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International Renewable Energy Agency

INCREASING TIME GRANULARITY IN ELECTRICITY MARKETS

INNOVATION LANDSCAPE BRIEF

ISBN 978-92-9260-127-0

Citation: IRENA (2019), *Innovation landscape brief: Increasing time granularity in electricity markets*, International Renewable Energy Agency, Abu Dhabi.

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**

Acknowledgements

This report was prepared by the Innovation team at IRENA's Innovation and Technology Centre (IITC) and was authored by Arina Anisie, Elena Ocenic and Francisco Boshell with additional contributions and support by Harsh Kanani, Rajesh Singla (KPMG India).

Valuable external review was provided by Helena Gerard (VITO), Pablo Masteropietro (Comillas Pontifical University), Rafael Ferreira (former CCEE, Brazilian market operator) and Gerard Wynn (IEEFA), along with Carlos Fernández, Martina Lyons and Paul Komor (IRENA).

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1 BENEFITS

Increasing time granularity in electricity markets

Short term:

Improved flexibility in operations through price signals

Long term:

Optimised investments in flexible generation capacity (through granular price signals)

Enable higher shares of VRE in the power system

3 SNAPSHOT

- Shorter market time units are explored in California (United States), Brazil, Germany and other European markets.
- Shorter lead times are proposed in Australia, the Nordic power market in Europe (reduced to 15 minutes), Austria, Belgium and Germany (reduced to 5 minutes).

2 KEY ENABLING FACTORS

- Advanced computational power and optimisation modelling software
- Efficient price formation in well-functioning markets

HOW TO INCREASE TIME GRANULARITY?

The value of flexibility can be internalised in the market price by reducing:
- the market time units (the duration of dispatch)
- the time span between trading gate closure and physical real-time delivery of power (the lead time).

INCREASING TIME GRANULARITY IN ELECTRICITY MARKETS

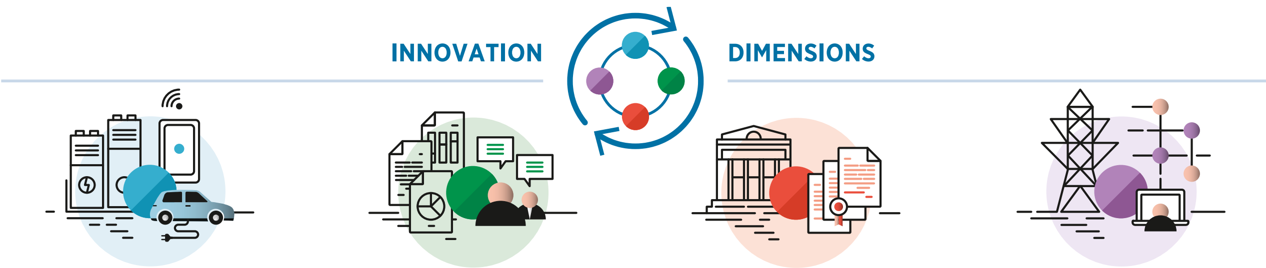
The better **prices reflect the system conditions** closer to real time, the better **the flexibility** incentives for the system.

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 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.



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 applies to liberalised, open electricity markets, where vertical integrated utilities have been unbundled and there is competition in electricity generation. It examines increasing time granularity in electricity markets with a well-functioning spot market as a key market design innovation that addresses the variability and the uncertainty of the VRE share in the grid. The brief focuses on the reduction of the duration of dispatch interval (pricing shorter market time units[1], shorter clearing and financial settlement periods) and the reduction of the time span between the trading gate closure and physical, real-time delivery of power,[2] etc. Increasing time granularity helps better manage the uncertainty in matching power demand and supply in a system with a high share of VRE through electricity prices that better reflect the system conditions in real time.

The brief is structured as follows:

I Description

II Contribution to power sector transformation

III Key factors to enable deployment

IV Current status and examples of ongoing initiatives

V Implementation requirements: Checklist

1 "Market time units" are also referred to as "dispatch time interval", "products" or "contracts", depending on the taxonomy used (e.g., 15-minute product).

2 The time span between the market gate closure and the physical delivery is also referred to as "lead time".

I. DESCRIPTION

Increasing shares of wind and solar generation result in growing volumes of intraday trading need, which in turn increases the need to adjust production schedules and commercial positions to the most recently updated VRE forecast and market conditions. This requires that market time frames – both the granularity of market time units and gate closure times – and financial settlement periods are adjusted to fully exploit the flexibility of existing generators in the system when needed. To enhance the operation of a system with high shares of VRE, the dispatch/scheduling time interval, the pricing of market time units, financial settlement periods, and the time span between gate closure and real time delivery of power should be reduced. The use of shorter market time units would help to internalise the value of flexibility in the market price. The more reflective the prices are of the short-term market conditions, the better the price signals sent to generators, which can quickly alter their output by the system when needed. The following parameters should be shorten in order to increase time granularity in electricity markets (IRENA, 2017)[3]:

- **Market time unit:** Wholesale electricity market products – contracts or a market time unit, depending on the taxonomy applied – refer to the dispatch period for which physical delivery of electricity is traded on a market. For example, an hourly product refers to 60 minutes of a physical electricity delivery. Similarly, a quarter-hourly product equals 15 minutes of a physical delivery of electricity in a given market. Across the European spot (day-ahead and intraday) markets, the vast majority of products traded are hourly products, but more and more products with a lower time granularity are being introduced, such as half-hourly products traded in continuous markets (as opposed to auctions) in France, Germany, the United Kingdom, Luxembourg and Switzerland or quarter-hourly products traded for continuous trading in intraday markets in Austria, Belgium, Germany, Hungary, Luxembourg, the Netherlands, Slovenia and Switzerland (ACER, 2018a). Brazil is testing dispatch intervals of 30 minutes, and California is transitioning from hourly products to quarter-hourly product.

3 For a detailed analysis of this topic please refer to: IRENA (2017), *Adapting market design to high shares of variable renewable energy.* International Renewable Energy Agency, Abu Dhabi

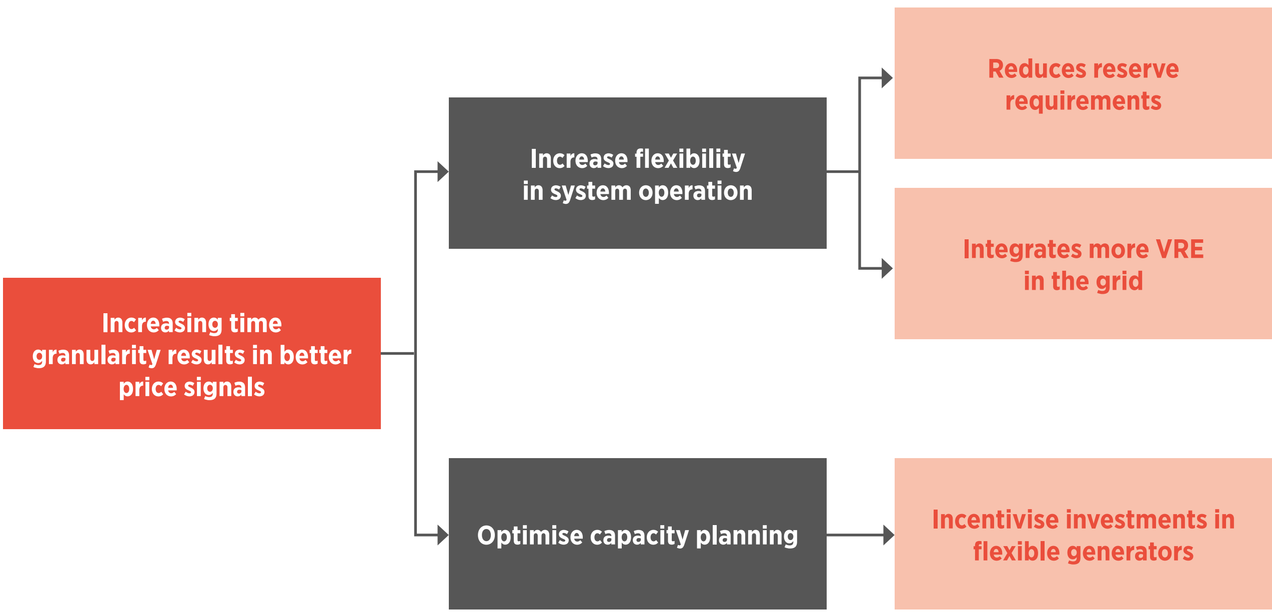
- **Gate closure:** Gate closure is the moment up to which market agents can either submit or modify their own bid or ask orders on the markets. After that point in time, the final binding schedule is determined for all participants. The timing of the last gate closure represents the dividing line between the market and the pure system operation. Setting a gate closure closer to real time helps market agents adjust their positions, with increased certainty about forecasted generation enabling them to minimise imbalances. This also benefits transmission system operators (TSOs), who need to procure and activate fewer reserves for balancing the system.

- **Financial settlement period:** The financial settlement period is a time interval during which financial transactions are being settled for energy being bid in the market. The settlement process ensures that market generators are paid for the energy provided in the market (AEMO, 2019). Generally, the settlement period and the dispatch interval are the same. However, in some markets, the settlement period is different from the dispatch period, which is defined as the time interval during which the agent's bids are received and the dispatch instructions are sent by the system operator. For instance, in Australia, the dispatch interval is 5 minutes, but the settlement period is 30 minutes. Therefore, the seller is not paid based on the price of power in 5-minute intervals but for the average price of a 30-minute block period (meaning 6 dispatch intervals) (AEMC, 2017a). An equal length of settlement period and dispatch interval can help increase the market participation of various players by providing accurate price signals to market participants.

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

The changes in market design in terms of the time granularity of settlement periods, market time units and bringing gate closure times closer to real time delivery in the short-term wholesale market are expected to better remunerate the flexible behaviour of existing generators. Consequently, increasing time granularity is likely to promote investments in flexible assets leading to better grid integration of renewable energy sources. Similarly, it also leads to price signals that can better direct investments towards renewable generation that brings the highest value to the system. The contributions of increased time granularity to the power sector transformation are shown in Figure 1.

Figure 1: Key contributions of increased time granularity in electricity markets



Increasing flexibility in system operation

As the amount of VRE generation is uncertain and difficult to accurately predict ahead of real-time delivery, the system operator may need to procure balancing services through the ancillary service market. A gate closure time that is closer to physical delivery allows market players to incorporate the updated forecast of power demand and variable power generation, leading to more accurate scheduling of power generators. Also, shorter dispatch intervals or market time units lead to increased system flexibility as they allow more frequent scheduling of the whole system, leading to the use of the flexibility available from demand loads and generators. Also, increasing the time granularity of traded products leads to better and more opportunities for market participants to adjust their commercial positions closer to real-time physical delivery of electricity, thus increasing the value obtained from trading electricity and reducing their costs for imbalance settlements, where penalties are paid in case of deviations from schedules.

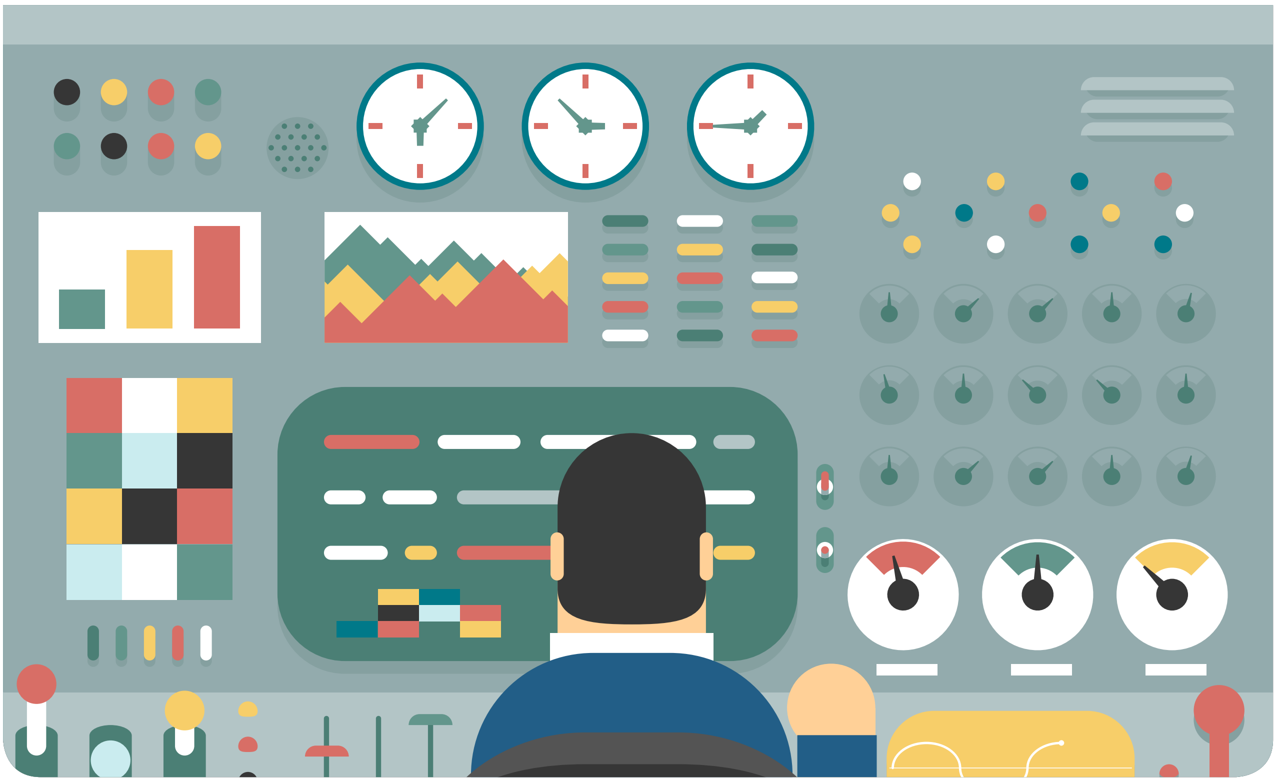
Increased time granularity in power markets, both with regard to market time units and closer-to-real-time gate closure times, helps system operators to forecast real-time operations with better accuracy. This helps avoid issuing re-dispatch instructions (which generally lead to increased power costs) to handle real-time mismatches in demand and supply.

Shorter market time units result in more time-granular wholesale prices, which can be transmitted in retail prices as dynamic time-of-use tariffs, unlocking demand-side flexibility through demand response.

With shorter dispatch periods, system operators need to maintain a lower quantity of reserves. This allows the power generating resources to follow the actual load more closely and the power generation schedule to be changed more frequently. Also, better scheduling of generators due to the reduced lead time between gate closure and real-time operation is expected to reduce the need of procurement of ancillary services and system reserves.

Optimise capacity investment planning

Increased time granularity in electricity markets sends better pricing signals to both power generators and suppliers without generating units, leading to efficient bidding and operational schedules. With flexibility services valued on short-term markets, investments in more flexible generation capacity are also incentivised. With deployment in utility-scale storage or aggregating distributed storage, new generation gas peak plants and rapid demand response are encouraged (AEMC, 2017). Therefore, a future flexible system would be able to cost-effectively integrate high shares of VRE.



III. KEY FACTORS TO ENABLE DEPLOYMENT

Information and communication technologies

Advanced computational power, optimisation modelling software, advanced weather forecasting tools, as well as automation of various processes and information exchange related to scheduling of power plants are key enablers for increasing time granularity in power markets. For example, higher computational power is needed due to the increased volume of information that needs to be processed. Both system and market operators would therefore require more computational power and/or advanced modelling software to run the model at an increased time granularity. Moreover, software for the specific needs of the system and market operators needs to be developed.

Regulatory measures for efficient price formation in wholesale electricity markets

One measure that could help form a price that reflects the conditions in the system, and therefore send the right price signals to participants, would be to remove price caps that are set administratively. Such a measure would allow free price formation in the wholesale electricity markets, including the occurrence of negative prices and price spikes. Negative prices occur in wholesale electricity markets during times of highly inflexible power generation and low demand, while price spikes occur when the system faces very high demand and relatively low generation.

For example, Nord Pool – the power exchange that operates the electricity market in several European countries, including Denmark – introduced negative pricing in 2009. Negative pricing has facilitated wind power integration in Denmark by motivating wind turbines to dispatch down when wind power is in excess, given that offshore turbines do not receive feed-in tariffs when wholesale power prices are negative. In addition, negative pricing is an obvious bonus for flexible storage options, such as Norwegian pumped storage hydropower (PSH) and Danish combined heat and power (CHP), which are effectively paid to consume (and store) electricity and then sell (and inject) it when power prices are positive, or use it for district heating (IEEFA, 2018).

At the European level, the Agency for the Cooperation of Energy Regulators (ACER) adopted Decision No. 05/2017 on 14 November 2017 harmonising the thresholds for the clearing prices for the pan-European single intraday coupling with the minimum at EUR −9 999/MWh and the maximum at EUR 9 999/MWh, which de facto allows for very high negative prices, as well as important price spikes (ACER, 2018b; ACER, 2017).

IV. CURRENT CONTEXT AND EXAMPLES OF LEADING INITIATIVES

Shorter market time units

California

Increasing the penetration of VREs without making changes to market rules and policies has resulted in significant strains on real-time power markets. With an aim to improve grid reliability and efficiency of the day-ahead market, the California Independent System Operator (CAISO) has proposed several changes in the day-ahead market. One of the proposed changes is to reduce the granularity of traded products from 1 hour to 15 minutes[4] (CAISO, 2018). This is in line with FERC Order No. 764, under which granularity in real-time markets was reduced to 15 minutes (for VREs) to remove barriers to the integration of VREs. The reduction in scheduling intervals would allow power-generating resources to more closely follow the load curve as forecasted by CAISO. CAISO may also be able to reduce procurement from real-time markets, especially during morning and evening ramping times as the day-ahead market would be able to commit sufficient resources with sufficient ramping capability.

Germany

The high variability of renewable energy production already requires flexible conventional power plants and other flexibility options to cover fluctuating residual loads (energy not covered by renewables). Increasing shares of wind and solar energy in the power system not only reduce the need for conventional generation capacity, but also influence the required structure of the conventional power plant fleet. In a power system with a share of variable renewables of 40%, such as in Germany, less conventional base load capacity and more peaking capacity is needed due to increased flexibility requirements (EPE, BMWi and GIZ, 2017).

Germany recently reformed its electricity market system to facilitate flexibility. Some of the measures adopted were related to wholesale price formation and time granularity in the market. For example, in 2011, Germany reduced the dispatch interval to 15 minutes from 1 hour for the intraday market to enable the valuation of flexibility (IEEFA, 2018). Based on the success of 15-minute contracts on the intraday market, EPEX launched an additional 15-minute auction at 3 p.m. one day before the delivery date (in the intraday market) in December 2014 (EPEX, 2014a), (EPEX, 2014b). This helps fine-tune the portfolios after the hourly day-ahead market and facilitate trading for intra-hour variations in power production and consumption. Moreover, free price formation in the wholesale market is allowed (i.e., no price caps, including negative prices).

4 Other changes proposed include combining integrated forward market (IFM) and residual unit commitment (RUC), and procuring imbalance reserves that will have a must-offer obligation to submit economic bids for the real-time market.

Single intraday coupling in Europe

Prior to the implementation of the pan-European single intraday coupling via the commercial XBID (cross-border intraday) project on 12 June 2018, several national intraday markets had sub-hourly products, such as 30-minute products, traded in continuous intraday markets in France, Germany, the United Kingdom, Luxembourg and Switzerland. In addition, 15-minute products were traded in continuous markets in Austria, Belgium, Germany, Hungary, Luxembourg, the Netherlands, Slovenia and Switzerland. In Germany and Luxembourg, 15-minute products were also auctioned (as opposed to continuously traded). Moreover, now that the first phase of the XBID project is active, the XBID system supports a wide range of products, including 15-minute and 30-minute products, which are available for specific market areas (XBID, 2018).

Brazil

The design of the wholesale power market in Brazil is heavily influenced by the presence of abundant hydropower. Because Brazil was never a capacity-constrained country (due to the fact that is a hydropower-based system), there was no need for an ancillary service market. Historically, the spot prices in Brazil were calculated for each week for three tiers of loads: peak, shoulder and valley. A computer-aided economic dispatch was performed for these loads for each week, though the system operator had some flexibility to conduct real-time dispatch.

In February 2018, the Brazilian Ministry of Mines and Energy proposed a law for the modernisation and expansion of the free market for electricity. This was in response to recent short-term flexibility needs in the system driven by increasing solar and wind shares, and hydro's changing role in system expansion given the socio-environmental constraints of building new large hydro reservoirs. Also because of these constraints, wind is becoming a relevant source in the Brazilian energy matrix (already 8 % of the electricity mix) (EPE, BMWi and GIZ, 2017).

Therefore, a full redesign of the wholesale power market's design aims to create a new energy market (including ancillary service market), a capacity market and a market for clean certificates. Brazil is now introducing hourly prices in power markets (Batlle et al., 2018). It also aims to introduce dispatch intervals of 30 minutes. The half-hourly dispatch and hourly pricing are currently being tested, and Brazil expects to fully introduce them at the beginning of 2020. The law also aims to increase the granularity of wholesale market price formation to increase short-term flexibility.

Gate closure times closer to real-time delivery of electricity

Australia

Perth Energy[5] proposed reducing the gate closure time to no more than 30 minutes from the current 2 hours (Economic Regulation Authority, 2017). Increased participation in the wholesale electricity market combined with growth in the energy sector have made market conditions more dynamic. Using data from between 14 January 2017 and 16 March 2017, Perth Energy showed that there is significant volatility in load forecast[6] in the last two hours. It was further argued that with the reduced gate closure time, market participants would be more confident about the load forecast, leading to better power generation planning and cost reductions. Per Perth Energy's analysis, the inability of generators to respond to price signals (which was due to the low predictability of load) cost consumers around AUD 8.9 million between 14 January 2017 and 16 March 2017. A shorter gate closure time would ensure the reduction of the share of inflexible power generators in the power mix and the increase of responsive power generator use.

5 Perth Energy is one of the largest business energy providers in Western Australia.

6 The document talks about variation in load forecast and price signals. The significant variation in demand may be due to the increasing penetration of solar rooftop systems.

Nordic market in Europe

With the increasing share of wind power in northern Europe, there is an increasing need to balance energy. To optimise investments in balancing resources, therefore, power market rules must change to engage all the balancing resources available. Of the many issues being identified, one was a longer gate closure period. The current gate closure periods of 60 minutes in the intra-day market and 45 minutes in the balancing market restrict the use of commercial power trade to cover the variations in power generation and demand. In its report “Building an efficient Nordic power market”, Fortum Energy suggested reducing the gate closure of Nord Pool to 15 minutes in both intraday and balancing markets. It argued that a 15-minute gate closure would help improve the use of commercial resources and reduce the number of occasions when the fast TSO reserves are activated (Fortum, 2016).

In 2016, Nord Pool, Elering (the Estonian TSO) and Fingrid (the Finnish TSO) launched a pilot with a 30 minute gate closure time in the intraday market on the Estonian-Finnish border, replacing the previous 60-minute gate closure. Based on positive feedback from market participants, this pilot was implemented as an interim solution until the XBID project commenced (Baltic Electricity Market Forum, 2016).

Single intraday coupling in Europe

ACER adopted Decision No. 04/2018 on 24 April 2018 harmonising the gate opening (at 3 p.m. on D 1) and closing times (60 minutes) for the pan-European intraday market. As such, the gate closing time on the Estonian-Finnish border (i.e., 30 minutes before physical delivery) “should not be considered as an exception, but rather as a preferred solution”, as ACER mentions, because it maximises opportunities for market participants to adjust their balances close to real time while also providing time for TSOs and market participants to schedule and balance processes in relation to network and operational security. Moreover, in other national markets across Europe, such as in Austria, Belgium and Germany/Luxembourg (in certain TSO areas only), the local intraday gate closure time (as opposed to the single intraday gate closure time) is 5 minutes before the beginning of physical delivery (ACER, 2018b).

Shorter financial settlement period

Australia

During its inception in the 1990s, the National Electricity Market (NEM) adopted a 5-minute dispatch period, which is considered the shortest possible timeframe practicable. However, it adopted a 30-minute settlement period based on the limitation in metering and data processing (AEMC, 2017b). Currently, the generators bid to supply electricity for 5-minute block periods because the physical electricity system matches the demand and supply for every 5 minutes. However, the financial settlement for generators is based on average prices over a 30 minute block period.

With the increasing penetration of VREs, the role of flexible technologies[7] in handling the intermittencies in power generation from VREs is expected to increase. However, the mismatch in dispatch and settlement periods has led to many inefficiencies in the operation and generation mix. Inefficient price signals have also impeded the entry of flexible sources, such as fast-response generation or demand-side response in power markets.

In the past few years, the difference between 5 minute dispatch prices and 30 minute settlement prices has increased and is expected to further rise. By matching the physical electricity system and financial settlement period, the Australian Energy Market Commission (AEMC) expects that investment in fast response and flexible technologies will increase. The change in this rule is expected to help power generators to take more efficient decisions, which would ultimately lead to lower power prices for consumers. The 5-minute financial settlement rule is also expected to reward customers who can respond to peak demand for short intervals only.

In this context, in 2017 the AEMC introduced a rule to change the financial settlement from 30 to 5 minutes. The rule is expected to apply as of 1 July 2021. Once the rule is implemented, the price in the market will align with the physical electricity system, which matches demand and supply every 5 minutes. With this change, the AEMC expects that in the long run, efficient price signals to the market will lead to lower wholesale electricity costs.

7 Hydro, gas peaking, diesel generators and coal-fired generators (to some extent) provide supply-side flexibility. Increasing adoption of solar, battery and other technologies has enabled demand-side participation by consumers.

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS	**Hardware:** • Flexible generators in the system **Software:** • Advanced weather forecasting tools • Higher computational power and better system modelling tools required for marginal price determination • Automation of various processes and information exchange related to the scheduling of power plants
REGULATORY REQUIREMENTS	**Wholesale market:** • A liberalised wholesale electricity market with unbundling across the electricity value chain • Clear and consistent rules in the market • Surveillance of the market to ensure market manipulation does not occur • Regular monitoring of the impact of increasing time granularity on the power costs for consumers and publication of the results for broader public awareness • Adapting the market design to the needs of market participants, system operators and consumers
STAKEHOLDER ROLES AND RESPONSIBILITIES	**Regulators, market and system operators:** • Regulators designing and enforcing required changes in market rules • Market operators implementing necessary regulatory changes on their platforms • Market operators and TSOs to perform pilots and conduct studies to assess the time granularity required in the market design

ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
AEMC	Australian Energy Market Commission
CAISO	California Independent System Operator
CHP	Combined heat and power
IFM	Integrated forward market
NEM	National Electricity Market
PSH	Pumped storage hydropower
RUC	Residual unit commitment
TSO	Transmission system operator
VRE	Variable renewable energy
XBID	Cross-border intraday

BIBLIOGRAPHY

ACER (2018a), *Annual report on the results of monitoring the internal electricity and natural gas markets in 2017 – Electricity wholesale markets volume,* Agency for the Cooperation of Energy Regulators and the Council of European Energy Regulators.

ACER (2018b), *Decision of the agency for the cooperation of energy regulators no 04/2018 of 24 April 2018 on all transmission system operators' proposal for intraday cross-zonal gate opening and intraday cross-zonal gate closure times,* Agency for the Cooperation of Energy Regulators, https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Individual%20decisions/ACER%20Decision%2004-2018%20on%20IDCZGTs.pdf.

ACER (2017), *Decision of the agency for the cooperation of energy regulators no 05/2017 of 14 November 2017 on the nominated electricity market operators' proposal for harmonised maximum and minimum clearing prices for single intraday coupling,* Agency for the Cooperation of Energy Regulators.

AMEC (2017a), *Fact sheet: How spot market works,* Australian Energy Market Commission, Australian Energy Market Commission, Sydney.

AMEC (2017b), *Rule determination – National electricity amendment (Five minute settlement) rule 2017,* Australian Energy Market Commission, Sydney.

AMEO (2019), *Settlements and payments,* Australian Energy Market Operator, www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Settlements-and-payments.

Baltic Electricity Market Forum (2016), *Nord Pool update 2016,* Baltic Electricity Market Forum, www.konkurentsiamet.ee/public/Baltic_Electricity_Market_Forum_2016/9_Nord_Pool_Energy_Forum_Tallinn_04112016.pdf.

Batlle, C. et al (2018), "Brazil considers reform of the electricity sector", *Oxford Energy Forum,* June, pp. 21–24.

CAISO (2017), *Day ahead market enhancements,* California Independent System Operator.

Economic Regulation Authority (2017), *Implementation of 30-minute balancing gate closure,* Economic Regulation Authority www.chooseenergy.com/blog/energy-101/how-will-texas-nodal-affect-business-electricity-rates/.

EPE, BMWi and GIZ (2017), "Untapping flexibility in power systems".

EPEX (2014a), *Successful launch of 15-minute intraday call auction in Germany,* EPEX Spot, www.epexspot.com/en/press-media/press/details/press/_Successful_launch_of_15-Minute_Intraday_Call_Auction_in_Germany.

EPEX (2014b), *15-minute intraday call auction,* EPEX Spot, www.epexspot.com/document/29113/15-Minute%20Intraday%20Call%20Auction.

Fortum (2016), "Building an efficient Nordic power market", *Fortum Energy Review,* http://apps.fortum.fi/corporaterelations/Nordic_power_market_12_2016.pdf.

IEEFA (2018), "Power-industry transition, here and now: Wind and solar won't break the grid", http://ieefa.org/wp-content/uploads/2018/02/Power-Industry-Transition-Here-and-Now_February-2018.pdf.

IRENA (2017), *Adapting market design to high shares of variable renewable energy,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2019), *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables*. International Renewable Energy Agency, Abu Dhabi.

XBID (2018), *XBID launch information package,* XBID Cross-Border Intraday Market Project, www.nordpoolgroup.com/globalassets/download-center/xbid/xbid-launch-information-package.pdf.

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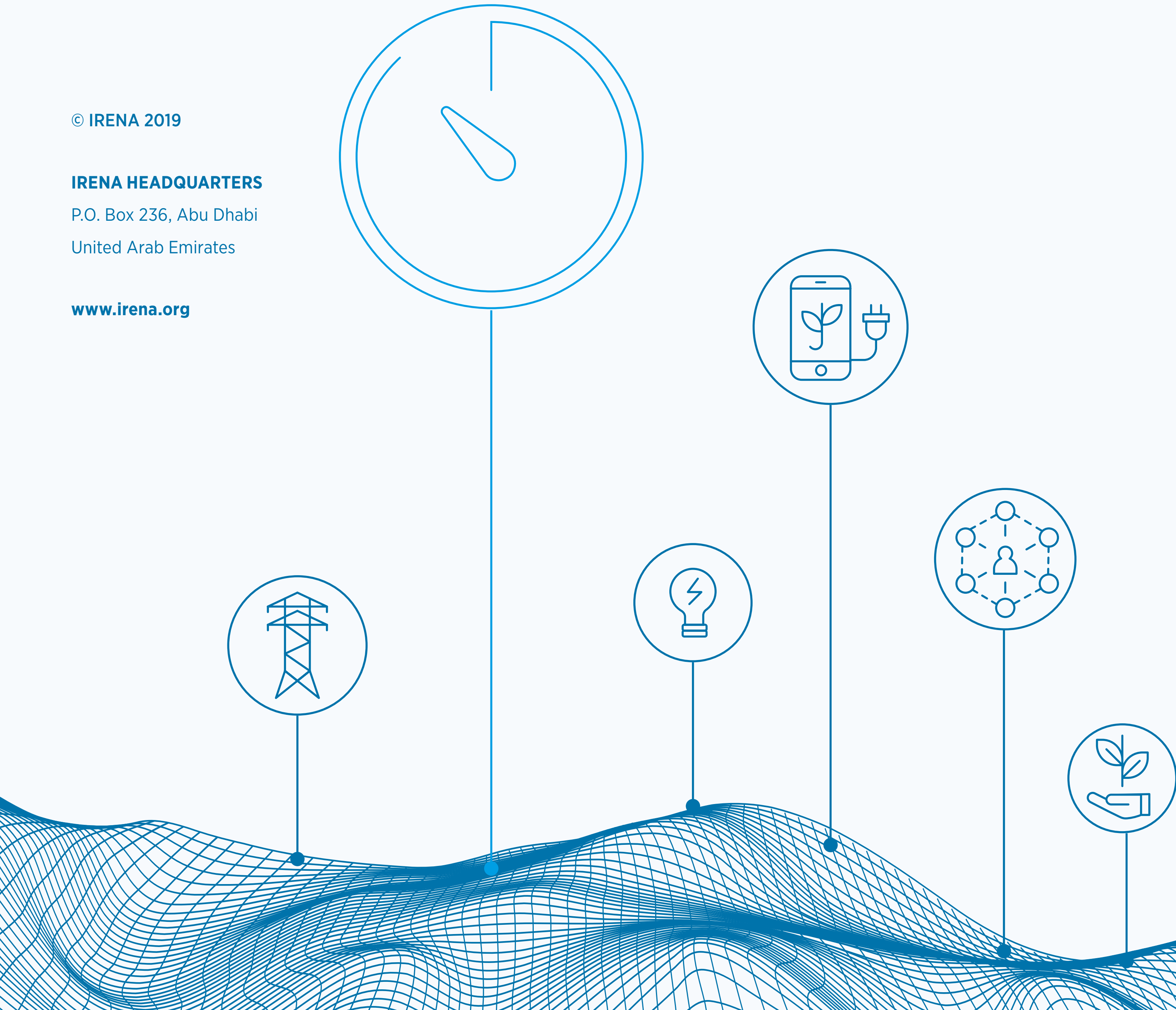

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