermal boilers, heat pumps, thermal storage, etc. used to provide heat for residential purposes.

The deployment of rooftop solar photovoltaic (PV) systems has increased significantly in recent years. Distributed storage has gained momentum as well. For example, behind-the-meter storage business models allow consumers to store the electricity generated by rooftop solar PV power plants and consume it later when needed or sell it (inject it) to the grid. Increased deployment of distributed generation, such as rooftop solar PV, illustrates the emergence of a decentralisation trend versus the traditionally centralised power system. This brings challenges to the system, as well as new opportunitites. Microlevel monitoring and control is needed to ensure optimal system operation and the integration of these resources into the system.

Taking a "connect and forget" approach to DERs would harm the system and result in a missed opportunity in the long term, given the increased deployment of wind and solar power plants connected at the distribution level. However, these resources can be integrated into the grid and provide flexibility services if the enabling policy and regulatory framework is in place.

A key innovation to achieve this is to enable distributed resources to participate in established markets, such as wholesale electricity markets, ancillary service markets and capacity markets (if applicable), so that DERs are exposed to market price signals. This can be done either via aggregators (either an electricity supplier or an independent service provider) or by decreasing the minimum capacity requirement for participating in such markets. For example, DERs should be allowed to participate in wholesale electricity markets (day-ahead and the intraday timeframes) in the same way that supply-side large generators bid in these markets. Exposing DERs to market price signals would in turn increase the demand-side flexibility of the system (also known as explicit demand response, as opposed to the implicit demand response approach used by setting time-of-use tariffs).[1,2]



1 There are two types of demand response: implicit demand response and explicit demand response. In implicit demand response, consumers are exposed to time-of-use electricity prices or time-of-use network prices. In explicit demand response mechanisms, DERs are exposed directly to market prices (Ma, Billanes and Jørgensen, 2017).

2 For implicit demand response, please refer to Innovation landscape brief: Time-of-use tariff (IRENA, 2019c).

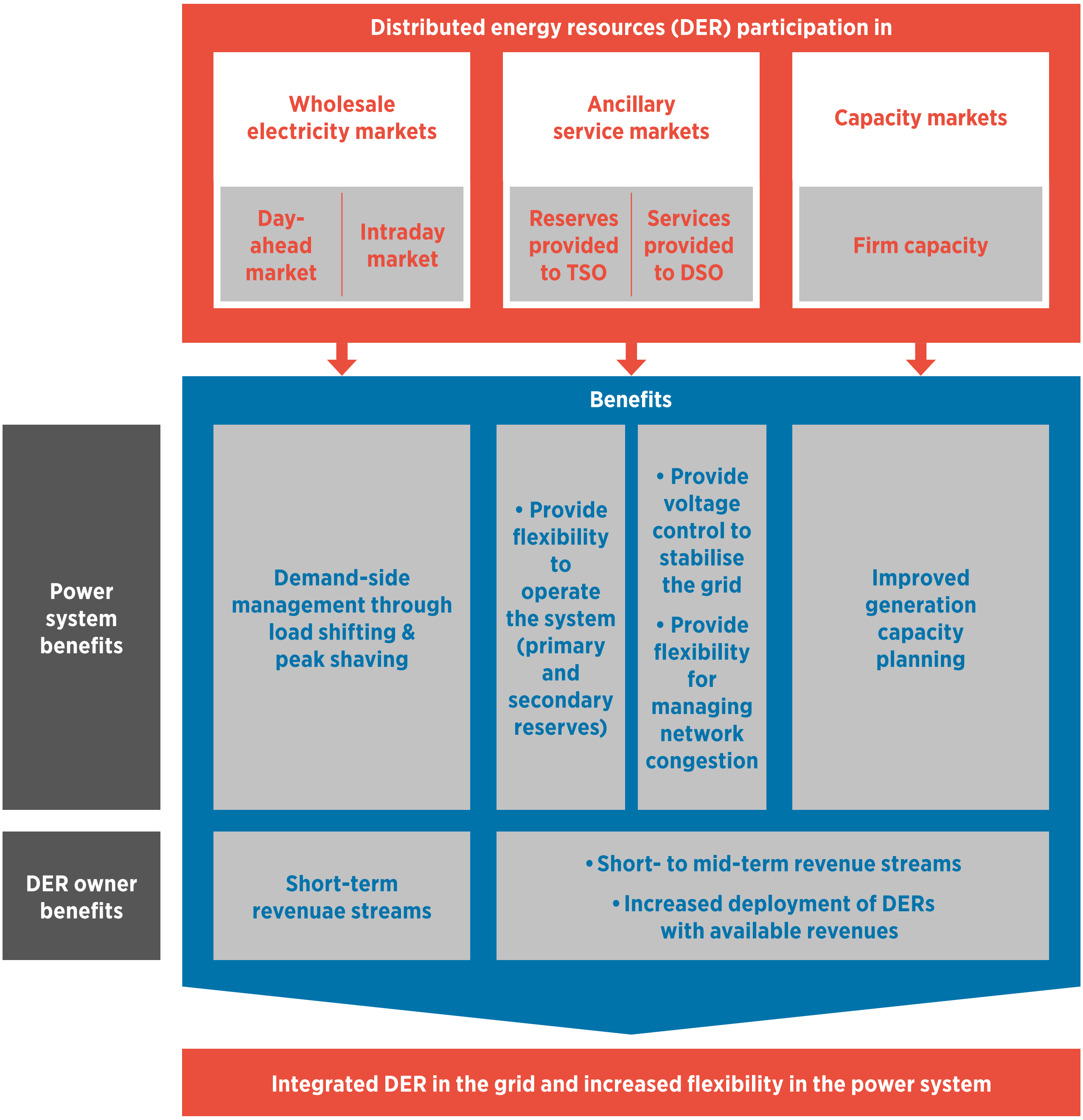
II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

The participation of DERs in wholesale electricity markets, ancillary service markets and/or capacity markets could offer many benefits to a high number of market participants. It could facilitate the integration of distributed renewable energy generation through the management of available resources and therefore better operation of the grid. It could also incentivise DERs to offer their flexibility, facilitating in turn the integration of distributed renewable energy generators into the system and providing benefits to the entire power system (European Commission, 2015). Moreover, DER participation would increase revenue streams for the asset owners and incentivise further deployment of such resources. While these revenue streams may be more volatile in short-term wholesale electricity markets, they tend to be more stable when entering medium- to long-term markets by providing reserves to transmission system operators (TSOs) or when participating in capacity markets.

While a single DER can offer limited services to the grid, aggregating a relatively large number of DERs can lead to the creation of a single, large and predictable entity (*i.e.*, like dispatchable fossil fuel generation). Bundled DERs can provide services for a longer duration, as opposed to single DERs that might not comply with TSOs' requirements. Aggregation can be achieved by co-ordinating the operation of bundled DERs using information and communication technology (ICT) devices (*i.e.*, create a virtual power plant, VPP) and algorithms (*i.e.*, artificial intelligence) to improve the forecast of renewable generation and electricity demand (see Innovation landscape brief: Aggregators [IRENA, 2019b]).

As shown in the figure below, DERs could participate across different markets and offer various services that would increase flexibility in power systems and facilitate the integration of DERs into the grid. For example, in the US market in December 2017, the New York Independent System Operator (NYISO) released a concept proposal of market design changes to enable the participation of DERs in wholesale, as well as ancillary service, markets. According to this proposal, DERs will be treated on par with other market players and will be able to participate in capacity reserve markets and regulation service markets either directly or via aggregators of small-scale DERs (<100 kW) (NYISO, 2017a).

Figure 2: Benefits of market integration of distributed energy resources



Distributed energy resources' participation in wholesale electricity markets

DER participation in wholesale electricity markets allows consumers who have the capacity to also produce electricity (*i.e.*, prosumers, which are actors that both consume and produce electricity) to respond to market price signals and alter their consumption or generation patterns. Prosumers would have two options for using the flexibility provided by their DERs: either they could sell it in the market (directly or via aggregators) or they could optimise their local consumption. While the first option enables stacking revenues from all the services provided in the market, the second option would help reduce final electricity bills. Both options unlock demand-side flexibility in the system through load shifting and peak shaving.

The participation of a significant amount of DERs in the wholesale electricity markets would also increase competitiveness in this market, lowering the volatility of the prices by reducing price spikes and reducing the occurrence of negative prices. For example, when large-scale wind generation produces less energy than forecasted, distributed generators connected to storage devices could bid into the wholesale market. This would reduce stress on the system and would be reflected in the wholesale electricity market, for example by avoiding or reducing price spikes. Similarly, when wind or solar generation surpasses demand, negative prices are sometimes observed. Owners or operators of generation assets connected to batteries could use these price signals to charge their batteries and sell (inject) this electricity at a later point, when prices are positive. DERs could therefore contribute to a more competitive, well-functioning market.

Table 1: Potential services provided by DERs in wholesale markets

Type of market	Trading time frame	Capacity/ Energy trade	Notification time before real time	DERs suited for market need	Examples
Wholesale electricity market	Intraday market	Energy	Usually 24 hours to a few minutes	Aggregated loads and generation	**Europe:** Nord Pool's intraday market (Nordic region) opened to demand response. The French Block Exchange Notification of Demand Response (NEBEF) mechanism allows trading of demand response as well. **US:** Some wholesale markets allow demand response trading, such as Pennsylvania-New Jersey-Maryland (PJM) Interconnection.
	Day-ahead market	Energy	Usually several days to a few hours		

Distributed energy resources' participation in ancillary service markets:

Providing flexibility to transmission system operators (TSOs)

Ancillary service markets are in place to manage demand and generation variations in the transmission network and to provide other transmission network-related services to allow for grid stability and security when assets are called upon by the TSO. DERs should be granted access to the ancillary services market (IRENA, 2017).

TSOs can procure ancillary services from DERs, which have been previously bundled by aggregators, such as primary and secondary reserves. Primary reserves involve response given in milliseconds and providing the service for up to seconds (<30 s). They refer to frequency control services that need to be provided by fast response resources with rapid ramping, such as storage batteries. Secondary reserves are provided in minutes and help stabilise the system by providing power over a longer period of time (compared to primary reserves).

Aggregating DERs to participate in ancillary services markets would allow TSOs access to a larger set of resources, which can provide more flexible, rapid responding services to the grid that last for a few hours (as opposed to one DER). At the same time, DERs get correspondingly remunerated for these services.

DERs can also support the TSO in network congestion management. For example, customers contracted with Voltalis, a French aggregator, receive Bluepod, a free box installed in their homes, which reduces their electric heating device operation in short time intervals whenever Voltalis receives a signal from the TSO. The dispatch signal is used primarily for electricity supply shortage in Brittany (a poorly interconnected French region) or when the network is congested. During these events, customers with Bluepod have their heating automatically controlled, but Bluepod gives them the option to and assume full control over their heating devices. While Voltalis is able to trade the aggregated flexibility in different ancillary services markets, customers observe a reduction of their normal electricity bills due to limited interruptions in electricity consumption for heating (Eid *et al.*, 2016).

Table 2: Potential services provided by DERs to TSOs in ancillary service market

Type of market	Service traded	Capacity/ Energy trade	Response time	Duration of service provision	DERs suited for market need	Examples[3]
Ancillary service market	Primary reserves	Capacity	<30 seconds	Up to 15 minutes (depending on the service)	**Direct control:** Aggrgated EVs, commercial and residential loads, electrical heating, storage systems	**UK:** Demand response with dynamically controlled refrigerators. **US:** EVs and stationary batteries for frequency regulation in PJM.
	Secondary reserves	Capacity	<15 minutes	From 15 minutes up to a couple of hours	**Direct control:** Aggregated EVs, residential continuous loads, electrical heating, storage systems	
	Transmission congestion management	Energy	13 minutes – 2 hours	Several hours	Aggregated EVs, energy storage and combined heat and power (CHP) units	**France:** Volatis, an aggregator, supports the TSO when the network is congested.

3 Source: Eid *et al.* (2016).

Providing flexibility to distribution system operators (DSOs)

Because they are connected to the distribution grid, DERs are potentially problematic for the stability and reliability of the distribution network. The management of DERs could be decentralised by the DSOs. There is an increasing interest in decentralised management of DERs due to expected associated risks for over-voltage, under-voltage and grid congestion caused by the penetration of distributed generation. Such management methods can be supported with the roll-out of smart meters and distributed automation and control.

DSOs can procure local system flexibility services from DERs to solve issues related to voltage regulation, power quality and distribution network congestion. DERs such as PV installations, energy storage devices and plug-in EVs can enable peak shaving during intervals of high demand by discharging and serving local demand. This could reduce the net load on the network and thereby reduce network congestion. By optimally managing DERs across the distribution network, either directly or through third parties (*e.g.*, via aggregators), DSOs could not only avoid congestion, but also defer costly grid reinforcement investments.

For example, battery storage systems deployed by end-consumers could store excess energy from renewable sources, such as solar PV, or be charged for using electricity from the grid when it is relatively cheap. This energy could then be discharged during peak time intervals to fulfil demand.

Aggregating DERs to provide power can also be used to manage grid congestion and avoid grid reinforcement investments. For example, the UK Power Networks, a distribution network operator in the United Kingdom, announced its plan to create London's first virtual power plant (VPP), comprising solar panels and a fleet of batteries across 40 homes in London. A trial of this concept was conducted in February 2018 wherein a fleet of 45 batteries was used to fulfil peak demand. The project is expected to provide an alternative to the traditional approach of increasing network capacity to meet peak demand (Hill, 2018).

Table 3: Potential services provided by DERs to DSOs in ancillary service market

Type of market	Service traded	Capacity/ Energy trade	Response time	DERs suited for market need	Examples[4]
Ancillary service market	Voltage control	Capacity	<1 minute	**Direct control:** Aggregted EVs, residential loads, energy storage systems	
	Distribution congestion management	Energy	<15 minutes	Aggregated EVs, energy storage and CHP units	**UK:** A DSO is using an aggregator to fulfil peak demand without increasing network capacity.

4 Source: Eid *et al.* (2016).

Distributed energy resources' participation in capacity markets: Improved generation capacity planning

Some capacity markets have opened up to the participation of aggregated DERs. The capacity value of aggregated DERs can be used to satisfy a utility's long-term resource adequacy requirements or to defer other infrastructure investments. DERs can also bid in as a resource in capacity markets, where they exist. For example, demand response has proven to be consistently competitive as a capacity resource in the capacity markets operated by PJM and ISO-New England. Demand response refers to the possibility of reducing electricity loads during times of supply scarcity or when system security is in jeopardy. In France, demand response has been allowed to participate in the capacity market (Le Réseau de Transport d'Électricité, 2018). Moreover, Alberta's capacity market allows DER participation, including demand response and distributed generation.

DERs may have different capabilities than traditional generators. This underlines the importance of developing the compensation mechanism for DERs, so that smaller DERs are incentivised to provide capacity services. PJM, a regional transmission organisation (RTO) in the United States, has a capacity market called the "Reliability Pricing Model" under which demand-response resources are treated like generation resources to ensure security of supply. Demand-response providers are paid to ensure resource availability during expected emergency conditions (PJM, 2018). PJM awarded 20 megawatts (MW) in its capacity market to a residential solar and storage provider. For providing 20 MW of power, 24 hours per day for a single year period, the company will be paid USD 912 million for the entire year (Weaver, 2019).

DERs help improve the economic efficiency of overall systems by reducing the need to call on high-cost peaking generating stations (NYISO, 2017a). In the long term, DERs can also help reduce overall investment in networks.

Table 4: Potential services provided by DERs to DSOs in ancillary service market

Type of market	Service	Capacity/ Energy trade	Contract signed	Response time and duration of service provision	DERs suited for market need	Examples[5]
Capacity market	Generation capacity planning	Capacity	Up to several years ahead	Response in minutes, lasting for several hours	Aggregated loads and generation	**US and France:** demand response participates in capacity markets. **Alberta (Canda):** DERs participate in capacity markets.

Potential impact on power sector transformation

For example, an assessment of power systems in Australia, performed by CSIRO and Energy Networks Australia, indicated that increasing the penetration of DERs would lead to the following impacts by 2050 (CSIRO and Energy Network Australia, 2017):

- DERs would supply 30–45 % of Australia's electricity needs.
- The electricity sector would achieve zero net emissions.
- Network operators would pay DER customers over USD 2.5 billion per annum for grid support services.
- Network charges in final electricity bills would be 30 % lower.
- Network infrastructure investment would be reduced by USD 16 billion if DERs were carefully planned.
- Total system costs would be reduced by USD 101 billion.

5 Source: Eid *et al.* (2016).

III. KEY FACTORS TO ENABLE DEPLOYMENT

Expanding the role of distribution system operators

To take advantage of the emerging penetration of DERs, DSOs would need to adjust their current role and transform their operation procedures (see Innovation landscape brief: Future role of distribution system operators [IRENA, 2019c]). For DSOs to consider DER flexibility as a real and effective alternative to grid investments, the regulatory framework should be adapted, introducing new incentives for DERs and enabling DSOs to interact with DERs to procure flexibility services from them. Such measures should aim at developing the mechanisms that encourage DSOs to take up this new role, as well as developing technical specifications and amending grid codes for the provision of such services.

Neutrality and transparency should govern any interaction between DSOs and network users. DSOs must maintain the role of a market facilitator or market maker, but not of a market actor. This means they should not build, manage or operate DERs on their own, like flexible assets. DSOs should be responsible for creating markets and setting the rules for market access. As such, there should be a clear split between the roles of regulated and non-regulated entities (*e.g.*, retail suppliers). Furthermore, regulation should incentivise the DSOs on total expenditures, rather than separately on CAPEX and OPEX.[6] This would in turn incentivise the DSO to better optimise the CAPEX and OPEX mix, and thus leverage the flexibility gained from DER to reduce CAPEX needs (European Commission, 2015).

Enhanced co-ordination between distribution system operators and transmission system operators

DERs can provide grid services to manage local grids. As the penetration of DERs increases, the role of DSOs is expected to become more important. Improved co-ordination between DSOs and TSOs can optimise investments in network enhancement. An institutional arrangement together with the definition of the right protocols for this co-ordination will become necessary. Such co-ordination is expected to benefit from increased DER participation in the power systems via their participation in power markets.

Aggregators, a key enabler of distributed energy resource participation in the market

To create a sizeable quantity of the flexible DERs' capacity to participate in electricity markets, aggregation of these resources should be allowed. Aggregated DERs can behave like traditional power plants – with standard attributes such as minimum/maximum capacity and ramp-up and ramp-down criteria – and can participate in markets by selling electricity or ancillary services. Many DERs can provide the fast response needed for some ancillary services, but they cannot provide the service for the duration needed. Aggregating DERs into a VPP with a fast response enables the provision of services for a long duration. A clear regulatory framework should be designed to allow fair competition among all market participants, including aggregators, whose role could be accomplished either by local electricity retailers or independent third-party aggregators.

6 Total expenditure (TOTEX) = capital expenditure (CAPEX) + operating expenditure (OPEX).

Allowing both electricity retailers and independent aggregators to compete in the market is key to providing cost-effective consumer services. Some countries with demand-response programmes have also allowed the aggregated load to participate in such schemes (*e.g.*, France, Belgium, Switzerland, Great Britain, Australia, etc.). In Western Australia, allowing independent demand-response aggregation has led to 12 % of the peak demand being met through dispatchable loads (SEDC, 2017).

Deployment of advanced metering infrastructure and communication protocols

Smart meters, network remote control and digitalisation, Internet of Things (IoT), broadband communication infrastructure, and smart charging stations for EVs are all fundamental enablers to services associated with DERs. Smart meters will allow real-time communication between system operators and the connected DERs. Network remote control and digitalisation will help improve low voltage network efficiency, since the data gathered can be used to detect outages and better forecast demand. Aggregators, retailers and utilities should be able to communicate with smart appliances and smart meters. Two-way communication network devices would become absolutely essential.

Grid modernisation plays an equally important role. This includes the transformation of the power grid to a platform that can detect, accommodate and control decentralised production and consumption assets, so that power flow in multiple directions can be measured and controlled to ensure the security and reliability of the active distribution network.

To integrate DERs effectively into system operations, communication protocols must be defined for different types of resources. In the case of independent aggregation, communication protocols are needed between system operators and aggregators, using the existing communication system. This ensures that the system operator is able to secure data without the addition of any special communication equipment. Moreover, rules and protocols must be defined to ensure the security of data, while protecting equipment from potential cyberattacks.

Better generation forecasting

A high level of forecasting accuracy of renewable energy generation may help better manage the impact of distributed generation on the grid. Smaller participants may lack the tools or experience that larger renewable players have. Having good weather datasets improves the forecasts of distributed generation. Forecasts for distributed solar PV, for example, can be integrated with load forecasting to obtain net-load forecasts, thus increasing the visibility of the demand-side variations.

IV. CURRENT STATUS AND EXAMPLES OF LEADING INITIATIVES

DERs are being increasingly deployed globally. Some of the key indicators are captured in Table 5.

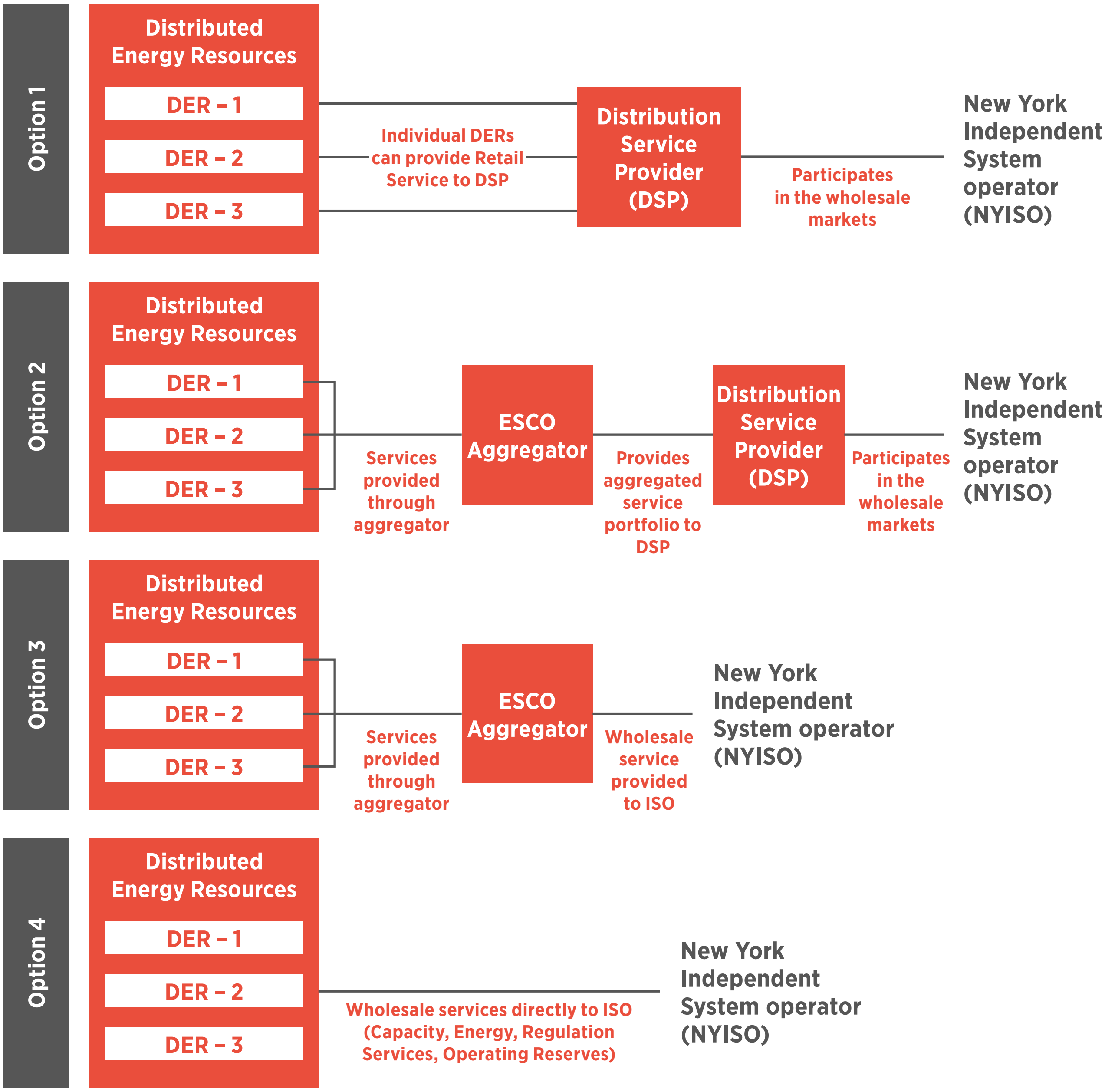
Table 5 Key indicators for DERs deployment in selected regions

Country/Region	Installed capacity of distributed energy resources
Australia	• Small-scale renewable capacity: 7 198 MW (until June 2018) (Clean Energy Regulator, 2018) • EV: 7 340 cars (IEA, 2018) ▶ 30–45 % of demand is expected to be met by DERs by 2050 (CSIRO and Energy Network Australia, 2017)
United States	• Small-scale renewable capacity: 20 125 MW (small-scale solar PV capacity – until February 2019) (US Energy Information Administration, 2018) • EV: 762 060 cars (IEA, 2018)
China	• Small-scale renewable capacity: 31 600 MW (distributed solar by June 2018) (Yuan, Hong, and Zhang, 2018) • EV: 1 227 770 cars (IEA, 2018)
European Union	• Demand response: 21 GW (Jiménez, 2017) • EV: 537 340 cars (IEA, 2018)

Integrating distributed energy resources into wholesale electricity markets: New York's Reforming the Energy Vision strategy

NYISO's December 2017 concept proposal (NYISO, 2017b) outlined a market design that would enable DER participation (NYISO, 2017a). The proposal called for developing market enhancements over the next three to five years that would permit DER participation in NYISO's energy, ancillary services and capacity markets. Under this new design, NYISO aims to replace the existing Day-Ahead Demand Response Program (DADRP) and the Demand Side Ancillary Services Program (DSASP) with a dispatchable DER programme. DERs would be treated on a par with other wholesale market resources by fully integrating them with the energy and ancillary services markets. The participation of DERs would be allowed either directly or via aggregators of small-scale DERs (<100 kilowatts [kW]). Figure 3 shows the various options available to DER participants to provide services in wholesale power markets.

Figure 3: NYISO integrating distributed energy resources in ancillary service markets



ESCO = energy service company; **Based on:** NYISO (2017b).

Integrating distributed energy resources in Europe

There is an increasing awareness among European policy makers that demand response is becoming a critical resource to manage the grid at a reasonable cost. This is evident from the fact that there is a thorough inclusion of demand response in the European Commission's legislative package on the new electricity market design within the Clean Energy Package. As such, the revised Electricity Regulation, which will enter into force on 1 January 2020, opens up electricity wholesale markets to renewables, energy storage and demand response (European Commission, 2019). Explicit demand response contributes around 15 GW out of a total 21 GW of demand-response capacity in Europe (Jiménez, 2017). Until now, the European countries with the most conducive frameworks for explicit demand response were Belgium, Finland, France, Ireland, the United Kingdom and Switzerland. Belgium, France, the United Kingdom and Switzerland have already enabled the participation of demand response either individually or via aggregators, while countries such as Slovenia and Poland have opened their power markets to individual demand response only (SEDC, 2017).

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS

Hardware:

- Widespread adoption of distributed generation sources and energy storage technologies.
- Equipment, such as smart meters (required to provide real-time power consumption and production data), home gateways (*e.g.*, energy boxes) and smart appliances for energy management.
- Smart grids enabling two-way flow of data and electricity.

Software:

- Aggregation and generation forecasting software: real-time communication between the aggregator and the smart meters, smart appliances and the energy storage systems.
- Distribution system management software ensuring reliability and safe operations.

Communication protocol:

- Common interoperable protocol to increase co ordination between DER assets, aggregators and system operators.

POLICIES NEEDED

Strategic policies could include:

- Supportive policies encouraging the decentralisation of power systems and better utilisation of existing infrastructure.
- Policies focusing on creating functioning markets (wholesale electricity, ancillary services and/or capacity markets), deploying innovative technologies and reducing grid costs.

REQUIREMENTS REGULATORY	
	Electricity wholesale market: • Allow aggregation of DERs to enable their participation in the markets or reduce the minimum bid sizes to allow DERs to participate. • Reduce the time before trading gate closure to better capture the short-term forecast of DERs.
	Ancillary service market: • Make ancillary service product requirements and local system service product requirements technology neutral. • Introduce shorter procurement times that facilitate DERs' participation.
	Transmission and distribution system: • Define geographic markets, *i.e.*, geographic segmentation into local zones, where DERs can provide balancing and flexibility services to meet local needs. • Incentivise network operators to upgrade their network infrastructure to facilitate wider DER adoption, or to use DERs to manage grid congestion.
STAKEHOLDER ROLES AND RESPONSIBILITIES	**Policy makers and regulators:** • Define a vision for DER deployment: DER implementation roadmap, planning and optimising the location of DERs, etc. • Develop pilot programmes to work as test beds and disseminate the results. • Establish innovation centres within research institutions, government and industry to further promote innovation in the operation of DERs.
	Distribution system operators and transmission system operators: • Change the role of DSOs to act as market facilitators for DERs or as buyers of local flexibility. • Strengthen TSO-DSO co-operation so information flows in both directions, thereby enabling DERs to provide services to the TSO by increasing the visibility of available flexibility at the DSO level to the benefit of the TSO.
	Consumers: • Engage consumers beyond the retail market (*e.g.*, reacting to prices in wholesale markets and changing consumption patterns accordingly). • Encourage consumers to become prosumers by owning DER assets (*e.g.*, behind-the-meter storage, solar PV plants, EVs, etc.).

ABBREVIATIONS

CAPEX	Capital expenditure
CHP	Combined heat and power
DADRP	Day-Ahead Demand Response Program
DER	Distributed energy resource
DSASP	Demand Side Ancillary Services Program
DSM	Demand-side management
DSO	Distribution system operator
ESCO	Energy service company
EV	Electric vehicle
ICT	Information and communication technology
IoT	Internet of Things
ISO	Independent system operator
kW	Kilowatt
MW	Megawatt
NYISO	New York Independent System Operator
OPEX	Operating expenditure
PJM	Pennsylvania-New Jersey-Maryland
PV	Photovoltaic
REV	Reforming the Energy Vision
RTO	Regional transmission operator
TOTEX	Total expenditure
TSO	Transmission system operator
VPP	Virtual power plant
VRE	Variable renewable energy

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MARKET INTEGRATION OF DISTRIBUTED ENERGY RESOURCES

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