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TIME-OF-USE TARIFFS
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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Disclaimer

TIME-OF-USE TARIFFS

Demand-side flexibility is key for a renewable-powered future.
Tariffs that change with time of use enable **demand response**.

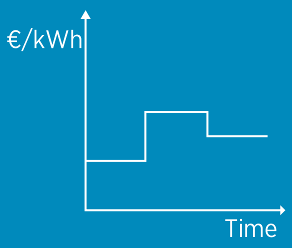
WHAT ARE THEY?

Time-varying tariffs incentivise load adjustment, either manual or automated.
This allows customers to save on energy expenses while benefitting the system.

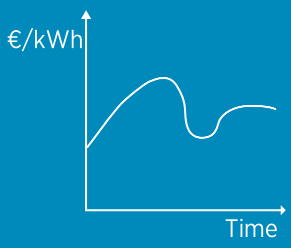
1 HOW THEY WORK

Tariffs send customers **price signals** that reflect **system conditions**.

Static (determined in advanced)



Dynamic (determined in real time based on actual system conditions)



2 BENEFITS FOR THE SYSTEM

- Unlock demand response
- Reduce peak load and investments in grid infrastructure

3 KEY ENABLING FACTORS

- Advanced metering infrastructure
- Digital technologies for automation
- Dynamic pricing, linking retail and wholesale markets

4 SNAPSHOT

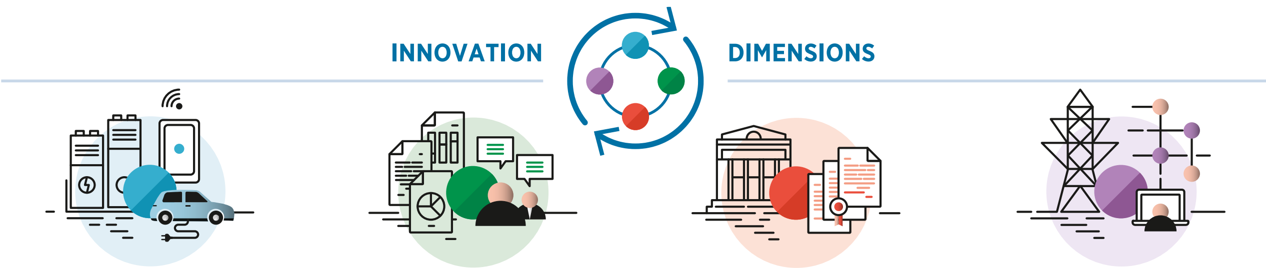
- → US saved over 5 % on retail electricity sales due to demand response, by implementing time-of-use tariffs in 2015
- → Nordic market could achieve 15–20 GW of demand-side flexibility
- → Implemented in at least 17 EU countries (including, Finland, France, Germany, Sweden)

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 between 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 synthesis 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

This brief provides an overview of a key innovation in market design: time-of-use (ToU) tariffs, also referred to as a mechanism for implicit demand response.

With a ToU tariff scheme, customers can adjust their electricity consumption voluntarily (either through automation or manually) to reduce their energy expenses. As the name indicates, the price signals are time-varying, determined based on the power system balance or on short-term wholesale market price signals.

Significantly, ToU tariffs unlocks demand-side flexibility and can thereby help to increase the penetration of renewable energy. Examples show how various countries and regions have adopted ToU tariffs and illustrate the impact of these tariffs on the power system.the electricity system, such as aggregators.

The brief is structured as follows:

I. DESCRIPTION

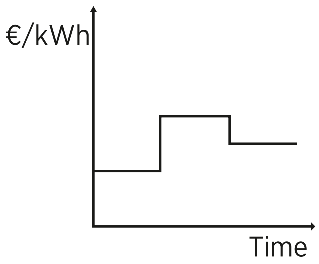
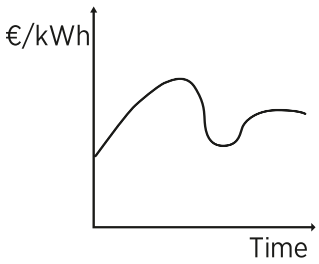
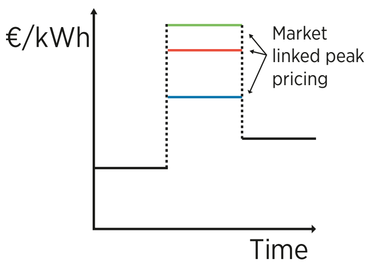
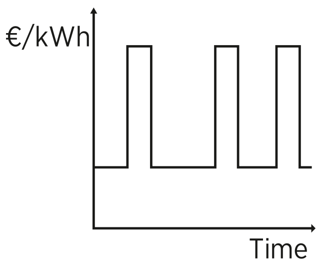
Demand response refers to the possibility of changing energy loads during specific time intervals by exposing consumers to the correct cost-reflective price signals. The US Federal Energy Regulatory Commission (FERC) defines demand response as "changes in the electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when the system reliability is jeopardised" (FERC, 2017).

Demand response can be achieved through ToU tariffs, based on consumers' reaction to price signals (also referred to as implicit demand response) or through incentive-driven demand response, by trading committed and dispatchable flexibility on energy markets (also referred to as explicit demand response) (SEDC, 2016).

This brief is focused on ToU tariffs, also called price-based demand response programs. ToU tariffs enable customers to adjust their electricity consumption voluntarily (either through automation or manually) to reduce energy expenses. As the name indicates, the price signals are time-varying, determined based on the power system balance or on short-term wholesale market price signals (such as day-ahead or intraday price signals).

Time-based tariff structures can be static (e.g., tariffs determined in advance) or dynamic (e.g., tariffs determined in "real time" based on the actual system conditions). Dynamic tariff structures include real-time pricing, variable peak pricing and critical peak pricing /critical peak rebates. Time-based rate programmes require advanced metering infrastructure (AMI). The table below gives an overview of time-based demand response pricing options.

Table 1 Forms of time-of-use tariffs

Type of tariffs	Nature of pricing	Illustrative graphical representation	Features
Static ToU pricing	**Static**		This typically applies to usage over large time blocks of several hours, where the price for each time block is determined in advance and remains constant. It can use simple day and night pricing to broadly reflect on-peak and off-peak hours, or the day can be split into smaller segments, allowing several slack periods. Seasonality can also be taken into account.
Real time pricing	**Dynamic**		Prices are determined close to real-time consumption of electricity and are based on wholesale electricity prices. Electricity prices are calculated based on at least hourly metering of consumption, or with even higher granularity (e.g., 15 minutes). Such tariffs are mostly composed of the wholesale price of electricity plus a supplier margin.
Variable peak pricing	**Combination of static and dynamic**		A hybrid of static and dynamic pricing, where the different periods for pricing are defined in advance, but the price established for the on-peak period varies by market conditions.
Critical peak pricing	**Combination of static and dynamic**		A rate in which electricity prices increase substantially for a few days in a year, typically during times the wholesale prices are the highest. E.g., French Tempo tariff is a contract with a fixed price all year except for a maximum of 22 days with very high prices. Customer are notified of

Source: Adopted from smartgrid.gov (n.d.) and EURELECTRIC (2017)

When there are constraints on the electricity network, it makes sense to introduce location-based tariff structures. Location-based tariffs reflect the cost associated with congestion in electrical networks (e.g., nodal pricing), incentivising the consumers and prosumers (i.e., participants who can both buy and sell electricity) to reduce electricity consumption from the grid or to inject electricity into the grid based on network congestion. As such, ToU tariffs can be applied to the supply of electricity or to the use of the electricity network, or both.

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

ToU tariffs do not impose a firm commitment on consumers. Consumers are free to decide how and when to react to price signals and to adjust consumption during specific time intervals. With consumers' higher responsiveness to price signals, the whole power system, as well as consumers themselves, can benefit.

Providing power system flexibility – Key for integrating variable renewable energy generation

Demand response has the potential to become one of the most cost-effective flexibility sources in a power system, key to enabling the integration of a high share of VRE generation. ToU tariff programmes can shift demand towards periods when renewable energy generation is abundant and decrease consumption when there are generation constraints in the system.

ToU therefore has the potential to substantially reduce the curtailment of VRE resources and improve the system's reliability and predictability. With real-time pricing, even shorter-term variations in renewable energy output can be balanced with demand.

Automation processes using smart appliances based on pre-set criteria according to consumers' preferences can increase the responsiveness of consumers to price signals. This can improve the predictability and reliability of demand response. In the case of dynamic ToU tariffs, automation is key to enabling consumers to react to price changes on short notice and to reaping the benefits of such a mechanism. Consumers can also use energy storage systems, integrated with smart meters, to automatically charge and discharge, depending on price variations. As an example, by applying dynamic prices in combination with smart charging of electric vehicles (EVs), EVs could alter their charging patterns to flatten the peak demand, fill the load valleys and support real-time balancing of the grids (Eid et al., 2016).

Reducing investments in grid reinforcement and peak capacity

The increasing responsiveness of customers to tariffs allows system operators to save investments in generation reserve capacities by shifting consumption to the off-peak time interval or lower price time intervals. By reducing peak demand, network upgraded investments can also be reduced, resulting in lower final tariffs.

Also, by providing information about grid conditions through location-based pricing, market participants know the time and location of system congestion and can react quickly based on the prices (IRENA, 2017). By optimising the distributed energy resource (DER) participation in the local grid – incentivising a prosumer to supply a specific demand to decongest a line – or by simply reducing demand in a specific location, investments in the grid may be reduced.

Potential impact on power sector transformation

The increased adoption of demand response programmes is expected to result in better network management, with consumers being conscious about their electricity consumption during high price time periods.

- In a pilot conducted in Gotland, Sweden, customers participated in a programme that used price signals. During the initial stage of the programme, **23 %** of total electricity consumption was experienced during the five most expensive hours. This **fell to 19 % and 20 % in the first and second year of the programme**, respectively (World Economic Forum and Bain & Company, 2017).

- According to an estimate provided by the American Council for an Energy-Efficient Economy (ACEEE), in the US during 2015, about **200 billion kWh** of electricity, or more than **5 %** of retail electricity sales, were **saved due to demand response programmes**. For each 1 % reduction in retail electricity sales for the retailers, on a median basis, a reduction in the peak demand of about 0.66 % was found to be achievable (ACEEE, 2017).

- A feasible potential of about **8 GW** of **demand side flexibility** is available in Sweden if ToU tariffs are implemented (The Nordic Council of Ministers, 2017).

- In a meta-study of several modelling exercises to determine the potential for demand flexibility in the Nordic market, the Nordic Council of Ministers estimate a **1520 GW potential for demand side flexibility** resources if, amongst others, real-time pricing and metering, information and communication technology (ICT) infrastructure and aggregator services are encouraged (The Nordic Council of Ministers, 2017).

III. KEY FACTORS TO ENABLE DEPLOYMENT

Deployment of advanced metering infrastructure

Advanced metering to track the consumption of individual consumers is a prerequisite for market-based pricing schemes. Smart meters that record the consumption at an hourly, half-hourly or quarter-hourly basis are required at each of the consumption connection points.

Advanced metering infrastructure (AMI) integrates smart meters, communications networks and data management systems to enable two-way communication between suppliers and customers. AMI also enables the collection and storage of customer consumption profiles on an hourly or sub-hourly basis. This allows retailers to implement refined rate structures that can better cover the costs of energy production and supply.

AMI can also integrate additional technologies, such as web-based portals that enable customers to analyse their hourly electricity usage, compare their usage to other local consumers and gather information about the options to manage their electricity consumption better. Such data could also be used by customers when requesting a new (or better) offer from other suppliers in the markets when switching contracts.

Adoption of smart appliances and automation control

Automation control using smart appliances based on pre-set criteria according to consumers' preferences can increase the responsiveness of consumers to price signals. Dedicated software can allow customers to set price preferences, using automation control, for operating the connected appliances. In addition, customers participating in price-based demand response programmes may allow the operators to make small adjustments to their energy consumption during critical periods in exchange for a payment or rebate from the retailer.

One example of automation control is electric heating at lowest daily prices. This can be done with relatively simple automation: the customer has hourly pricing based on the day-ahead price. An algorithm can determine how many hours the water boiler (storing electrical heating) needs to be turned on during one day based on previous data and outdoor temperature (for example, seven hours). Then, the algorithm creates a calendar that determines on which hours the heaters is turned on or off (for example, choosing the seven cheapest hours). This calendar is then sent daily to the smart meter, which has a relay that is connected to the heater/boiler and controls it.

This example requires very little communication between the customer and the supplier (calendar updated daily), and the algorithm can be relatively simple. The main requirements are that the smart meter is equipped with the relay, the heater/boiler is connected to the relay and there is an interface that can be used to send the calendars. If this interface is open and standardised, customers can contract with any chosen market party to give consent to control the relay to provide customers with the control service needed to benefit from implicit demand response.

Consumer engagement and communication

Because ToU tariffs do not require a firm commitment by consumers, who are left to decide how and when to react to the price signals given, consumer engagement is often a challenge. For example, a 2015 study in a selection of European Union countries showed the main underlying barriers to dynamic pricing in electricity supply tariffs to household consumers are a lack of awareness of consumer benefits, followed by insufficient savings to be made (as perceived by consumers) and the lack of policy framework in support of dynamic pricing (ACER/CEER,2016).

Some consumers may be satisfied with business as usual, even though they could save money within demand response programmes. For industrial loads where the cost savings can be substantial, higher responsiveness to demand response programmes might be easier realised.

For domestic consumers, effective demand response might be easier achieved with automation control that enables their loads to respond automatically to price signals, without their active participation via manual response.

However, the focus should be on finding the customers that can benefit the most (by reducing their electricity bill and providing benefits to the system). These are domestic customers with loads that are large enough and controllable enough, namely electric heating, cooling and ventilation loads, as well as EVs, if available. For example, Finland has an estimated 1 800 MW of domestic heating loads that could relatively easily participate in demand response.[1]

Defining the methodology for formulating dynamic prices

Dynamic tariffs, in particular real-time pricing, are more difficult to implement, as they require continuous exchange of information between actors in the retail market, the wholesale market and system operators. Dynamic prices can be derived using various methods, such as indexing with a weighted average of current and past wholesale prices, using advanced statistical techniques, and so forth.

For example, the Finnish system is an interesting case study because the whole value chain from wholesale market to the individual smart meter is unbroken, in the sense that suppliers pass the wholesale market price directly on to consumers. Therefore, one day after physical delivery, suppliers get the measured hourly consumption data of each of their customers (smart metering point). Consequently, the retail supplier can define dynamic pricing as spot-price plus a margin.

1 *Based on discussions during the IRENA Innovation Week, September 2018.*

IV. CURRENT STATUS AND EXAMPLES OF LEADING INITIATIVES

Some of the key indicators about ToU tariffs have been captured in the table below, followed by case studies on country-specific adoption of ToU tariffs.

Table 2 ToU tariffs: Key indicators

Key parameters	Description
Countries where ToU tariffs are applied	17 European countries (including Sweden, Germany, Finland, France, Germany), USA, India
Types of ToU adopted	**Static ToU tariffs:** Day/night ToU differentiation (this is very common in Europe; e.g., in Italy, all low-voltage consumers are mandatorily exposed to ToU pricing if they do not choose a supplier in the liberalised market). **Dynamic real-time pricing:** Estonia, Romania, Spain Sweden and the UK applied such tariffs (e.g., between 25 % and 50 % of all households in Estonia and Spain incur their supply charges based on hourly pricing). **Other dynamic pricing methods:** These apply in Denmark, Norway and Sweden, where electricity consumers incur spot-market-based pricing through the monthly average wholesale price. **Critical peak pricing:** This is applied to a smaller extent in the UK, Lithuania, Portugal, Romania and France (ACER, 2016).
Services provided	• Implicit demand response (participation of consumers in the energy transition). • Consumers benefits, such as electricity bill savings. • Cost-reflective tariffs benefiting suppliers • Increased competition among suppliers in the retail market, as a driver for innovative business models.

Finnish dynamic pricing structure

In Finland, consumers have the option of choosing a dynamic pricing tariff structure for electricity. Retail suppliers offer dynamic pricing to consumers who chose to do so in the liberalised market (as opposed to regulated markets).

The price is determined based on the Nord Pool spot price for the price area of Finland. The customer, who chooses a dynamic price tariff structure, pays the hourly price, retailer's premium and a monthly fixed fee to the retailer with which they opted to enter into a contract.

By the end of 2017, approximately 9% (about 340 000) of customers had opted for this tariff structure (Energy Authority, Finland, 2018; EURELECTRIC, 2017). The customer can check electricity prices for each hour of the succeeding day from the chosen retailer's website. The published prices are based on the spot market timetable. Therefore, the prices for the next day (24 hours), starting from midnight, are finalised at around 2 p.m. of D-1 (day ahead). The price that the customer pays for a particular time slot depends on the time of consumption. This customer requires hourly metering, which is the case for all consumers in Finland. Customers can see their hourly consumption one day after delivery on their local distribution system operator's (DSO's) web portal or application.

Apart from the above pricing structure, some retailers offer price-optimised heating hours, depending on weather conditions and actual heating capacity. This enables the current heating system to operate efficiently and helps to save up to 15% on heating expenses (EURELECTRIC, 2017).

New market design in the European Union

While there is significant variation in the penetration of ToU tariffs among electricity consumers in the European Union, the new draft Electricity Directive and Electricity Regulation (being part of the Clean Energy for All Europeans legislative package) sets new rules for consumers throughout the union. For example, via the new market design rules, every consumer in the European Union would be able to offer demand response and to receive remuneration, directly or through aggregators. Dynamic electricity price contracts reflecting the changing prices on the day-ahead or intraday markets would allow consumers to respond to price signals and actively manage their consumption. As such, consumers would be able to freely choose and change suppliers or aggregators, while also being entitled to a dynamic price contract. Additionally, the new framework foresees the entitlement of every consumer to request a smart meter equipped with a minimum set of functionalities, and it improves pre-existing rules on the consumers' ability to share their data with suppliers and service providers by clarifying the role of the parties responsible for data management and by setting a common European data format (EU Commission, 2016).

Real-time pricing in Illinois (U.S.) – Consolidated Edison (Con Ed)

In a demand response programme in Illinois, launched by Con Ed, a utility operating in the United States, consumers were given the opportunity to participate in an hourly pricing programme in which electricity prices were reflective of the electricity load (i.e., prices were low during the low demand period and prices were high during the high demand hours). An example of demand shifting by consumers includes pre-cooling the house in early morning hours, when prices are lower, and setting the cooling systems to an idle mode when prices are higher. The programme has allowed consumers to save about 15% on their electricity bills (USD 15 million from 2007 to 2016) (Energy News Network, 2016).

Reducing renewable energy curtailment – Reverse demand-response programme in Arizona (U.S.)

The Arizona Public Service Company (APS), a utility in the United States, experiences demand peaks in summer due to increased space cooling use. However, with more moderate temperatures during the remaining nine months of the year, the utility has excess renewable energy that is often curtailed. The electricity prices during some time intervals in the daytime turn negative on account of solar generation exceeding demand.

APS recently proposed a new programme that aims to reduce the need to curtail solar energy during the periods of negative pricing. Instead of curtailing renewable production, APS will pay customers to use energy to keep the renewables online and smooth the load curve. This is similar to load shifting. However, since it is less predictable in terms of the on-peak/off-peak price arbitrage (due to the intermittency of the renewables), the APS programme will be specific to the dispatchable non-essential loads. For example, EVs with smart charging could off-take the free or negatively priced energy when the reverse demand response is activated, and smart appliances (e.g., dishwashers, washing machines, dryers, etc.) could be set to run during these times as well.

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS

Hardware:

- Advanced metering infrastructure (AMI) to enable two-way communication between the demand response participants and the system operators. AMI will also enable the collection and storage of the customer consumption profile on an hourly or sub-hourly basis.

Software:

- Energy management systems that can respond to electricity price signals and automatically adjust consumption according to the customer's preferences, such as during peak price periods.

Communication protocols:

- Agree to and develop common interoperable standards (at both the physical and ICT layers) to increase the co-ordination between the consumer, demand response aggregators and system operators.

REGULATORY REQUIREMENTS

Wholesale market:

- Allow easier and equal access to the wholesale market to all kinds of flexibility service providers.
- Reveal the value of flexibility by a more granular market time representation.

Distribution system:

- Incentivise distribution system operators and/or consumers to adopt smart metering solutions, including innovative ICT infrastructure financing models.

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

STAKEHOLDER ROLES AND RESPONSIBILITIES

Consumers:

- Engage in demand response programmes.
- Change to suppliers/retailers offering ToU tariffs.

Retailers:

- Customers should be adequately informed about the opportunities and risks of dynamic pricing contracts. As these contracts become more commonplace, consumers' awareness and learning will further increase with their participation or the participation of someone they know.
- Involve the customer in the design of the tariff. The involvement of customers in the design phase, such as through public consultations, could improve the acceptance of the dynamic pricing scheme as consumer preferences could be taken into consideration.

State institutions/Regulators:

- Conduct cost-benefit analyses assessing to what extent demand response would bring social welfare benefits before investing in costly enabling infrastructure.
- Provide incentive-based policy frameworks for the deployment of innovative technologies in the distribution network.
- Understand customer behaviour and create awareness of the possibility of using load management.
- Encourage pilot programmes and disseminate the results publicly.

ABBREVIATIONS

ACEEE	American Council for an Energy-Efficient Economy
AMI	Advanced metering infrastructure
APS	Arizona Public Service Company
BtM	Behind-the-meter
ConEd	Consolidated Edison
D-1	Day ahead
DER	Distributed energy resource
DSO	Distribution system operator
EV	Electric vehicle
GW	Gigawatts
ICT	Information and communication technology
IoT	Internet of Things
kWh	Kilowatt-hours
P2P	Peer-to-peer
ToU	Time-of-use
TSO	Transmission system operator
VRE	Variable renewable energy

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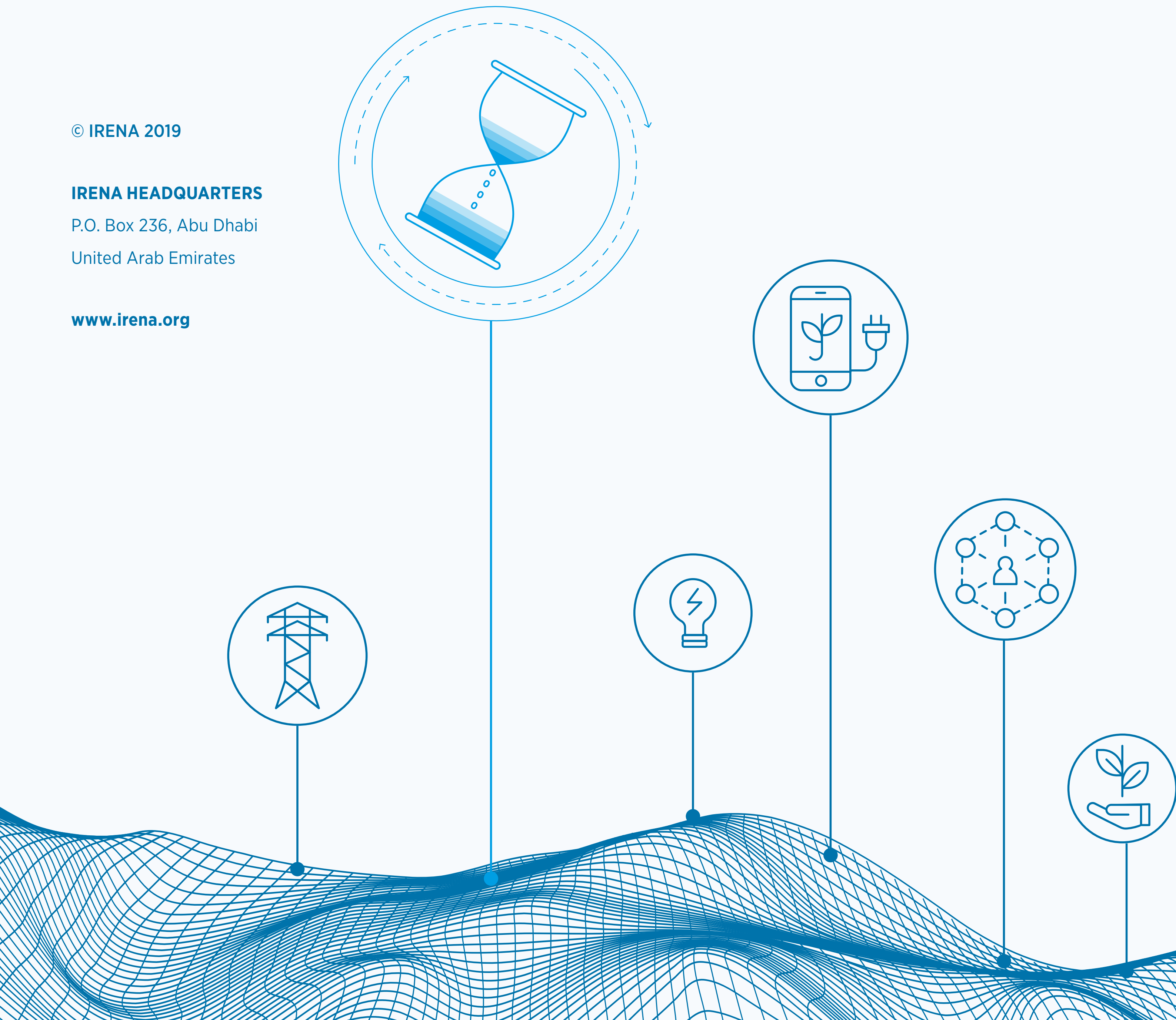

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P.O. Box 236, Abu Dhabi
United Arab Emirates

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