IRENA
International Renewable Energy Agency

AGGREGATORS

INNOVATION LANDSCAPE BRIEF

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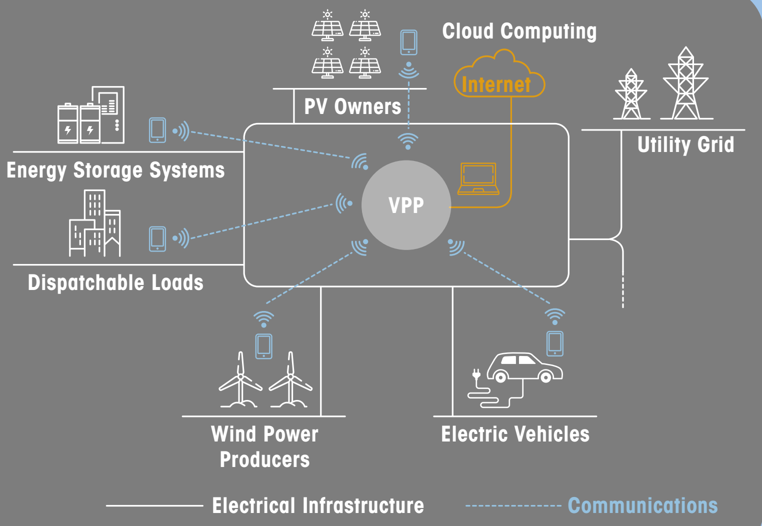
1 BENEFITS

Aggregators use a centralised IT system to remotely control the DERs and optimise their operation.

They can provide:

- ➜ Load shifting
- ➜ Balancing services to TSOs
- ➜ Local flexibility to DSOs



3 SNAPSHOT

- Global market value of USD 762 million in 2016, expected to reach USD 4 597 million in 2023
- World's Largest VPP is expected to connect DERs in 50,000 homes to meet 20 % of South Australia's daily power demand.
- Projects in Netherlands, Germany and Australia are aggregating behind the meter batteries to provide grid services.

2 KEY ENABLING FACTORS

- Smart meters & Communication Infrastructure
- Regulatory framework allowing participation of new market players
- Accurate data (weather forecast, load projections, wholesale prices)

WHAT ARE AGGREGATORS AND DERs?

Distributed energy resources (DERs) are small and medium-sized power resources connected to the distribution network.

Aggregators bundle DERs to engage as a single entity – a virtual power plant (VPP) – in power or service markets.

AGGREGATORS

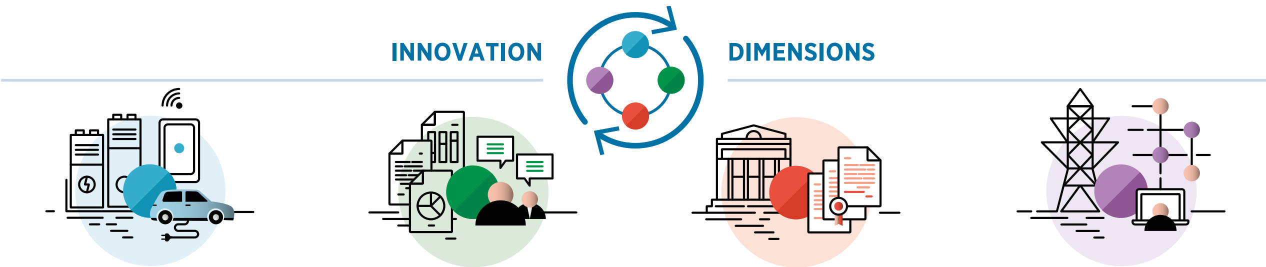
Increased digitalisation and smart metering have created new business models. **Aggregators are a new market player that can optimise the use of distributed energy resources.**

ABOUT THIS BRIEF

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

The synthesis report, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (IRENA, 2019), illustrates the need for synergies among different innovations to create actual solutions. 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 main report, the project includes a series of briefs, each covering one of 30 key innovations identified across those four dimensions. The 30 innovations are listed in the figure below.



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

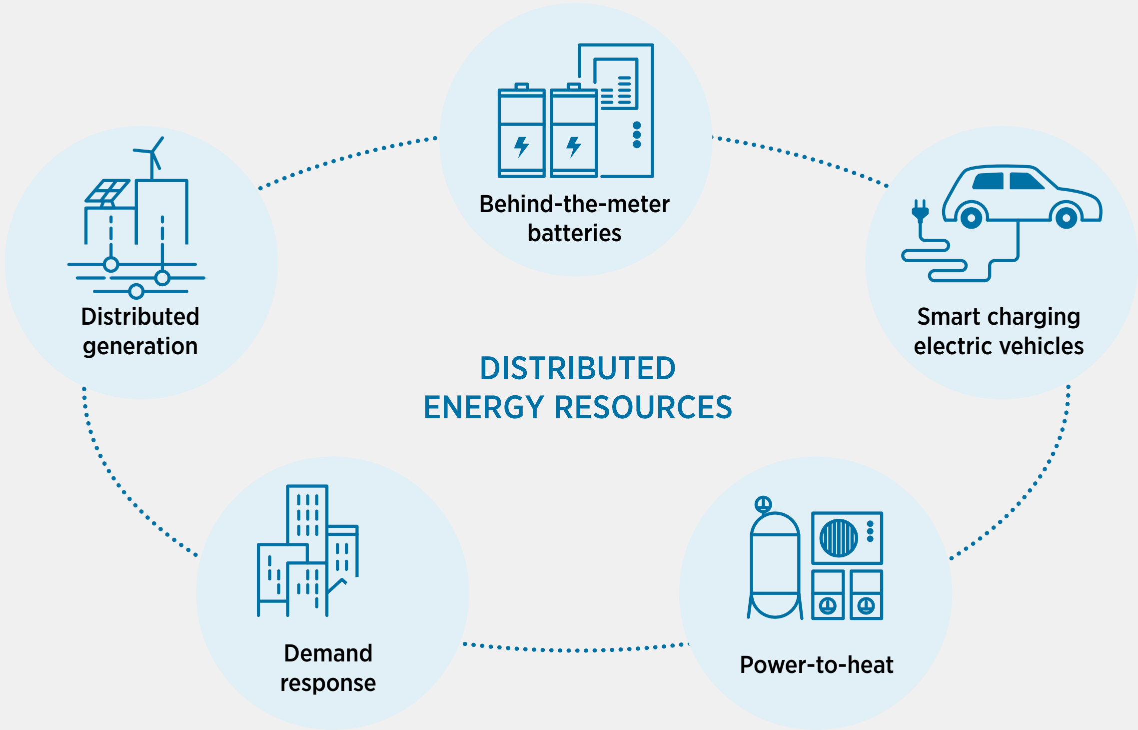
SYSTEM OPERATION

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

Distributed energy resources (DERs) are small or medium-sized resources, directly connected to the distribution network (EC, 2015). DERs include distributed generation, energy storage (small scale batteries) and controllable loads, such as electric vehicles (EVs), heat pumps or demand response.



This brief provides an overview of an innovative business model: aggregators.

An aggregator can operate many distributed energy resources (DERs) together, creating a sizeable capacity similar to that of a conventional generator. This aggregation also can be called a "virtual power plant". Aggregators can then sell electricity or ancillary services via an electricity exchange, in the wholesale market, or through procurement by the system operator. The brief focuses on the various services that aggregators can provide to support power system transformation and the integration of VRE.

The brief is structured as follows:

I. DESCRIPTION

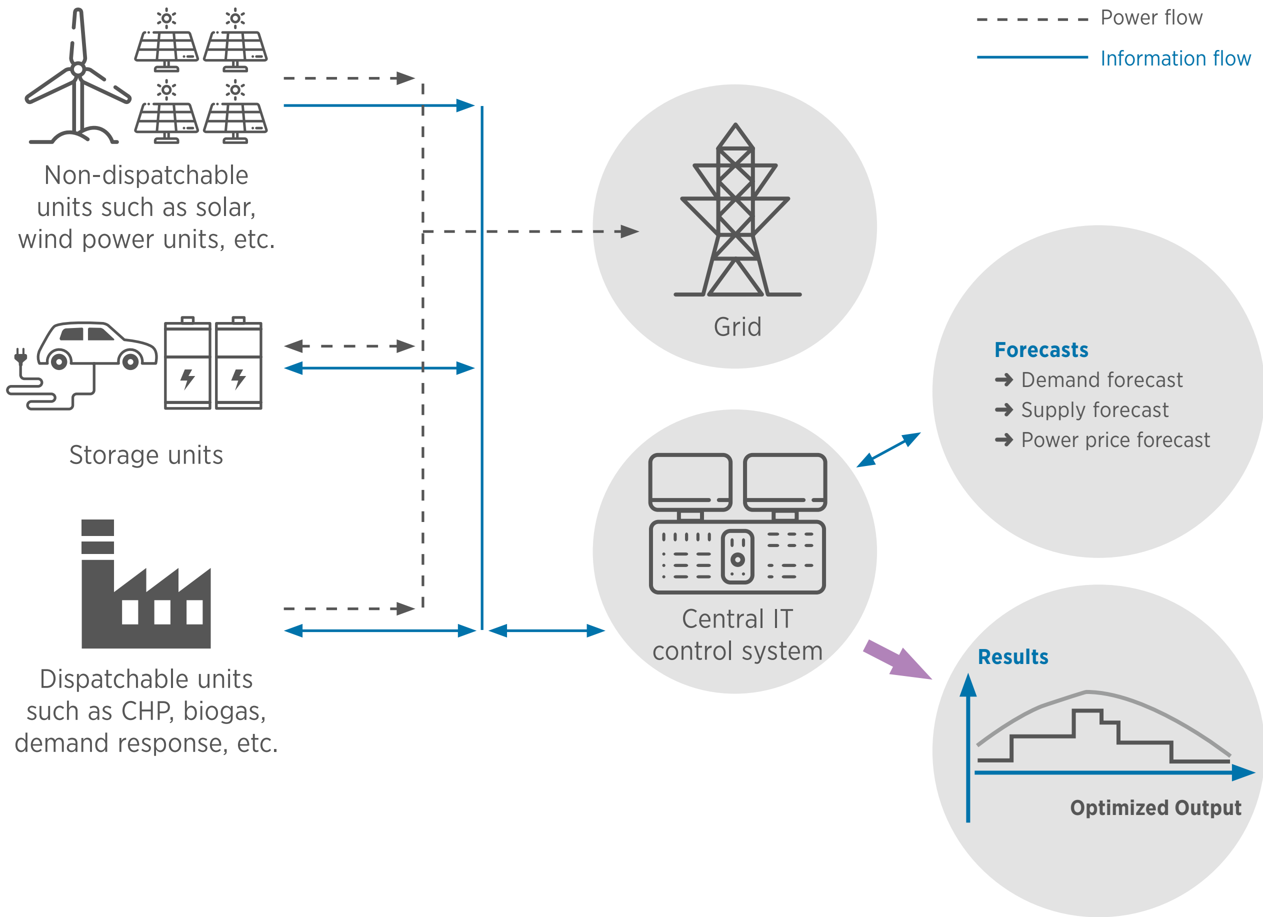
An aggregator is a grouping of agents in a power system (*i.e.*, consumers, producers, prosumers or any mix thereof) to act as a single entity when engaging in power system markets (both wholesale and retail) or selling services to the operator (MIT, 2016). In the context of this brief, an aggregator is a company that operates a virtual power plant (VPP), which is an aggregation of disperse DERs with the aim of enabling these small energy sources to provide services to the grid.

VPP operators aggregate DERs to behave like a traditional power plant with standard attributes such as minimum/maximum capacity, ramp-up, ramp-down, etc. and to participate in markets to sell electricity or ancillary services. The VPP is controlled by a central information technology (IT) system where data related to weather forecasts[1], electricity prices in wholesale markets, and the overall power supply and consumption trends are processed to optimise the operation of dispatchable DERs included in the VPP.

An aggregator can help in better integration of renewable energy resources by providing both demand- and supply-side flexibility services to the grid. Demand-side flexibility is provided by aggregating demand-response resources or energy storage units to act to grid requirements. Supply-side flexibility is provided by optimising power generation from flexible resources such as combined heat and power (CHP) plants, biogas plants, etc. and the use of energy storage units. Operation optimisation is done based on data on historical and forecasted data on demand, generation and prices. Figure 1 provides an overview of how an aggregator operates the distributed energy resources.

1 *Weather forecasts are used to predict power generation from non-dispatchable renewable energy resources such as solar and wind power.*

Figure 1 Overview of an aggregator



Note: A central IT control system or a decentralised energy management system (DEMS) sends an optimised schedule to the dispatchable distributed energy resources.

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

By bundling DERs and creating VPPs, aggregators create a sizeable capacity that becomes eligible to participate in wholesale power markets. The aggregator can provide various grid services such as frequency regulation, operating reserve capacity, etc. by optimising a suitable portfolio of distributed energy resources. A VPP can include fast-response units such as super capacitors and batteries, along with CHP and biogas power plants and demand-response resources to provide different flexibility services (Ma et al., 2017).

The benefits that an aggregator can provide include:

Services to help operate the power system

- **Load shifting**: Aggregators can enable real-time shifting of commercial and industrial loads to provide demand-side management services to grid operators, based on price signals. A field trial conducted with the PowerMatcher[2] Suite in the Netherlands showed that peak demand can be reduced by 30 % to 35 % by managing heat systems (micro CHP and heat pumps) (TNO, 2016). This makes a business case for deferred investments in distribution and transmission grid infrastructure.

- **Balancing services**: Aggregators can use optimisation platforms to provide a range of ancillary services, increasing the system's flexibility to integrate VRE resources. Aggregators can mitigate the "ramps" caused by solar going down in the evening (*i. e.*, the neck of the duck in the duck curve) or any other variable generation output. In addition to providing ramping requirements, VPPs can be used to provide ancillary services. Next Kraftwerke, a VPP in Germany, has its power shifted up and down as often as 20 times a day. The power plant can be controlled in 15-minute increments based on current prices on the spot market. The transmission grid operators benefit from valuable control reserve. The power plant offers an average electric capacity of 1.2 megawatts (MW), while the installed capacity is nearly 4 MW. Inclusion of the power plant's added flexibility from storage plants can help compensate for fluctuations in wind and solar (Next Kraftwerke, *n.d.*).

- **Local flexibility**: Aggregators can provide flexibility at the distribution system operator level, if there is a regional/local market for flexibility in place.

Decreasing the marginal cost of power

In some cases, large power plants are used to supply electricity in order to meet a small quantity of demand, leading to a higher cost of power production. For example, for an increase in peak demand, an additional fossil fuel plant needs to be dispatched, increasing the system's marginal cost. Instead, an aggregator might be able to reduce the load and therefore decrease the marginal cost. Also, resources included in an aggregator can replace the peak power plant by dispatching the aggregated distributed generation technologies and charged batteries.

2 *PowerMatcher is a smart grid co-ordination mechanism developed by the Netherlands Organisation for Applied Scientific Research (TNO).*

Optimising investment in power system infrastructure

An aggregator can bundle and control the DERs to provide real-time operating reserve capacity that can participate in ancillary markets when needed. This can enhance the economic return for the owners of the distributed energy resources. Further, using existing distributed energy resources to provide reserve capacity services can help in avoiding investments in peak generating capacity. For example, in the US state of New Mexico, the Enbala VPP is being used to provide 20 MW to 25 MW of flexibility, mitigating the need for expensive traditional power generation resources. A VPP helps save on the cost of new capacity additions while generating additional revenues for already connected distributed energy resources (Next Kraftwerke, *n.d.*).

The US Energy Information Administration estimated the cost of building a new coal-fired power generation unit in the range of USD 2 934 to USD 6 599 per kW, depending on the technology used. The cost of building a gas-fired plant would range from USD 676 to USD 2 095 per kW.

Both of these options have significant environmental and stranded investment risks. Using already connected energy resources, through aggregators, can minimise the investment needed in additional capacity. Aggregators can provide financial benefits to owners of distributed energy resources by maintaining demand and supply balance at a cost of USD 70 to US 100 per kW (Enbala, *n.d.*).

By using aggregators to provide demand-side management and load shifting, investments in transmission and distribution grid reinforcements also could be minimised.

Potential impact on power sector transformation

In South Australia, aggregators can meet 20 % of daily power demand and provide 30 % savings on energy bills.

The South Australian government and Tesla are developing a network of 50 000 household solar PV units connected into an aggregator. This is expected to meet around 20 % of South Australia's average daily power demand (250 MW).

Additionally, the new power plant is expected to lower energy bills for participating households. The wholesale price is estimated to drop by around **USD 3 per MWh** for all customers **with each additional 50 MW of capacity** that is brought onto the system via the aggregator. The Australian VPP Tesla proposal could reduce the wholesale electricity price by around **USD 8/MWh**, or around **USD 90 million per year** across all South Australian customers, which means **30 %** of the total energy bill (Frontier Economics, 2018).

III. KEY FACTORS TO ENABLE DEPLOYMENT

Regulatory framework

A liberalised wholesale power market with no price caps (especially with spot markets in place) is essential for establishing aggregators. The main incentives for creating an aggregator are given by the difference between peak/off-peak pricing on wholesale markets or by signals from transmission system operators to deliver control reserve or other ancillary services.

The regulatory framework should enable aggregators to participate in the wholesale electricity market and also in the ancillary services market. For example, the New York Independent System Operator (NYISO) proposed aggregating DERs connected to the same bulk transmission node to ensure that these resources are compensated based on their locational and temporal value (NYISO, 2017). While NYISO has restricted aggregation of DERs to a specified geographical limit, other system operators can allow DER aggregation without geographical barriers.

Advanced metering infrastructure

Real-time data acquisition from DERs is necessary for the creation and operation of a VPP. This would require smart meters, broadband communication infrastructure, network remote control and automation systems (network digitalisation). Real-time communication between VPP operators and the connected DERs is needed. Network remote control and digitalisation help in improving network efficiency since the data gathered can be used to better forecast demand. Two-way communication network devices are essential.

Better generation forecasting

Advanced forecasting tools and techniques are essential to predict power generation from renewable energy and load forecast in the power system for deriving an optimised schedule of dispatchable DERs. Forecasts for distributed generation can be integrated with load forecasting to obtain net load forecasts, thus increasing the visibility of demand-side variations.

IV. CURRENT STATUS AND EXAMPLES OF ONGOING INITIATIVES

Some of the key indicators about aggregators have been captured in the table below, followed by examples of aggregators.

Table 1 Aggregators: Key indicators

Description	Value
Virtual power plant (VPP) global market value	USD 762 million in 2016; expected to reach USD 4 597 million in 2023 (compound annual growth rate of 25.9 % from 2017 to 2023) (Research and Markets, 2018)
Countries with established regulatory frameworks allowing VPP trading	Australia, Austria, Belgium, Germany, Denmark, France, Netherlands, UK, US, etc.
Services provided by aggregators	• Forecasting and trading of distributed energy resources • Optimised dispatching of distributed energy resources according to intraday pricing on spot markets • Delivery of ancillary services to transmission (and potentially distribution) system operators

VPP contributes to renewable energy integration and system stability in South Australia

Tesla proposed the development of a 250 MW virtual power plant to contribute to stabilising South Australia's electricity infrastructure and to improve the security and reliability of the grid in an area where nearly half of the electricity comes from wind farms. The initiative will start with a trial in 1 100 public housing units (Government of South Australia, 2017).

The technology involves four key components:

- Smart meters installed in every participating household to assist in controlling the rooftop solar and battery, and to measure the power flows;
- A network of rooftop solar PV systems installed on public housing (5 kW solar panel system);
- Battery storage installed on public housing in South Australia (5 kW/13.5 kWh Powerwall 2 Tesla battery); and
- A computer system to control the storage, use and transfer of renewable and battery-stored power between houses and the grid, to maximise the value for customers while delivering services to the grid when needed.

The impact of such a solution would be considerable in terms of renewable energy integration, with approximately 130 MW of added rooftop solar PV generation capacity and 130 MW/330 GWh of distributed, dispatchable battery storage. This approximately doubles if the roll-out is extended to a similar number of private customers.

In terms of the flexibility added to the system, the participation of 50 000 households in the programme would add 250 MW of peak capacity to the system or, alternatively, reduce the demand on the central grid by 250 MW, freeing the capacity to be supplied to other customers.

In terms of cost reduction, the wholesale price in South Australia is estimated to drop by around USD 3/MWh for all customers, with each additional 50 MW of capacity brought into the system that would not otherwise be operating. This suggests that if only the public housing customers participated in the arrangement, the Tesla proposal could reduce the wholesale price by around USD 6/MWh[3], or about USD 65 million per year, across all South Australian customers. The savings would be approximately double if the project could achieve its full scale of production of 250 MW. Moreover, the government has provided estimates showing that the project could lower the power bills of those who sign up by 30 % (Frontier Economics, 2018).

Other examples of aggregators

Table 2 Key features of leading aggregators

Aggregator	Country/Region	Key features
AGL	**Australia**	• AGL's VPP consists of a network of behind-the-meter batteries providing a range of benefits to the household, the retailer and the local network. The VPP aims to both cut consumer electricity costs and help maintain grid stability in South Australia (AGL, *n.d.*).
Eneco CrowdNett	**Netherlands**	• Founded in 2016, Eneco CrowdNett is a Dutch-based aggregator of home batteries and provides grid services through a network of behind-the-meter batteries owned by prosumers. • Consumers are provided batteries at a discount and receive an additional EUR 450 annually in exchange for access to 30 % of the battery capacity at any time during the day (Hanley, 2016).
Energy & meteo systems (emsys)	**Germany**	• Emsys supports power aggregators in efficient market integration of their power assets. • Emsys's offering in VPP includes: connection to distributed power plants through various interfaces, real-time data management, remote control of wind and PV (*e.g.*, to avoid negative spot market prices), generation forecast optimisation, energy scheduling, trading on the day-ahead and intraday spot markets, provision of balancing power by distributed power plants (primary, secondary and tertiary control), provision of balancing power by wind farms (tertiary control in Germany), demand-side management and balancing group management. • Emsys is one of the first aggregators to execute primary control using batteries in the German balancing power market.
Next Kraftwerke	**Europe**	• Next Kraftwerke is a network of multiple power-producing and power-consuming units of varied sizes distributed across Europe. • Next Kraftwerke forecasts the approximate production and consumption of energy on a real-time basis for the balancing group. It then transmits the schedule to the TSO on a daily basis and trades the forecasted volumes on the day-ahead market on the stock exchange. Deviations from the forecast are compensated through intraday trading. • Next Kraftwerke's VPP delivers ancillary services (primary reserve, secondary reserve, tertiary reserves) in seven European TSO zones and uses its algorithms to send optimised schedules to the networked units to benefit from peak pricing on wholesale markets. • The VPP consists of around 5 500 units amounting to over 4 500 MW (Next Kraftwerke, *n.d.*).
Stem	**United States**	• This California-based start-up with artificial intelligence technology focuses on behind-the-meter energy storage systems and VPPs. • It uses energy storage systems to reduce the cost of electricity for commercial consumers. The batteries are charged when the cost of electricity is low and discharged when the cost of electricity is high (typically during peak demand period). • Stem can use its software to reduce the net demand of its customers, thereby reducing the demand of the whole area when the existing supply system cannot supply in the local area (Stem, 2019).

3 *Converted from AED at the rate of 1 AED = 0.72 USA*

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS

Hardware:

- Controllable load and supply assets such as energy storage, electric vehicles and distributed generation
- Smart meters (to provide real-time power consumption and production), home gateways (energy boxes) and smart appliances for energy management, to enable VPP operation

Software:

- Aggregation software, algorithm to calculate the optimal operation of each unit
- Real-time communication between the aggregator and the hardware system
- Advanced demand and supply forecasting models/platforms for optimised scheduling of dispatchable distributed energy resources

Communication protocols:

- Common interoperable protocol for co-ordination among system operators, network operators and prosumers

REGULATORY REQUIREMENTS

Wholesale market:

- Participation of aggregators should be allowed in electricity wholesale markets and ancillary service markets
- Introduce regulations allowing decentralised sources to provide services to the central/local grids
- Clear price signals to guide the aggregators' operations
- Regulations to mandate implementation of smart meters and smart grid infrastructure

Distribution:

- Establishment of local markets for DSOs to procure services to avoid grid congestion and ensure grid stability
- Data collection, management and sharing rules for DSOs to ensure consumer privacy

Retail market:

- Regulators should define a standardised methodology for computing dynamic prices that can be adopted by retailers.
- Functioning retail markets could provide innovative products and pricing models for various customer needs. For example, in Finland innovative products are being introduced, and customers can opt to choose the product and pricing method best suited to their needs (such as hourly dynamic pricing, retailers buying excess solar photovoltaic generation as a marketbased solution, ToU tariffs, etc.).
- Regulation should set clear roles and responsibilities for market parties. Long-term foreseeable regulation is needed.
- Liberalised markets, as opposed to regulated markets, could facilitate the market entry

System operation:

- Defining rules for co-ordination between distribution and transmission system operators

STAKEHOLDER ROLES AND RESPONSIBILITIES

Aggregators:

- Provide grid-related services to DSOs, if a market is established
- Information exchange with DSOs related to capacity, location, type of DERs

Distribution system operators:

- Ensure a level-playing field for all flexibility providers
- Procure market-based flexibility services from aggregators
- Securely share consumer and grid-related data with third parties as per applicable data privacy and sharing norms
- Better forecasts for DER services based on past data or historical performance and weather forecasts

ABBREVIATIONS

AMI	Advanced metering infrastructure
BtM	Behind-the-meter
DEMS	Decentralised energy management system
DER	Distributed energy resource
DSO	Distribution system operator
EV	Electric vehicle
GW	Gigawatts-hour
IT	Information technology
kWh	Kilowatt-hour
TSO	Transmission system operator
VPP	Virtual power plant
VRE	Variable renewable energy

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